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Editorial

This Volume 39 Number 1 includes ten (10) research articles. The relevance and usefulness of respective articles are summarised below.

Obada, D.O. et al., "Flame Temperature Characteristics and Flue Gas Analysis of an Improvised Biogas Burner", present the results of an experimental investigation of a prototype and an improved burner to report the quality of biogas which was produced from a mixture of cattle dung and poultry droppings operated as feedstock in the ratio of 1 part of dung and droppings to 2 parts of water at a retention time of 30 days. A liquefied natural gas burner was used to do a comparative analysis with the aid of a thermocouple. The ambient temperature of the flame produced was taken at three positions viz; the cone flame, the burning flame, and the flue gas. The results showed that the improvised burner had the lowest temperature at the three positions of measurement and provides room for subsequent improvement for household use in farmsteads and rural applications.

Oladele, I.O. and Khoathane, M.C., "Influence of Chemically Modified Sisal Fibre on the Mechanical Properties of Reinforced Homopolymer Polypropylene Composites", investigate the influence of chemical modification on the mechanical properties of soil-retted, sisal-fibre-reinforced homopolymer polypropylene (PP) composites. Sisal fibre was extracted by the soil-retting process, after which parts were treated with selected chemicals—KOH, HCl, NaCl and Ethanol—with varying mole fractions, producing 16 chemically modified sisal-fibre samples. Reinforced homopolymer PP composites were formed by using a compression molding machine to develop samples for mechanical tests—tensile, impact and hardness. This treatment gave the best sisal-homopolymer PP composite in terms of hardness, tensile strength and impact strength. The chemical treatments were found to be effective in enhancing the properties of sisal-homopolymer PP composites.

Thin wall ductile iron (TWDI) castings are a viable substitute for lightweight applications for energy saving in automotive industries. In their article, "Mechanical Properties of Thin Wall Ductile Iron Cast in Moulding Sand/ Aluminum Dross Mix", **E.F. Ochulor at al.** investigate into the effect of incorporating 2-12 wt. % aluminum dross (AlDr) on the thermal properties of moulding sand and on the microstructure and mechanical properties of as-cast TWDI parts. Moulding sand thermal characteristics is vital to defining the solidification mechanism of a cast part, which in turn influences evolving microstructure and mechanical properties. The results showed that aluminum dross used as a moulding sand additive reduced the hardness and ultimate tensile strength values but significantly improved percent elongation.

C.A. Fapohunda, et al., "Suitability of Crushed Cow Bone as Partial Replacement of Fine Aggregates for Concrete Production", present an assessment of the strength properties of concrete containing crushed cow bone (CCB) as partial or full replacement of fine aggregates. The slump test and the compacting factor test were used to assess the workability of the concrete sample specimens. The density and compressive strength were determined using 150 mm cube specimens. The results showed that: (i) increase in the percent replacement of sand with CCB resulted in less workable concrete, (ii) replacing sand with CCB resulted in different types of concrete, and (iii) a compacting factor test will be appropriate to assess the workability of concrete containing CCB because of the resulting dry mix and (iv) up to 20% of sand replacement with CCB will result in compressive strength that is not significantly different from the control.

H. Martin et al., "Risk Perception in a Multi-Hazard Environment: A Case Study of Maraval, Trinidad", investigate the relation of risk perceptions to the socio-economic impacts of hazards and explore how this would determine the pivotal decision elements in planning mitigation strategies. A survey of 119 persons in Maraval, Trinidad was undertaken. Analysis of variance (ANOVA) and regression analysis showed that risk perception of flooding is influenced significantly by previous experience. Hence, to minimise the development of inappropriate cultural norms, communities must be reminded of the dangers associated with occupying hazard-prone locations. High risk perception towards landslides, storms and earthquakes is significantly affected by low levels of income and education. This suggests that disseminating scientific information through educational programs should change people's beliefs about a hazard, and lead to the adoption of appropriate mitigation strategies.

In their article, "A Study of Stakeholder Perception Regarding Quality of Education in Civil and Environmental Engineering at The University of the West Indies", **L.A. Ellis and E.J. Ochieng**, attempt to evaluate the quality of the undergraduate programmes offered. The study utilised questionnaires which were administered to undergraduate and recently graduated students as well as employers. The results showed that the majority of undergraduates and graduates shared concerns on the lack of practical content in the course material and the high work load due to the condensed length of the programmes. Employers agreed that although graduates had a positive work ethic, they were found to be lacking critical workplace skills. The findings indicate that efforts must be made to strengthen the link between theory and practice in the curriculum, and serious consideration given to the extension of the current 3-year programme to 4-year programme.

I.O. Oladele, and I.S. Afolabib, "Development of Brown Paper Pulp Filled Natural Rubber Composites for

Structural Applications", describe the influence of natural rubber on the flexural and water absorption properties of paper-pulp-filled natural rubber composites for structural applications. The developed composites were detached from the mould and allowed to cure in air at room temperature for 27 days. Flexural and water absorption tests were done on the samples. The composite developed from the mixture of 70 wt % brown paper pulp and 30 wt % natural rubber gave the best result for flexural properties, while the sample with 60-40 wt % emerged the best composition for the water absorption property.

S.O. Adeosun et al., "Mechanical and Microstructural Characteristics of Rice Husk Reinforced Polylactide Nano Composite", explore the application of polylactides in tissue engineering in their paper. The morphological, mechanical and water permeability properties of electrospun treated and untreated rice- husk reinforced polylactide- nano- composite fibres are presented. The treated rice- husk particulates were ground, subjected to steam explosion and chemical treatment to remove its lignin and hemi-cellulose contents so as to increase the crystallinity of the filler. Young's modulus, fracture stress, water permeability and other properties are also enhanced. This work shows that; the mechanical properties and biodegradability of scaffolds for tissue engineering can be improved by reinforcing polylactide with rice-husk instead of petroleum- based polymeric-nano- fiber composites.

D.O. Obada et al., "Physical and Mechanical Properties of Porous Kaolin Based Ceramics at Different Sintering Temperatures", investigate the properties of the sintered samples of the kaolin based ceramics as pore formers. It was observed that the apparent porosity and water absorption of the samples decreased with increased sintering temperature, while the bulk density, apparent density and cold crushing strength of the samples increased with increased sintering temperature. It was concluded that the samples which were sintered at 850°C with 5% wt pore former of powdery high density polyethylene gave the optimum properties in terms of the porosity and mechanical strength of the samples.

In their article, "A Biosensor for Automated Feature Extraction and Non-invasive Cardiovascular Diagnosis Using Photoplethysmography Waveforms", **N. Gayapersad and S. Rocke,** derive indices from the morphological features of photoplethysmography waveforms and link the results to enhance patient risk assessments on cardiovascular diseases. A system that performs real-time, automatic feature extraction for cardiovascular diagnosis is presented. Results demonstrate the feasibility and utility of the system as an enabler of personalised healthcare systems, for cardiovascular care. This paper also offers valuable insights into the challenges in deploying automated, non-invasive, continuous monitoring systems for extraction of cardiovascular features beyond heart rate and blood pressure.

On behalf of the Editorial Office, we gratefully acknowledge all authors who have made this special issue possible with their research work. We greatly appreciate the voluntary contributions and unfailing support that our reviewers give to the Journal.

Our reviewer panel is composed of academia, scientists, and practising engineers and professionals from industry and other organisations as listed below:

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KIT FAI PUN, *Editor-in-Chief*

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Flame Temperature Characteristics and Flue Gas Analysis of an Improvised Biogas Burner

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Abstract: *This study presents the results of an experimental investigation of an initial burner prototype and an improved prototype to report on the quality of biogas, which was produced from a mixture of cattle dung and poultry droppings, operated as feedstock in the ratio of 1 part of dung and droppings to 2 parts of water at a retention time of 30 days. A liquefied natural gas burner was also used for a comparative analysis. The flame temperature testing was carried out with the aid of a Kane–May (KM340) thermocouple. The ambient temperature of the flame produced was taken at three positions—the cone flame, the burning flame, and the flue gas. The results showed that the improved burner had the lowest temperature at the three positions of measurement and is in need of improvement for household use. Also, flue gas analysis was carried out to establish the emissions of the stove. The combustion efficiency of the improved stove recorded by the flue gas analyser was 86.9%.*

Keywords: *Biogas, Temperature, Flame, Flue gas, Thermocouple*

1. Introduction

Biogas, an alternative fuel that is both sustainable and renewable, is produced from anaerobic fermentation of organic material in digestion facilities (Anggono et al., 2012; 2013; Cacua et al., 2012). It does not contribute to the increase in atmospheric carbon dioxide because it comes from an organic source with a short carbon cycle and is a green solution in the development of sustainable fuels (Anggono et al., 2012; 2013). Furthermore, the digestion facilities can be constructed quickly in a few days using unskilled labor (Lichtman et al., 1996). Biogas contains 50–70% methane and 30–50% carbon dioxide, as well as small amounts of other gases and typically has a calorific value of 21–24 MJ/m^3 (Cacua et al., 2012; Ferrer et al., 2011; Bond et al., 2011). Based on chemical analysis, the composition of the biogas produced in East Java is 66.4% methane, 30.6% carbon dioxide and 3% nitrogen (Anggono et al., 2012; 2013). Methane is a flammable gas, whereas, nitrogen and carbon dioxide are inhibitors (Ilminnafik et al., 2011).

Various wastes have been utilised for biogas production and they include amongst others, animal wastes (Nwagbo et al., 1991); industrial wastes (Uzodinma et al., 2007); food processing wastes (Arvanitoyannis and Varzakas, 2008); and plant residues (Ofoefule et al., 2008; 2009). Many other wastes are still being researched as potential feedstock for biogas production. Biogas is best used directly for cooking, heating, lightening or even absorption refrigeration rather than using it to generate electricity, as converting biogas to electricity is complicated and incurs waste. Pumps and equipment can also run on a gas powered engine rather than using electricity (Fulford, 1996).

The percentage of methane in the biogas is generally determined by the Orsat apparatus, gas-chromatograph, etc. (Holman, 1995). The quality of biogas depends mainly the presence of methane, and a good quality biogas has high caloric value and burns in air with a blue flame. This is due to its presence of a high percentage of methane (Mandal et al, 1999). The quality of biogas generated by waste materials does not remain constant but varies with the period of digestion (Khandewal and Mahdi, 1986). Biogas is somewhat lighter than air and has an ignition temperature of approximately 700 °C (Kohler, 2007).

It has been reported that the ignition temperature for biogas (65% CH_4, 34% CO_2 and 1 % rest) is 650-750°C (Werner et al, 1989), and the temperature of the flame is 870 °C (Sasse,1988). The flame is generally considered to have two regions, referred to as preheat and reaction zones. The reaction zone is further divided into two parts, the primary and secondary reaction zones. The primary zone is approximately coincident with the luminous zone, while the secondary zone is associated with an area of weak secondary luminosity due to CO oxidation (Rallis and Garforth, 1980).

The flame temperature of the fuel is proportional to its caloric value and the quality of the fuel (Shah, 1974).

Hence, the flame temperature of biogas indicates its quality, i.e. the percentage of methane in it. The temperature can be obtained from any of the spectroscopic methods by comparing the line intensity as a function of energy level. The most direct technique for temperature measurement is the use of small thermocouples. Thermocouples are widely used electric output device for obtaining temperature measurements during experimentation (Wheeler and Ganji, 2004).

Obada et al. (2014a; 2014b) designed and constructed a prototype and an improvised biogas burner for use in domestic cooking. The present study is an experimental investigation of the flame temperature of the developed biogas burners with respect to the methane content in the biogas and also the measurement of the flue gases emitted during combustion.

2. Methodology

2.1 Analysis of Produced Biogas

The biogas produced was analysed qualitatively using gas chromatography. The biogas produced was evacuated from the gasholder bottles (cylinders) and taken to the laboratory for analysis. The biogas was passed through solutions of lead acetate and potassium hydroxide. Hydrogen sulphide (H_2S) and carbon dioxide (CO_2) were absorbed respectively, leaving methane (CH_4) gas to be collected at the exit. Figure 1 shows an experimental set up for biogas analysis.

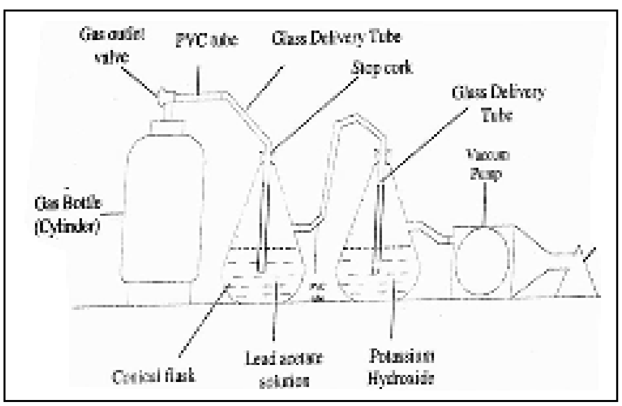

Figure 1. An experimental set up for biogas analysis

2.2 Flame Temperature Measurement

This was carried out with the aid of a Kane – May (KM340) thermocouple. Three (3) different burners were used for this analysis. These included the prototype burner, the improved burner and a liquefied natural gas burner. The temperature of the flame produced was taken at three positions: the cone flame, the burning flame, and the flue gas. The temperatures obtained were recorded. Figures 2 and 3 show the thermocouple and an exploded view of the developed improvised burner used in this study.

Figure 2. A Kane – May (KM340) thermocouple

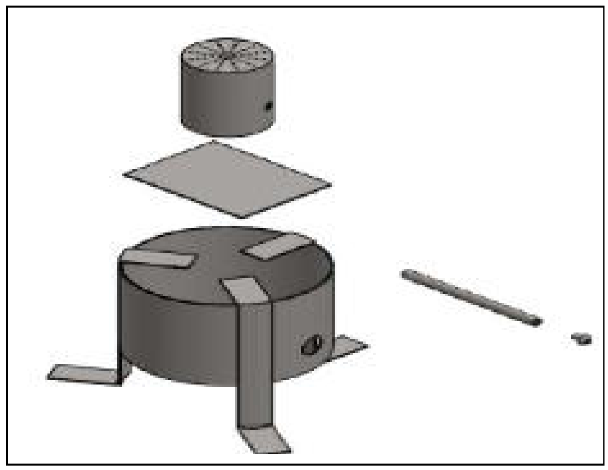

Figure 3. An exploded view of the developed improvised burner

2.3 Flue Gas Analysis

A flue gas analyser, IMR 1400 PL model was used for this study. Figure 4 shows the gas analyser used in this study.

This analysis was carried out by first switching the analyser on in fresh, outdoor air to set its' zero value, following the manufacturer's instructions. It was then taken into the hood to be monitored. The equipment analysed and documented whether the flue gas limit values were being complied with or whether the system was running at the optimum settings. Two (2) gas sensors, which measure oxygen (O_2) and carbon monoxide (CO) gases directly, formed the basis of the flue gas analysis. The analyser also enabled the measurement of CO_2 concentration on the burner system. When the analyser measured CO levels above 9 ppm, an investigation was made. Also when the reading was over 35ppm for CO, prompt action was taken to release the openings around the hood.

The gas analyser was used to measure and calculate the following parameters from the flue gases:

i. Combustion efficiency
ii. Excess Air

iii. Carbon monoxide (CO)
iv. NO_x
v. SO_2
vi. Carbon dioxide (CO_2).

Figure 4. IMR 1400 Gas Analyser PL model

3. Results and Discussion

3.1 Qualitative Analysis of Biogas Produced

The laboratory analysis of the biogas gave the following percentage constituent compositions of biogas produced, assuming that water vapour and other trace gases were negligible. Biogas produced from cow dung contained CH_4:58.0%, CO_2: 39.0%, and H_2S: 3.0%; The biogas produced from chicken droppings contained CH_4:59.5%, CO_2 37.5% and H_2S: 3.0% (see Table 1). Chicken droppings had a higher percentage of combustible gas compared to cow dung produced within the same fermentation period.

Table 1. Percentage compositions of biogas produced using cow dung as biomass

Component	Cow dung %	Poultry dropping %
Carbon Dioxide (CO_2)	39.0	37.5
Hydrogen sulphide (H_2S)	3.0	3.0
Methane (CH_4)	58.0	59.5

It was observed from the study that poultry droppings show a relatively higher methane and lower CO_2 yield. This could be attributed to the quicker degradation of poultry droppings than the cow dung substrates within the period of experimentation. As a result, it could be inferred that there is an inverse relationship between methane and carbon dioxide production.

3.2 Flame Temperature

The temperature of the flame using poultry droppings as biomass, by virtue of its increased composition of methane (59.5%) using the thermocouple, is summarised in Table 2.

Table 2. Flame Temperature Results

Burner	Cone flame Temperature (C.F.T) (^{0}C)	Burning flame Temperature (B.F.T) (^{0}C)	Flue Gas Temperature (F.G.T) (^{0}C)
Prototype Burner (P.B)	1221	814	203
Improvised Burner (I.B)	1032	611	95
LNG Burner (L.B)	1093	650	103

It was found that the improvised burner has the lowest temperature at the three positions of measurement. The instability of the flame observed when the prototype burner was put to use was a reason for its high flue gas temperature. The improved burner produced a stable flame, resulting in its low temperature at its point of measurement. This is justified by its biogas consumption rate, as the consumption rate is much less than that of the prototype burner. The LNG burner also produced a relatively stable flame hence a lower flue gas temperature compared to the prototype burner.

The flame temperature of the biogas sample increased with the increase of the methane percentage in the biomass (poultry droppings). This result is in agreement with the published data by Wheeler and Ganji (2004). Due to the obvious reason, temperature is considered as an indicator for the methane percentage in biogas while burning. The intermediate value of the LNG burner is understandable because methane is the main constituent of natural gas and it accounts for about 95% of the total volume. Other components are ethane, propane, butane, pentane, nitrogen, carbon dioxide, and traces of other gases. Very small amounts of sulphur compounds are also present. Since methane is the largest component of natural gas, there is a basis of close results as investigated with the biogas fuelled burners.

The constituents of the flue gases were measured, and major constituents like carbon monoxide (CO), Nitrogen Oxide (NOx), Sulphur Oxide (SO_2), Carbon dioxide (CO_2), excess air etc. were quantified in parts per million and percentages by the gas analyser used. The results obtained are recorded in Tables 3, 4 and 5. It was found that the percentage composition of O_2 and SO_2 were the same for all the stoves. Variations were observed in the percentage composition of carbon monoxide (CO) and NO_x for the stoves.

From these tables, it can be seen that the improved burner produced the least percentage of carbon monoxide (CO). This was as a result of the stable flame it produced when put to use. The reduced number of burner ports using flame stabilisation theory (Fulford, 1996; Obada et al., 2014) was instrumental to reduced percentage of CO emitted, which makes it safer to use domestically and requires a minimum amount of ventilation during usage.

Table 3. Flue gas constituents for prototype stove

Gas Constituent	1st Reading (%)/ppm	2nd Reading (%)/ppm	3rd Reading (%)/ppm	4th Reading (%)/ppm	5th Reading (%)/ppm	Average (%)/ppm
O_2	20.90	20.90	20.90	20.90	20.90	20.90
CO	33.00	37.00	35.00	39.00	37.00	36.20
CO_2	11.80	11.80	11.80	11.80	11.80	11.80
SO_2	0.00	0.00	0.00	0.00	0.00	0.00
NO_X	3.00	1.00	1.00	2.00	2.00	1.80
Excess air	1.00	1.00	1.00	1.00	1.00	1.00

Table 4. Flue gas constituents for improved stove

Gas Constituent	1st Reading (%)/ppm	2nd Reading (%)/ppm	3rd Reading (%)/ppm	4th Reading (%)/ppm	5th Reading (%)/ppm	Average (%)/ppm
O_2	20.90	20.90	20.90	20.90	20.90	20.90
CO	4.00	6.00	5.00	6.00	4.00	5.00
CO_2	11.80	11.80	11.80	11.80	11.80	11.80
SO_2	0.00	0.00	0.00	0.00	0.00	0.00
NO_X	2.00	1.00	3.00	1.00	3.00	2.00
Excess air	1.00	1.00	1.00	1.00	1.00	1.00

Table 5. Flue gas constituents for LNG burner

Gas Constituent	1st Reading (%)/ppm	2nd Reading (%)/ppm	3rd Reading (%)/ppm	4th Reading (%)/ppm	5th Reading (%)/ppm	Average (%)/ppm
O_2	20.90	20.90	20.90	20.90	20.90	20.90
CO	8.00	10.00	11.00	10.00	9.00	9.60
CO_2	0.00	0.00	0.00	0.00	0.00	0.00
SO_2	0.00	0.00	0.00	0.00	0.00	0.00
NO_X	0.00	0.00	0.00	0.00	0.00	0.00
Excess air	1.00	1.00	1.00	1.00	1.00	1.00

The prototype burner, as can be observed from Table 3, produced a high percentage of CO. This was as a result of the plentiful burner ports which made the stove produce unstable flames. This makes it unsafe to use domestically and if it is to be put to use, a great degree of ventilation is needed. The CO emission of the LNG can be said to be within tolerable limits for domestic usage, as it is customary all over the world.

NO_x and some impurities were not present in the LNG burner as recorded by the flue gas analyser, but there were 2% and 1.5% in the prototype and improved burners respectively as shown in Tables 3 and 4 respectively. This percentage is relatively small compared to the CO emissions recorded. However, ventilation is still needed in terms of its domestic use.

The percentage of O_2, CO_2 and excess air were constant for the flue gas analysis done on the three (3) burners tested. This was because the machine worked on some preset values inputted during calibration for different kinds of fuel.

4. Conclusions

The following could be concluded from this study:

1) The minimum cone flame temperature was 1032^{o}C, while the maximum was 1221^{o}C corresponding to the improvised and prototype burners respectively. Also, the minimum burning flame temperature was 611^{o}C while the maximum was 814^{o}C, this is also applicable to the flue gas temperature which read 95^{o}C and 203^{o}C corresponding to the improvised and prototype burners respectively.
2) The results indicated that the relationship between the flame temperature and methane percentage was found to have a direct relationship.
3) Determining the biogas quality (methane percentage) was possible by using the physical properties of biogas burning such as flame temperature.
4) The improved burner produced more tolerable emissions than the prototype burner. This was significant for carbon monoxide emission which is a dangerous gas to the user and those in close proximity.

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Influence of Chemically Modified Sisal-Fibre on the Mechanical Properties of Reinforced Homopolymer Polypropylene Composites

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Abstract: *This research investigated the influence of chemical modification on the mechanical properties of soil-retted, sisal-fibre-reinforced homopolymer polypropylene (PP) composites. Sisal fibre was extracted by the soil-retting process, after which parts were treated with selected chemicals—KOH, HCl, NaCl and Ethanol—with varying mole fractions, producing 16 chemically modified sisal-fibre samples. Reinforced homopolymer PP composites were formed by using a compression molding machine to develop samples for mechanical tests—tensile, impact and hardness. From the results, it was revealed that 0.75 M : 0.25 M has higher synergistic effect than others, with 0.75 M HCl + 0.25 M KOH, thus emerging as the best chemical treatment. This treatment gave the best sisal-homopolymer PP composite in terms of hardness, tensile strength and impact strength (in the as notched condition). The chemical treatments were found to be effective in enhancing the properties of sisal-homopolymer PP composites.*

Keywords: *Sisal fibre, Chemical treatment, Homopolymer PP, Mechanical Properties, Reinforcement, Composites*

1. Introduction

The emergence of polymers in the beginning of the 19th century ushered in a new era of using fibres in diverse applications. Because of their superior dimensional and other properties, synthetic fibres gained popularity and slowly replaced natural fibres in different applications. However, the production of synthetic composites requires a large quantum of energy and pollutants are generated during the production and recycling of these synthetic materials. This has renewed interest in natural fibres, spurring research in making natural fibres superior to synthetic ones. There have been tremendous strides in improving the quality of natural fibres, and as such they are fast emerging as the preferred reinforcing material in composites.

Considering the high performance standard of composite materials in terms of durability, maintenance and cost effectiveness, natural-fibre-based composites find extensive use in building and civil engineering applications. In the case of synthetic-fibre-based composites, despite their usefulness in service, they are difficult to be recycled after the designed service life. But, natural-fibre-based composites are environmentally friendly to a large extent. Natural fibres like jute, flax, hemp, coir, and sisal have all been proved to be good reinforcement in thermoset and thermoplastic matrices which are used in the automobile, construction, as well as packaging industries, with a few drawbacks (Mohanty *et al.*, 2002; Bledzki *et al.*, 2002; Gross and Karla, 2002; Puglia *et al.*, 2004). Fibre-reinforced polymers have better specific properties compared to conventional materials and find applications in diverse fields, ranging from appliances to spacecraft (Saheb and Jog, 1999).

Most of the composite materials used in different sectors are principally fabricated using thermosetting matrices. However, there are some disadvantages in using thermosets, which include brittleness, lengthy cure cycles and inability to repair and or recycle damaged or scrapped parts. These disadvantages have led to the development of the thermoplastic matrix composite system. Compared with thermosets, composites fabricated from thermoplastic materials typically have a longer shelf life, higher strain to failure, are faster to consolidate and retain the ability to be repaired, reshaped and reused as the need arises (Chand and Hashmi, 1993).

This paper presents the main findings from a research that investigated the suitability of chemically modified soil-retted sisal fibre as reinforcement in a homopolymer polypropylene (PP) thermoplastic material, to enhance the properties of the developed composite for building applications.

2. Materials and Methods

2.1. Materials

Homopolymer polypropylene (PP) which was used for this work was sourced from Sasol, South Africa. Other materials that were used; Sisal plant leaves, Teflon sheet, Silicones, KOH, HCl, NaCl, H_2SO_4, Ethanol, Acetic Acid, Nitric Acid, Benzene, Ether, Distilled Water, Loamy Soil, Stream Water, Sample Bags and Adhesive Glue.

2.2. Methods

2.2.1. Extraction of the sisal fibre material

The extraction of sisal fibre was carried out by soil-retting process using loamy soil as the retting medium. The source of sisal leaves used was from a sisal plantation. The leaves were cut and buried inside soil for 15 days so as to allow fermentation and decay of chlorophyll matter. For extraction to take place normally, the leaves were buried close to a stream of water and are watered daily. The fermented leaves were exhumed and washed thoroughly, after which the resulting fibres were sun dried. Figure 1 shows the sisal plant leaves while Figure 2 shows the extracted sisal fibre.

Figure 1. Sisal Plant

Figure 2. Extracted Sisal Fibre

2.2.2. Chemical treatment

To improve the surface morphology of the fibre for good adhesion between fibre and matrix, as well as prevent degradation of sisal fibre due to water absorption, chemical treatment was carried out on 60g samples of sisal fibre as follows:

i. 1M each of selected chemicals

The samples were treated with 1M each of KOH, HCl, NaCl and Ethanol, respectively in a solution of 450 ml inside a shaker water bath maintained at 50 ºC for 4 hours. The treated samples were washed thoroughly with water and finally washed with distilled water. Four samples were prepared during this stage.

ii 0.5 M : 0.5 M Mixture of two selected chemicals

The samples were treated with 1M each from the mixture of 0.5 M: 0.5 M from the following; KOH + HCl, HCl + NaCl, KOH + Ethanol and, HCl + Ethanol, respectively in a solution of 450 ml inside a shaker water bath maintained at 50 ºC for 4 hours. The treated samples were washed thoroughly with water and finally washed with distilled water. Four samples were prepared in this way.

iii. 0.75 M : 0.25 M Mixture of two selected chemicals

The samples were treated with 1M each from a mixture of 0.75 M: 0.25 M of the following; KOH + HCl, HCl + NaCl, KOH + Ethanol and, HCl + Ethanol, respectively in a solution of 450 ml inside a shaker water bath maintained at 50 ºC for 4 hours. The treated samples were washed thoroughly with water and finally washed with distilled water. Eight samples were prepared in this stage.

iv. Control sample

An untreated sisal fibre sample was used as control.
Different cellulose micro-fibrils were prepared using combinations of chemical and mechanical treatments. Sixteen different treatments were carried out on various samples, while some parts were left untreated and served as control samples.

2.2.3. Preparation of sisal fibre and compounding of composite materials

The sisal fibre preparation, determination of fibre diameter and compounding of the materials for the development of composites were carried out in accordance with Oladele *et al.* (2014).

2.2.4. Production of sisal fibre-reinforced polypropylene composites by a compression molding process

Homopolymer PP and sisal fibres were mixed together in predetermined proportions of 3-5 wt% for the development of the composites. To produce these composites, two moulds were used. A tensile test mould and a rectangular mould of dimension 150 x 100 x 3 mm were used. The filled mould was placed inside a compression moulding machine maintained at 190 ºC and 15 tons for 15 minutes followed by air cooling. Teflon sheet and silicone were used as releasing agents. The unreinforced PP was also produced as neat material.

2.2.5. Testing and structural characterisation of cast samples

After forming the composites, samples were prepared for hardness, tensile and Charpy impact tests. A Scanning Electron Microscope (SEM) was used to investigate miscibility between the fibre and matrix at the fractured surfaces. These tests were carried out as follows:

i. Hardness test

A hardness test was carried out on the samples using a Shore D hardness tester in accordance with ISO 868. The test was carried out by indenting the sample with the instrument for about 5 seconds before taking the reading. Ten values were taken for each sample: the average is used as the representative value.

ii. Tensile test

Tensile tests were carried out on the samples using an Instron Universal Tensile Testing Machine in accordance with ISO / R 527. To carry out the test, the test piece, with a gauge length of 25 mm, was fixed at the edges of the upper and the lower grip of the machine and the test commenced. As the test piece was extended, a graph was automatically plotted and important tensile properties data were generated. The load applied was 25 KN at a crosshead speed of 5 mm/minute. Three samples were tested: the average value was used as the representative value.

iii. Impact test

Impact tests were carried out using a Charpy impact testing machine in accordance with ISO 179. Notched and unnotched impact tests were carried out on the samples. To carry out the tests, the samples were cut into the impact test dimension of 80 x 10 x 3 mm maintained at a distance of 60 mm between lines of supports. The notched samples were further prepared by notching them with the notching machine at the center of the samples. The test was carried out by placing the sample horizontally on the machine, taking the initial reading of the gauge and finally releasing a suspended handle that swings and fractures the sample. The final reading was taken after the sample fractured. For the notched samples, the samples were placed with the notched surface opposite to the swinging handle. Three test pieces were tested for each sample and the average value was taken as the representative value.

iv. Scanning electron microscope (SEM) examination

The fractured surfaces of the composites were examined using a JEOL SEM: JEOL JSM-5899 Scanning Microscope, JEOL, Tokyo Japan and a Zeiss SEM: Zeiss Ultra Plus 55 FECSEM, Zeiss, Oberkochen Germany respectively. Before the examination, the samples were prepared by cutting with a hacksaw followed by gluing on sample holder and finally coated with carbon using Carbon Coater: EMITECH K950X, EM Technologies, Kent England.

3. Results and Discussion

3.1. Hardness Properties of the Composites

Figure 3 shows the response of the composites, control and neat samples. From the results, it was observed that improved hardness properties were obtained for most of 5 wt% sisal-fibre reinforced composites compared to 3 wt%. The best results were obtained from the composite developed with sisal-fibre treated with 0.75 M HCl + 0.25 M KOH at 5 wt% sisal-fibre reinforcement which has a value of 75.7 HS, followed by sample from sisal-fibre treated with 0.75 M KOH + 0.25 M Ethanol and sample treated with 1 M HCl which has 75.5 HS and 75.0 HS, respectively.

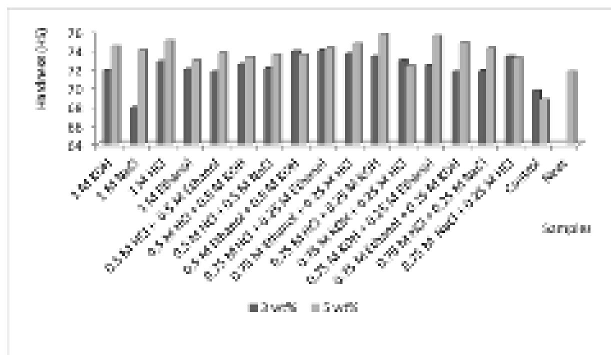

Figure 3. Hardness values of chemically treated and untreated sisal-fiber reinforced homopolymer polypropylene composites and the neat

It was also observed that hardness properties of most of the treated sisal fibre reinforced homopolymer PP composites were higher than neat material with a value of 71.7 HS whereas the reverse was the case for untreated sisal-fibre reinforced polypropylene composites with the best result of 69.7 HS from 3 wt% reinforcement. The observed results were due to the influence of chemical treatments on constituents of fibres. The exposed surfaces of sisal fibres after treatment allow proper binding of fibres and matrixes at their interface, thereby improving the hardness of the materials. Hardness of composites depends on distribution of fibre in the matrix (Premlal *et al.*, 2002; Jamil *et al.*, 2006). Usually, the presence of a more flexible matrix causes the resultant composites to exhibit lower hardness (Jamil *et al.*, 2006).

As shown in Figure 2, the incorporation of treated sisal-fibre into the PP matrix reduced the flexibility of the matrix resulting in more rigid composites. The hardness of treated sisal-PP composites showed a slightly increasing trend with an increase in the fibre content. The treated sisal-PP composites seem to have much better hardness values than the untreated ones. This may be attributed to better dispersion of fibre in matrix with minimisation of voids and stronger interfacial adhesion between matrix and fibre.

3.2. Tensile Properties of the Composites

3.2.1. Young's modulus of elasticity

Figure 4 shows the plots of Young's Modulus of Elasticity for homopolymer polypropylene composites, control and neat. From the results, it was observed that 3 wt% of sisal-fibre reinforcement enhanced the Young's Modulus of Elasticity of the materials more than 5 wt% sisal- fibre reinforcement in most of the samples produced from treated fibres. The best result was obtained from 3 wt% sisal-fibre reinforced sample treated with 0.75 M Ethanol + 0.25 M HCl with a value of 837.38 MPa followed by sample treated with 1 M KOH with a value of 830.50 MPa. The sample treated with 0.75 M HCl + 0.25 M NaCl at 5 wt% sisal-fibre reinforcement was next with a value of 830.44 MPa. Comparing these with the best from the control at 3 wt% reinforcement and the neat material which have 747.21 and 710.64 MPa, respectively, it becomes obvious that chemical treatment enhances this property.

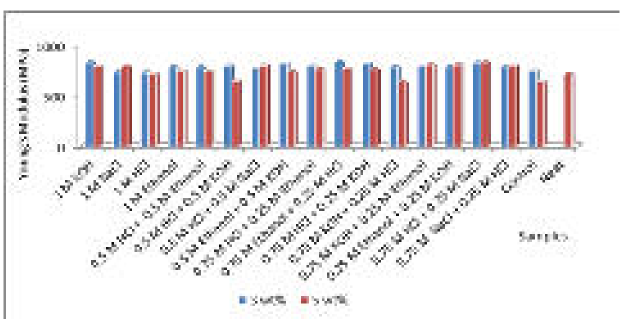

Figure 4. Young's modulus of elasticity for chemically treated and untreated sisal-fiber reinforced homopolymer polypropylene composites and the neat

The importance of natural fibre reinforced composites for polymeric materials comes from substantial improvement of the strength and modulus, this in turn improves the possibility of practical applications for composites. The addition of fibre is expected to increase the modulus of thermoplastic matrix composites (ASTM, 2002; Liu *et al*., 2005). It is evident from the Figure that treated sisal-PP composites are found to show higher modulus compared to composites of untreated sisal fibre. Usually crystallites possess higher modulus compared to amorphous substances (Karmakar *et al*., 2007). When sisal is treated with chemicals, crystallisation of the sisal surface probably dominates over its bulk nature, giving a higher modulus of treated sisal-PP composites. Furthermore, incorporation of fibre into the polymer matrix reduced the matrix mobility, resulting in stiffness of the composite.

3.2.2. Ultimate tensile strength (UTS)

The ultimate tensile strength is a measure of the maximum stress a material can withstand before it fails. Figure 5 shows variations of the ultimate tensile strengths for varous samples where it was observed that the strength of the materials was enhanced with 3 wt% of sisal fibre reinforcement than with 5 wt% in most of the samples produced from treatments. The best results were obtained with 3 wt% reinforcement with samples developed from sisal-fibre treated with 0.75 M HCl + 0.25 M KOH with a value of 34.53 MPa followed by unreinforced homopolymer polypropylene with a value of 33.88 MPa and a sample from sisal-fibre treated with 0.75 M HCl + 0.25 M NaCl with a value of 33.86 MPa.

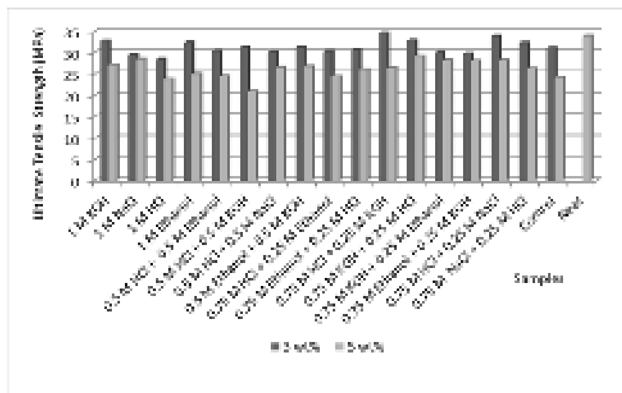

Figure 5. Ultimate tensile strength of chemically treated and untreated sisal fiber reinforced homopolymer polypropylene composites and the neat

The tensile strengths were found to decrease with increasing fibre loading. As fibre load increased, weak interfacial area between the fibre and matrix increased, this consequently decreased the tensile strength (Yang *et al*., 2004; Lou *et al*., 2007). An increase in fibre content increases the micro spaces between fibre and matrix, which weaken filler–matrix interfacial adhesion. As a result, the values of tensile strength show a decreasing trend with increasing fibre content in the composite. The presence of hydroxyl groups in cellulose of raw sisal is responsible for its inherent hydrophilic nature. As a result, it becomes difficult to compound hydrophilic sisal with hydrophobic PP, resulting in inefficient composites with weak interfacial bonding.

In order to improve mechanical properties of composites, sisal was chemically treated. Of the three hydroxyl groups present in a cellulose anhydro glucose unit, one is primary hydroxyl group at C6, while the other two are secondary hydroxyl groups at C2 and C3 positions. Although the primary hydroxyl group is more reactive than the secondary ones, the chemical treatment breaks some of the OH groups thereby reducing the hydrophilic nature of the sisal. Due to the replacement of most of hydroxyl groups by compound groups upon chemical treatment of sisal, interfacial bonding between fibre and matrix increased in the resultant composites. This in turn enhanced the tensile properties of the developed composites compared to untreated sisal-PP composites as shown in Figures 4-5. The observed improvement may be attributed to the effect of chemical treatment on the interfacial bonding between the matrix and the fibre. This indicates the efficacy of the chemical treatment of sisal in improving the interfacial adhesion between sisal and PP leading to increased stress transfer efficiency from the matrix to the fibre with a consequent improvement in the mechanical properties of the composites.

3.3.3. Stress at 0.2% yield

Yield stress is defined as the stress at which a material will undergo an increase in strain at a constant stress. At this point, the microstructure of the material will be distorted, that is, there will be a change at microstructural level. Figure 6 shows the stress at 0.2 % yield for the composites and neat. The results show that stress at 0.2 % yield were enhanced at both weight fractions.

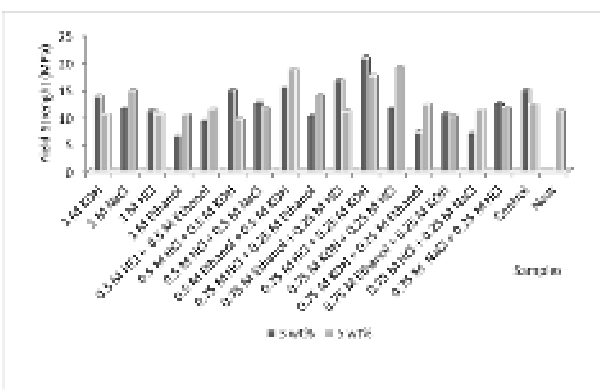

Figure 6. Yield strength (0.2 % proof stress) of chemically treated and untreated sisal fiber- reinforced homopolymer polypropylene composites and the neat

However, highest stress value was obtained at 3 wt% for a sample developed from sisal fibre treated with 0.75 M HCl + 0.25 M KOH with a value of 20.88 MPa followed by 5 wt% sisal fibre reinforced samples that are treated by 0.75 M KOH + 0.25 M HCl and 0.5 M Ethanol + 0.5 M KOH having 19.09 and 18.64 MPa respectively.

3.3.4. Strain at peak

Figure 7 shows the variation of strain at peak for homopolymer polypropylene composites and the neat. From the result, it was observed that 3 wt% sisal-fibre reinforcement enhanced strain at peak in almost all samples produced than that of 5 wt%. The best result was obtained from a 3 wt% sisal-fibre reinforced sample treated with 0.75 M HCl + 0.25 M NaCl which has a value of 16.11 mm/mm followed by the neat (unreinforced homopolymer polypropylene) with a value of 13.83 mm/mm and 3 wt% sisal fibre reinforced sample treated with 0.75 M HCl + 0.25 M Ethanol with a value of 12.38 mm/mm.

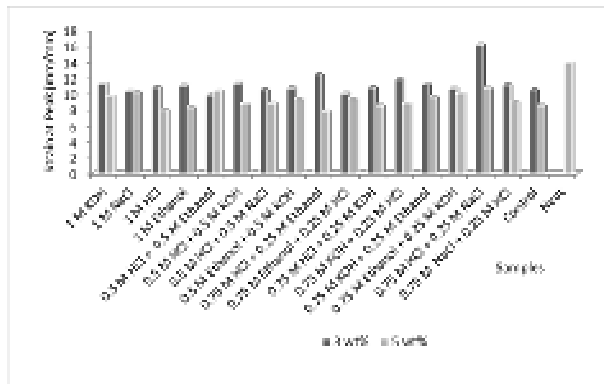

Figure 7. Strain at peak for sisal fiber-reinforced homopolymer polypropylene composites and the neat.

3.3.5. Impact properties of the composites

Variation of impact strengths for notched and unnotched homopolymer polypropylene matrix composites and the neat are shown in Figure 8. Samples were prepared in these forms so as to investigate the effect of sudden loading on the presence of fracture in case of notched samples while the unnotched accounts for the effect of sudden loading on thermoplastic materials where there is no fracture but there exists curve or bend. From the results, it was observed that both 3 wt% and 5 wt% sisal-fibre reinforcement enhanced the impact strength of the composites but were more enhanced with 3 wt%. The unnotched samples were noticed to possess better impact strength than the notched samples.

Considering notched samples, composites developed from 3 wt% sisal fibre reinforcement treated with 0.75 M HCl + 0.25 M KOH with a value of 0.016 J/mm^2 followed by 5 wt% sisal fibre reinforced sample treated with 0.5 M HCl + 0.5 M Ethanol having a value of 0.014 J/mm^2 gave better performance than the neat material. The neat follows with a value of 0.010 J/mm^2. This shows that in the as notched condition, reinforcement with chemically treated sisal fibre gave promising results compared to the control and the neat materials.

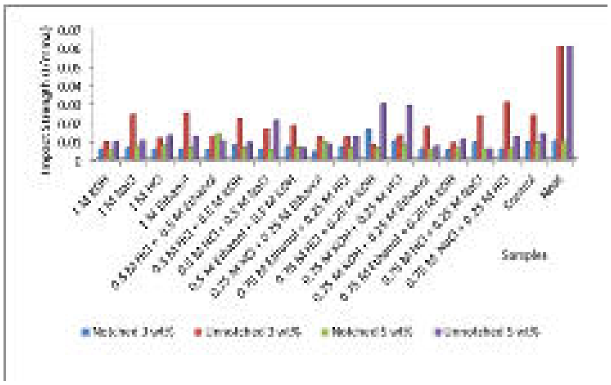

Figure 8. Notched and unnotched impact strength values for sisal fiber-reinforced homopolymer polypropylene composites and the neat

The neat material, in unnotched condition, had the best impact strength with a value of 0.061 J/mm^2 , followed by a composite developed from 3 wt% sisal-fibre reinforced sample treated with 0.75 M NaCl + 0.25 M HCl with values of 0.031 J/mm^2 , and then a 5 wt% sisal- fibre reinforced sample treated with 0.75 M HCl + 0.25 M KOH with a value of 0.029 J/mm^2.

The impact strength of a material provides information regarding the energy required to break a specimen of given dimensions; the magnitude of which reflects the ability of the material to resist a sudden impact. There is a diminishing effect of fibre on impact strength due to a drastic decrease in break elongation, because fibre bridges the crack and increases the resistance of crack propagation (Liu *et al*., 2005; Sanadi *et al*., 1997). The impact strength is found to decrease with an increase in fibre content due to poor interfacial bonding that induces micro-spaces at the fibre–matrix interface. These micro-spaces cause micro-cracks when impact occurs, resulting in crack propagation and decreased impact strength of the composites.

The impact strength of the treated sisal-PP composites were found to be higher than those of the untreated ones, indicating that better interfacial bonding between the matrix and the fibre occurred upon chemical treatment. As a result, the chemically treated sisal-PP composites are capable of absorbing a higher amount of energy, stopping crack propagation compared to the untreated ones.

3.3.6. Surface morphology

Different approaches have been applied to change the fibre/matrix adhesive properties in natural fibre-reinforced composites: chemical or physical modifications of the matrix, fibre or both the components. Mohanty *et al.,* (2000) studied the effect of alkali treatment, cyanoethylation and grafting of jute fabrics in jute/biopol composites and found a 50 % enhancement in tensile strength and 30 % in bending strength compared to the untreated fibre-reinforced composites. Pothan *et al.,* (2002) examined the mechanical properties of various silane treated and mercerised banana fibre-reinforced polyester composites and concluded that alkali treated composites have better mechanical properties due to the better packing of the cellulose chains after dissolution of lignin, the cementing material.

Rout et al. (2001) studied the effect of alkali treatment on the performance of coir–polyester composites and found that as the concentration of sodium hydroxide increased, the mechanical properties decreased due to the cell wall thickening, which lead to poor adhesion with polyester resin. Guduri, (2006) and co-workers proved that an alkali treatment of the lignocellulosic natural fabric Hildegardia Populifolia is a good method to improve the fibre/matrix interaction. Various physical methods such as corona treatment (Belgacem et al., 1994), plasma treatment (Felix et al., 1994) and heat treatment (Sapieha et al., 1989) have been reported to affect the compatibility in natural fibre composites; in most cases positively.

Using the SEM Morphology of the fractured surfaces of sisal fibre/homopolymer PP composites, it was observed that proper wetting of the sisal fibres occur in the developed composites, which was likely to be one of the reasons for the improved mechanical properties. Figure 9 shows the SEM image of untreated sisal fibre, while Figure 10 show sisal fibre with 0.75 M HCl + 0.25 M KOH treated.

Wetting of the fibre by the matrix is what aids proper binding between the fibre and the matrix. And, this is responsible for the transfer of load from the matrix to the fibre, which is a critical factor/issue in the production of composite materials. The morphology of the fracture surface shows the face information reflecting the reasons why the mechanical properties of the composites fabricated under different conditions are different. The solid white strand parts represent the fibre while the dark parts represent the matrix. Also seen from the surfaces are voids caused by trapped gases during compaction. These voids account for the porosity of some materials during production. Too much porosity in most cases adversely affects the mechanical properties of the materials as shown in both figures.

The SEM images of the untreated sisal-PP composites show a number of pullout traces of fibre with smooth surfaces and micro-voids as well as agglomeration of the fibre in the PP matrix as shown in Figure 9. These features suggest weak interfacial bonding between the fibre and the matrix. On the other hand, chemically treated sisal-PP composites show better dispersion of the fibre into the matrix, which results in better interfacial adhesion between the fibre and the matrix.

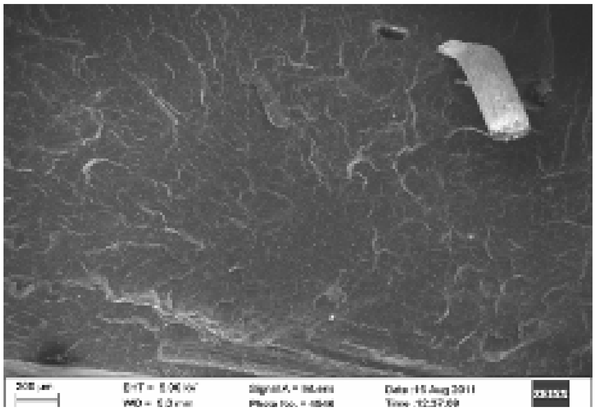

Figure 9. SEM image of untreated sisal fibre

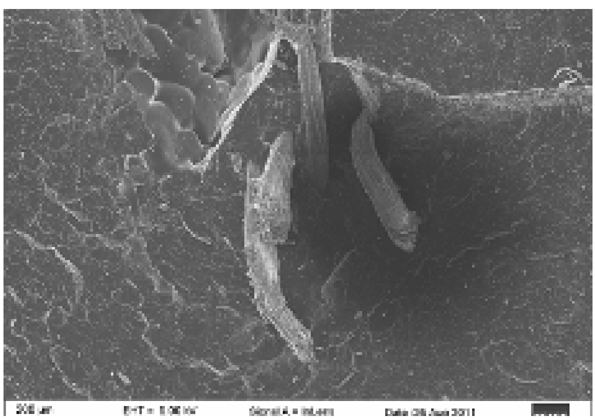

Figure 10. SEM image of sisal fibre with 0.75 M HCl + 0.25 M KOH treated

As clearly seen in the micrograph in Figure 10, both fibre pull-out traces and the agglomeration of sisal in the matrix have substantially reduced in the treated sisal-PP composites, suggesting that interfacial bonding between the treated fibre and the matrix is much more favorable compared to that of the untreated one. The outcome of the better interfacial bonding between the fibre and the matrix is reflected in the improvement of the mechanical properties of the treated sisal-PP composites.

4. Conclusion

Several deductions can be made from the research. Firstly, in all samples where sisal-fibre reinforced homopolymer PP composites perform better than the unreinforced homopolymer PP or compete favourably, chemically treated samples happened to be the best compared to the untreated samples. Treated sisal-fibre reinforced homopolymer PP composites had the best hardness, tensile strength and impact strength in the as notched condition properties than both untreated sisal-fibre reinforced homopolymer PP composites and unreinforced homopolymer PP. This may be attributed to better dispersion of the fibre into the matrix with minimisation of voids and stronger interfacial adhesion between the matrix and the treated fibres. The improved mechanical properties of the treated sisal-fibre reinforced homopolymer PP composites are further supported by SEM images of the fracture surface that show better matrix/fibre interaction compared to those prepared from untreated sisal-fibre.

Secondly, low weight fraction (fibre content) gave the best properties except in hardness. Tensile and impact strengths are found to decrease with increasing fibre loading. As the fibre load increased, the weak interfacial area between the fibre and the matrix increased, this consequently decreased these strengths. An increase in the fibre content increases the micro spaces between the fibre and the matrix, which weaken the fibre/matrix interfacial adhesion and allow moisture absorption. As a result, the values of these strengths show a decreasing trend with increasing fibre content in sisal-fibre reinforced homopolymer PP composites. Conversely, the presence of a more flexible matrix causes the resultant composites to exhibit lower hardness.

Considering the mixing ratios studied, 0.75 M: 0.25 M has higher synergistic effect than that of others. The treatment that has the highest best performance was 0.75 M HCl + 0.25 M KOH. The treatment gave the best result obtained in treated sisal-homopolymer PP composites for hardness, tensile strength and impact strength in the as notched condition properties.

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Mechanical Properties of Thin Wall Ductile Iron Cast in Moulding Sand/ Aluminium Dross Mix

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Abstract: *Moulding sand thermal characteristics is vital to defining the solidification mechanism of a cast part, which in turn influences evolving microstructure and mechanical properties. Thin wall ductile iron (TWDI) castings are a viable substitute for lightweight applications for energy saving in automotive industries. Carbide precipitation and non-nodular graphite in the structure of TWDI remains a production challenge in many foundries. Hitherto, charge material composition and liquid treatments were considered important in the production of sound TWDI castings. Literature is very scanty on the strategy for modifying the thermal properties of moulding sand for cooling rate and under-cooling controls for preventing carbide precipitation and non-nodular graphite in TWDI castings. This study investigates the effect of incorporating 2-12 wt. % aluminum dross (AlDr) on the thermal properties of moulding sand and on the microstructure and mechanical properties of as-cast TWDI parts. Microstructural and mechanical property characterisation of TWDI cast samples using sand-aluminum dross mix reduced BHN values from 179, 185 and 123 BHN to 67, 54 and 71 BHN, UTS values from 248, 300 and 389 MPa to 208, 168 and 221 MPa for 0 and 12 wt. % AlDr (2, 3, 4 mm thick samples, respectively). However the percent elongation increased up to 7.3% for the 3 mm thick sample. The results showed that aluminum dross used as a moulding sand additive reduced the hardness and ultimate tensile strength values but significantly improved percent elongation.*

Keywords: *Mould materials, sand mix, cooling rate, mechanical properties, thermal conductivity*

1. Introduction

The mechanical properties of ductile iron depend primarily upon the microstructures developed during solidification (Sheikh, 2008). The manufacture of thin wall ductile iron (TWDI) sand castings presents unique problems. The high surface area to volume ratio in the thin sections results in very high solidification rates and can lead to incomplete filling or other casting defects, undesirable microstructures (poor nodularity and nodule count) and mechanical properties. In recent years, many researchers such as Bockus et al (2008) and Fraś et al (2013) considered TWDI as a substitute for steels and light alloys owing to its high strength; good ductility; good castability; machinability; with high wear and fatigue resistance. However the literature identifies some drawbacks with TWDI castings: the presence of massive carbide precipitates (see Figure 1); and poor graphite shape characteristics (Figure 2) (Li et al 2000), which cause poor functional properties such as reduced ultimate tensile strength (UTS), low ductility, poor crack propagation resistance and machinability (Bockus et al., 2008; Ochulor et al, 2015). To date, most methods used to produce thin wall castings focus on metal chemistry, inoculation and gating practice. Few practical methods have been developed to control cooling and the reduction of solidification rates in convectional sand moulds. However, improvement in the heat capacity and thermal conductivity of the mould and core materials may have the potential to reduce casting wall thickness, more than all the other factors combined. By adjusting the density and thermal properties of individual mould and core components or inserts, the mould/core package can be engineered to give optimum flow and cooling characteristics (Afterheide and Showman, 2003).

During casting, heat transfer occurs between the hot liquid metal and the mould and the temperature decreases from that of the cast to the surrounding temperature. The process involves three successive stages: the cooling of the liquid metal; solidification; and finally cooling of the solid metal (Abed, 2011). The properties of the mould sand have an influence on the solidification process and behaviour of the liquid metal in it.

Figure 1. Microstructure of TWDI showing carbide precipitate
Source: Ochulor et al. (2015)

(a) (b) (c)

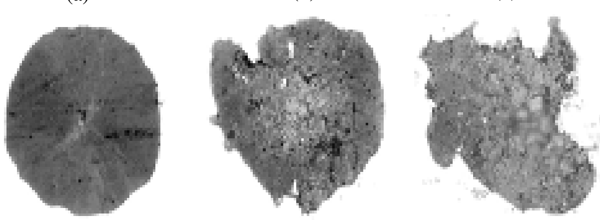

Figure 2. Types of graphite shapes (a) Spherical/nodular, (b) Slightly nodular and (c) Non-nodular
Source: Abstracted from Li et al. (2000).

The process of solidification—the change of liquid to solid metal after pouring into the mould—is the defining event in the life cycle of the casting (Rihan, 2010). The time involved in this transition may be as short as a few seconds or as long as hours, depending upon the casting process; the size of the casting; the chemical composition of the metal being cast; the manner in which solidification occurs; and the subsequent solid state treatment which determines the ultimate microstructure and properties (mechanical and physical) of the casting (Schmidt, 2010).

The heat exchange in the metal mould system is essential to the kinetics of cooling and solidifying of a casting, especially in TWDI casting, which starts to solidify during mould filling, and determines the cooling rate (Gorny, 2009). The goal here would be to control the solidification event so that the desired microstructure (nodularity and nodule count, and matrix type) of the final product with enhanced mechanical properties is obtained. The ultimate physical and mechanical properties of the cast metal will depend on one hand on intrinsic factors, such as chemical composition; cooling rate during solidification; and heat and mechanical treatments after solidification. On the other hand, it will depend on extrinsic factors, namely metal cleanliness; additives for microstructure control; casting design; riser and gating design; solidification rate control; and temperature control subsequent to solidification, which are both present (extrinsic and intrinsic) in each casting event and processing event subsequent to casting (Cantor, 2003; Kalpakjian, 2008). The cooling rate is largely determined by the size of the casting in its cross-section. Heat treatment may be used to overcome the difficulty, but this is usually undesirable because of cost and the extra processing steps required (Bockus and Zalgarys, 2010).

Ruxanda et al. (2002) in their study of the microstructural characterisation of TWDI castings, observed that high solidification cooling rates, the presence of carbide forming elements in the charge materials, low carbon equivalent and/or silicon content, low nodule count (poor inoculation) and poor nodularity as some parameters responsible for carbide formation. The main constituents of the matrix of TDWI castings are ferrite, pearlite and carbides, if any; their actual ratio is highly dependent on the processing parameters which include cooling rate, liquid treatment, chemical composition, and pouring temperature. The thermo-physical property of the mould is a crucial variable that affects the chilling tendency of TWDI castings (Stefanescu et al., 2002). Moulds with high thermal conductivity remove heat faster from the molten metal, causing it to solidify earlier. Moulds with high heat diffusivity transfer heat faster from the molten metal, causing it to stop flowing so that solidification occurs faster.

Aluminium dross, a by-product of aluminium smelting, is a mixture of metallic aluminium and non-metal mostly aluminium oxide. It usually forms on the surface of molten aluminium or its alloys by oxidation. In this study it is used as a moulding sand constituent and this study investigated its effect on the thermal characteristics of moulding sand and consequently on the microstructure and mechanical properties of TWDIs cast from the mould mix. The aim was to impart some level of thermal insulation into the mould material using the refractory properties of Al_2O_3 and SiO_3 present in the dross: This approach was predicated on the reduction in moulding sand thermal conductivity and finally on cooling rate of the melt.

2. Methodology

2.1 Aluminium Dross Additive to Moulding Sand on TWDI castings

The dross used was collected from Aluminium Rolling Mills, Ota, Nigeria, after a recovery process was carried out to remove valuable aluminium. Table 1 shows the chemical composition of the Aluminium Dross. Sieve analysis was carried out on the dross and only particles sizes between 250-300 µm were used. This ensured that the particle size is similar to that of the silica moulding sand used, as good surface finish is required in TWDI castings.

The chemical composition of cast the TWDI sample is shown in Table 2, and a control composition of the green moulding sand used is shown in Table 3. This control composition is used to cast 2, 3 and 4 mm plates so as to compare its properties with that of the other sand mixes, containing varied wt. % of the aluminium dross.

Table 1. Chemical Composition of Aluminium Dross

Consti.	Al_2O_3	SiO_2	MgO	NaO	K_2O
Wt. %	43.38	3.12	0.12	9.84	0.72

Consti.	CaO	Fe_2O_3	Sulphate	Chloride	Al
Wt. %	1.57	0.70	0.60	1.98	37.97

Table 2. Chemical Composition of cast TWDI sample

Element	Fe	C	Si	Mn	P	S	Cr
Compo (Wt. %)	92.47	3.44	3.21	0.32	0.057	0.071	0.025

Table 3. Control Composition of the green moulding sand

S/No	Materials	Weight Composition (wt. %)
1	Silica Sand	96.4
2	Bentonite	2.2
3	Starch	0.8
4	Water	0.4

The sand constituents are mixed using a Rhino model IRM-500 sand mixer with a mixing time of 5 minutes. Using this standard composition of moulding sand, six other different compositions of the moulds were prepared by adding varying weight percentages of aluminium dross (AlDr) to the moulding sand as in Table 4. The choice of the weight percentages used is based on a preliminary trial test conducted on 600g of moulding sand. The result helped determine the upper limit (i.e. 12 wt. % AlDr) of the dross to be used. Higher weight percentages had an adverse effect on the moulding sand properties. The moulding sand property test was conducted to ensure that the sand/AlDr blend had the required properties necessary for ductile iron casting in the foundry. This was vital to preparing dense moulds with sufficient strength for close dimensional accuracy of the samples.

Table 4. Sand Specimen with wt% of Aluminium Dross

S/No	1	2	3	4	5	6	7
Specimen	D	D1	D2	D3	D4	D5	D6
Wt% of AlDr	0	2	4	6	8	10	12

The thermal properties of importance in this work are (1) thermal conductivity and (2) heat/ thermal diffusivity. These thermal properties of the sand-Al dross blend were determined after moulding just before coupling, using the KD 2 Pro Thermal Conductivity Meter (see Figure 3a). Both the TR-1 (see Figure 3b) and SH-1 (see Figure 3c) sensors were used to measure thermal conductivity and thermal diffusivity respectively at 28.83 ^{0}C read temperature. The charge composition is shown in Table 5.

(a) (b) (c)

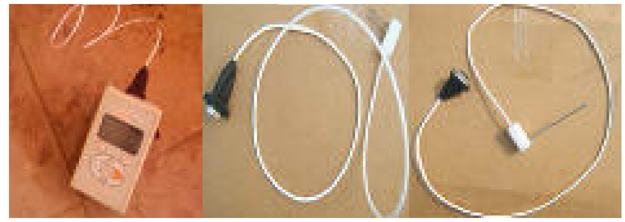

Figure 3. (a) KD 2 Pro Thermal Conductivity Meter, (b) TR-1 sensor (c) SH-1 sensor

Table 5. Chemical composition of charge materials

Charge	wt. % (Kg)	% of Charge	C (Ch. Comp.%)	Si (Ch. Comp.%)	Mn (Ch. Comp.%)
Mild Steel	300	60	0.1	0.1	0.2
Ductile Iron Returns	80	34	0.1	0.1	0.2
Ferro Silicon	7	1.4	0.00	70	0.00
Graphite	23	4.6	70	0.00	0.00
Charge	wt. % (Kg)	% of Charge	C (Ch. Comp.%)	Si (Ch. Comp.%)	Mn (Ch. Comp.%)

2.2 Microstructural Characterisation of Experimental TWDI Castings

The samples (of 2, 3 and 4 mm thicknesses) were cast using the standard casting procedure after melting the charge materials. Samples for microstructural analysis were cut from the centre; ground; and polished according to the standard procedure outlined in ASTM Standard E3 for metallographic analyses. The prepared samples were viewed in their unetched and etched (using 2% nital solution) conditions using a CETI Optical Metallurgical Microscope Model No. 0703552 at a magnification of X100.

2.3 Mechanical Property Testing

The Brinell hardness test was carried out using a 10/3000kg indenter ball in accordance with the ASTM E10 standard. The results are shown in Table 5. A tensile property test was carried out on a test piece sample 2 mm in thickness, as shown in Figure 4 in accordance with ASTM E8 standard.

Table 6. BHN results for the samples cast with moulding sand-aluminium dross mix

Wt.% Al.Dr	0	2	4	6	8	10	12
2	179	48	37	26	55	47	67
3	195	63	33	30	52	52	54
4	123	69	48	25	63	47	71

Figure 4. Dimension for Tensile Test Sample

3. Results and Discussion

3.1 Effect of Aluminium Dross addition on Moulding Sand Thermal Characteristics

The effects of the aluminium dross addition on the thermal conductivity and diffusivity of the sand mixes are presented in Figures 5 and 6 respectively. The thermal conductivity of the sand mix, shown in Figure 5, increased significantly from that of the control mix up to 6 wt. % AlDr, after which it dropped progressively with further increases in weight percent of AlDr from 8-12wt. % AlDr. This can be attributed to high initial thermal conductivity imposed by aluminium in sand mix i.e., 2-6 wt. % aluminium dross, then as the weight percent of additive is increased i.e., 6-12 wt. % the insulating properties of both alumina and silica became evident causing reduction in thermal conductivity (see Table 1).

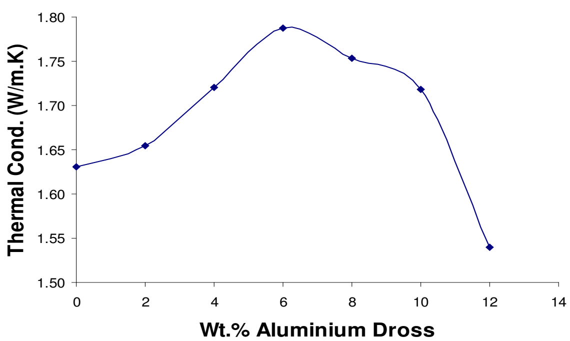

Figure 4. Moulding sand thermal conductivity with weight % Al dross in sand mix

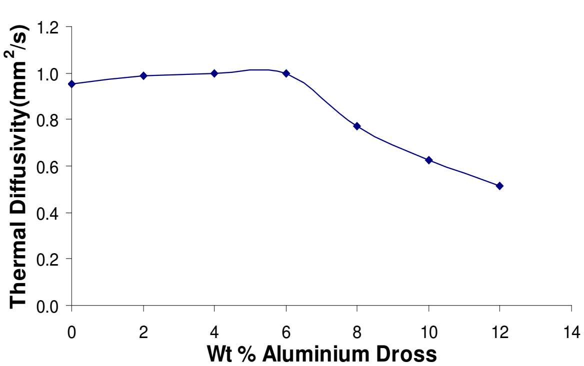

Figure 5. Moulding sand thermal diffusivity with weight % Al dross in sand mix

This indicates a faster cooling/heat transfer rate for the TWDI samples up to 6 wt. % AlDr. This faster cooling rate implies that there is insufficient time for graphite segregation i.e. formation of graphite nodules. It then reduced on further AlDr addition to the sand mix, thereby aiding thermal insulation which is the desired property here. The reduction in thermal conductivity from 6 wt. % AlDr implies that there is more time for graphite segregation but it should be noted that these values of 1.787, 1.753, 1.718 W/m K for 6, 8 and 10 wt. % respectively (except that of 12 wt. % AlDr of 1.540 W/m K) are still lower than that of the control sand mix of 1.631 W/m K. The thermal diffusivity which is a function of thermal conductivity increased only slightly from 2 to 6 wt. % AlDr, after which it dropped significantly from 8 to 12 wt. % AlDr, reaching 0.514mm^2/s for 12 wt. % (see Figure 5). This implies that the solidification of samples is delayed when cast in these moulding sand/aluminium dross sand mix. This is expected to aid proper graphite segregation (carbon diffusion) in melt solidification, enhancing better nodularity and nodule count.

3.2 Microstructural Analysis of Sand – Aluminium Dross Cast Samples

All the optical micrographs (see Appendix 1, Plates 1-21) of the samples cast using an aluminium dross additive showed that this additive yielded undesirable graphite characteristics i.e., low nodularity and nodule count, and consequently undesired mechanical properties of cast TWDI samples. The control samples showed good nodularity, good nodule count and control of carbide precipitates. Non-nodular graphite and poor matrix structure were observed in the samples cast using the moulding sand-aluminium dross blend. Plates 1-3 shows micrographs of samples cast without the use of moulding sand-AlDr blend (control samples). The samples show good nodularity and nodule count. The matrix constituents are mainly ferrite and pearlite exhibiting the bull-eyed structure. The graphite nodules were mainly of type IV and V.

The microstructures of samples cast using 2wt. % AlDr show poorly formed graphite nodules for all thicknesses. In addition to non- nodular graphite, there is the presence of a dark phase which is suspected to be a reaction product formed by reactions between elements in the melt (see Table 5) with aluminium, alumina or sulphur from sulphate in the moulding sand mix (see Table 1). Thermal conductivity increased slightly from 1.631 to 1.654 W/m K thereby reducing the time for nucleation of graphite nodules (Plates 4-6). Due to the reduction in solidification time, insufficient time is available for graphite nucleation leading to carbide precipitates in TWDI matrix.

Plates 7-9 for 4 wt. % AlDr show these dark reaction product phases, poor nodularity and nodule count with carbide precipitates in the structure. Plates

10-12 show samples cast from 6 wt% AlDr. This corresponds to the highest thermal value of 1.787 W/m K, indicating a high heat transfer rate. The samples also exhibited poor nodularity and nodule count; undesirable reaction products were created and the resultant matrix structure is not clearly defined. The same is also observed for Plates 13-15 where thermal conductivity started dropping, the structure here also shows the presence of a ferrite phase. The thermal conductivity was further reduced, though it is still higher than that of the control sand mix. Increased thermal conductivity drops resulted in better nodularity and nodule count. The matrix type is ferrite-pearlite for the three thicknesses as shown in Plates 16-18. The shape characteristics of formed nodules improved significantly for 12 wt. % AlDr sand mix (see Plates 19-21). Thermal conductivity dropped to 1.540 W/m K, which was lower than that for control sand mix of 1.631 W/m K. This is responsible for a better but not desired microstructure observed in these plates. The matrix is still ferrite-pearlite.

3.3 Hardness Characteristics of TWDI Castings Produced in Al Dross-Sand Mould

The chemical composition of cast TWDI sample is shown in Table 2. The variation of Brinell hardness number (BHN) with weight percent aluminium dross is shown in Figure 7. The hardness values were highest for the control samples 179, 195 and 123 for 2, 3 and 4 mm thick samples, indicating that casting using the AlDr as a moulding constituent did not produce the required hardness. However, the BHN values increased from 2-12wt% aluminium dross, dropping slightly again at 10wt%. AlDr. These lower BHN values observed in samples cast from moulding sand-aluminium dross mix can be attributed to the reaction product formed; this compound had a softening effect on the matrix of the samples.

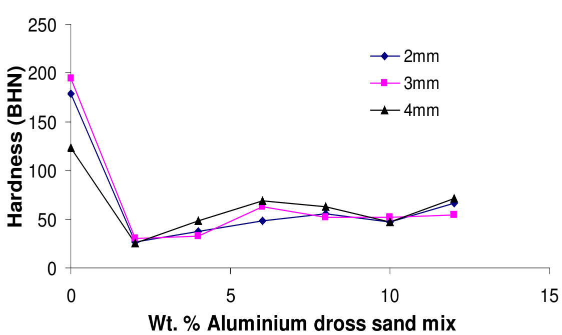

Figure 7. Variation of BHN with weight % Al Dross in sand mix

3.4 Tensile Characteristics of TWDI Castings Produced in Al Dross-Sand Mould

The variation of ultimate tensile strength (UTS) with weight percent aluminium dross is shown in Figure 7. The UTS responses show that aluminium dross addition to sand mould negatively affected the UTS of the cast samples. The control samples that were cast in sand mould without AlDr addition gave the best UTS of 248, 300 and 389 MPa. The lowest UTS values occurred at 2wt. % AlDr corresponding to the second lowest thermal conductivity value. This pattern is similar to that obtained for hardness responses. The percent elongations at fracture are higher from 8-12wt. % AlDr.

The highest values of 4.5, 7.3 and 4.7 % at 12wt. % AlDr for 2, 3 and 4 mm thicknesses, respectively, were observed (see Figures 9). Thus, the percent elongations of cast samples were high, indicating that the dross-sand mould positively impacts ductility, while sacrificing tensile strength. As mentioned previously the suspected reaction product nucleated in the melt during solidification had a softening effect on the matrix of TWDI samples, also as thermal conductivity dropped from 6-12 wt. %, the cooling rate is reduced and further softening of matrix is suspected as the percent elongation values were highest for all thicknesses investigated at 12 wt. % aluminium dross (see Figure 9).

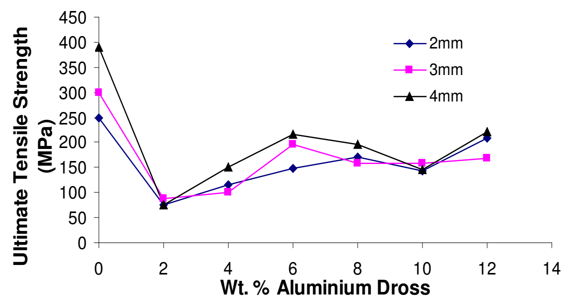

Figure 7. Variation of UTS with weight % Al Dross in sand mix

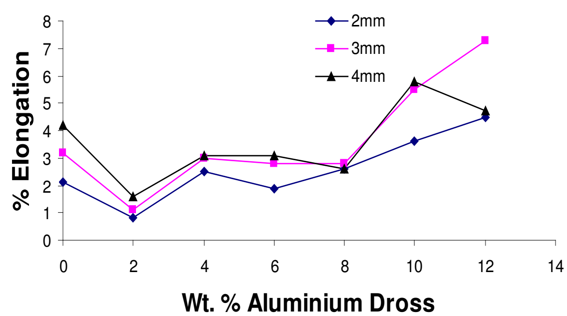

Figure IX. Variation of % elongation with weight % Al Dross in sand mix

Regression analysis was used to correlate the effect of weight percent aluminium dross in moulding sand on percent elongation of samples. The analysis shows that the percent elongation follows a quadratic relationship according to equations 1, 2 and 3 for 2, 3 and 4 mm thick samples, respectively.

$$\%_{Elong.}(_{2mm}) = 0.0301(AlDr_{Wt\%})^2 - 0.1304(AlDr_{Wt\%}) + 1.7905$$
$$R^2 = 0.8328 \qquad (1)$$

$$\%_{\text{Elong.}}\ (_{3mm}) = 0.0711(AlDr_{Wt\,\%})^2 - 0.4804\ (AlDr_{Wt\,\%}) + 2.8548 \quad R^2 = 0.8849 \tag{2}$$

$$\%_{\text{Elong.}}\ (_{4mm}) = 0.0446(AlDr_{Wt\,\%})^2 - 0.5107(AlDr_{Wt\,\%}) + 4.2829 \quad R^2 = 0.8940 \tag{3}$$

4. Summary of the Findings

The study shows that the thermal conductivity of aluminium dross-sand mix is not favourable for casting TWDI as it causes a high heat transfer/cooling rate and this hinders equilibrium transformation. Thermal conductivity increased for all sand mixes except for 12wt. % AlDr. Samples cast from the aluminium dross sand mix are structurally defective both in graphite shape characteristics and matrix type formed. It was difficult to determine the nodularity and nodules count, as the graphite structures formed were mostly non-nodular/ deformed in shape. The matrix was also not clearly defined due to the presence of a reaction product. However, the percent elongation increased at the expense of tensile strength and hardness properties of these samples. The highest elongation values of 4.5, 7.3 and 4.7 were observed for 2, 3 and 4mm samples respectively at 12 wt. % AlDr, this can be attributed to the suspected matrix softening effect of both the reaction product and the lowest thermal conductivity value obtained at 12 wt. % Al dross.

5. Conclusion

This work has shown that aluminium dross addition to moulding sand mix caused a reduction in mould thermal properties (thermal conductivity and diffusivity); undesirable nodule characteristics; and a reduction in hardness and tensile strength of TWDI cast samples. However, samples show good percent elongation values reaching 7.3 for 3mm thick sample cast using 12wt. % aluminium dross in the sand mould. Although, this sand mix may not be a suitable mould for components requiring high strength and hardness, it can be used to cast profiles or automobile parts requiring considerable elongations and mild strength.

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Appendix 1: Optical Micrographs of Samples

(a) (b)

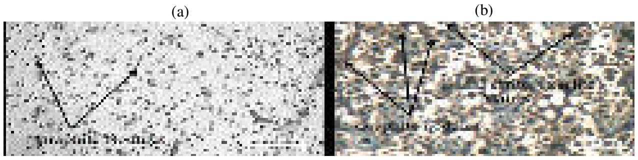


Plate #1: Optical micrograph of 2mm thick section
(a) unetched (b) etched of D

(a) (b)

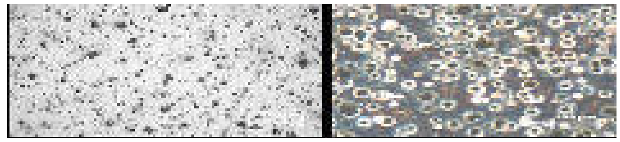


Plate #2: Optical micrograph of 3mm thick section
(a) unetched (b) etched of D

(a) (b)

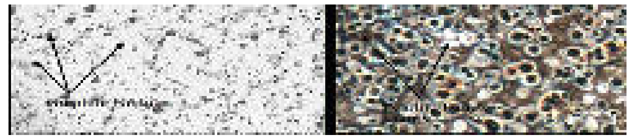
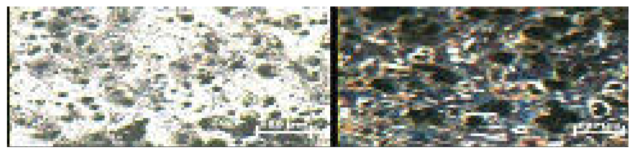


Plate #3: Optical micrograph of 4mm thick section
(a) unetched (b) etched of D

(a) (b)



Plates #4: Optical micrograph of 2mm thick section
(a) unetched (b) etched of D1

(a) (b)

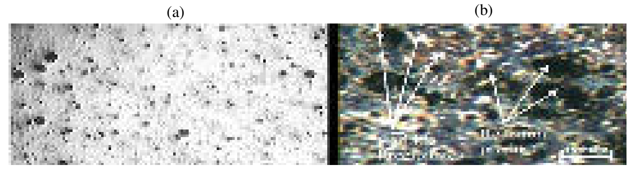
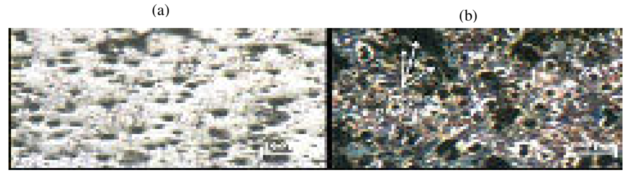


Plate #5: Optical micrograph of 3mm thick section
(a) unetched (b) etched of D1

(a) (b)



Plates #6: Optical micrograph of 4mm thick section
(a) unetched (b) etched of D1

(a) (b)

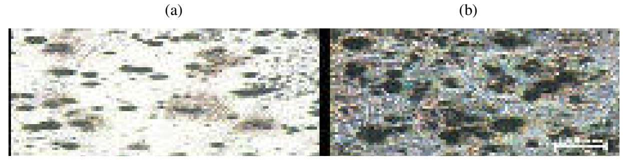


Plate #7: Optical micrograph of 2mm thick section
(a) unetched (b) etched of D2

(a) (b)

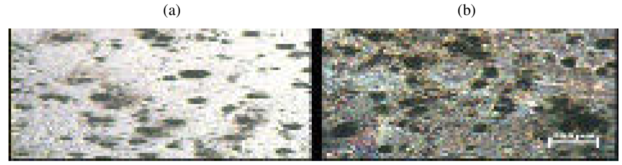
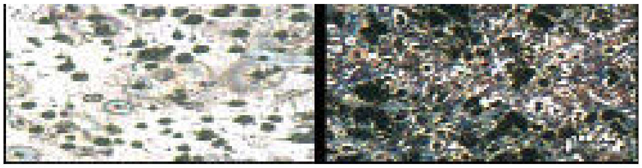


Plate #8: Optical micrograph of 3mm thick section
(a) unetched (b) etched of D2

(a) (b)



(a) unetched (b) etched of D2

(a) (b)

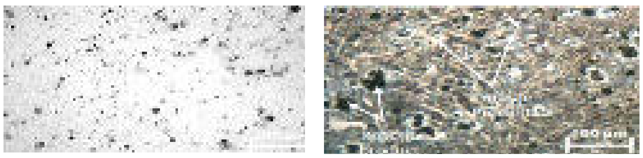


Plate #10: Optical micrograph of 2mm thick section (a) unetched (b) etched of D3

(a) (b)

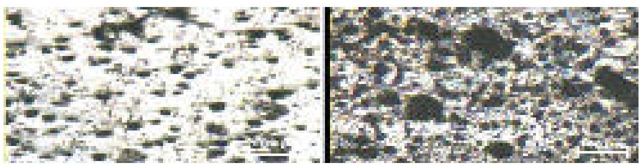


Plate #11: Optical micrograph of 3mm thick section (a) unetched (b) etched of D3

(a) (b)

Plate #12: Optical micrograph of 4mm thick section (a) unetched (b) etched of D3

(a) (b)

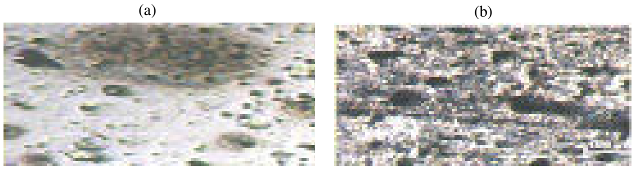


Plate #13: Optical micrograph of 2mm thick section (a) unetched (b) etched of D4

(a) (b)

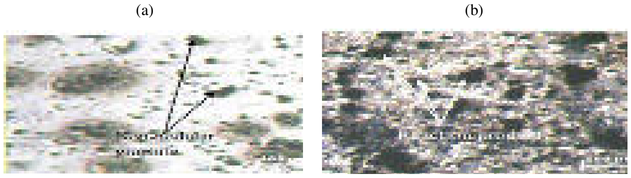


Plate #14: Optical micrograph of 3mm thick section (a) unetched (b) etched of D4

(a) (b)

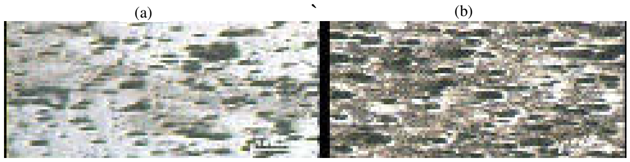


Plate #15: Optical micrograph of 4mm thick section (a) unetched (b) etched of D4

(a) (b)

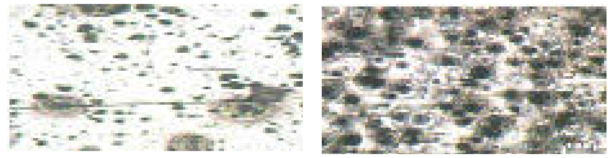


Plate #16: Optical micrograph of 2mm thick section (a) unetched (b) etched of D5

(a) (b)

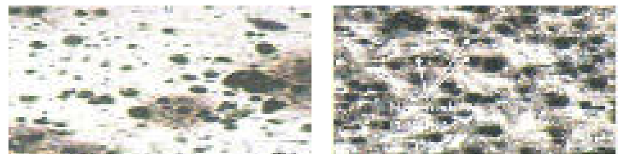


Plate #17: Optical micrograph of 3mm thick section (a) unetched (b) etched of D5

(a) (b)

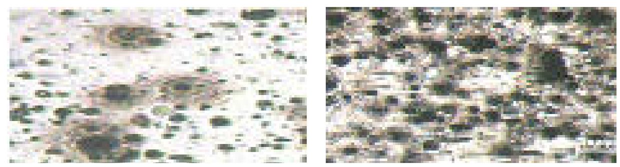


Plate #18: Optical micrograph of 4mm thick section (a) unetched (b) etched of D5

(a) (b)

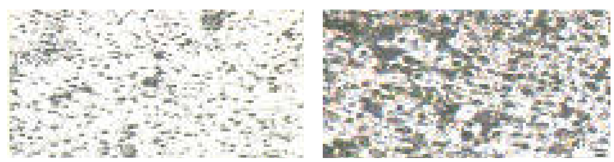


Plate #19: Optical micrograph of 2mm thick section (a) unetched (b) etched of D5

(a) (b)

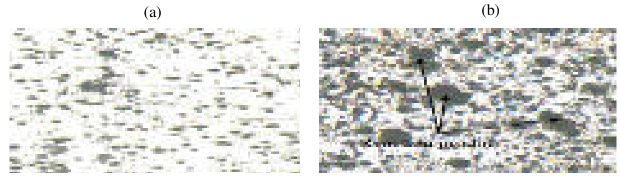


Plate #20: Optical micrograph of 3mm thick section (a) unetched (b) etched of D6

(a) (b)

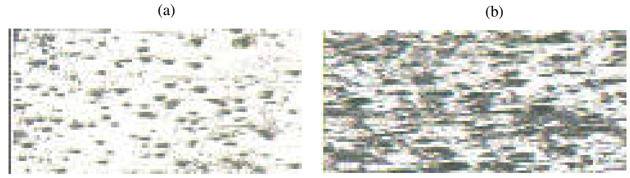


Plate #21: Optical micrograph of 4mm thick section (a) unetched (b) etched of D6

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Suitability of Crushed Cow Bone as Partial Replacement of Fine Aggregates for Concrete Production

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Abstract: *This paper presents an assessment of the strength properties of concrete containing crushed cow bone (CCB) as partial or full replacement of fine aggregates. Fine aggregate was replaced with CCB by weight up to 100 % at intervals of 10%. The properties investigated were: workability, density and the compressive strength. The slump test and the compacting factor test were used to assess the workability of the concrete sample specimens. The density and compressive strength were determined using 150 mm cube specimens. The results showed that: (i) increase in the percent replacement of sand with CCB resulted in less workable concrete, (ii) replacing sand with CCB resulted in different types of concrete, and (iii) a compacting factor test will be appropriate to assess the workability of concrete containing CCB because of the resulting dry mix and (iv) up to 20% of sand replacement with CCB will result in compressive strength that is not significantly different from the control.*

Keywords: *Compressive Strength, Concrete, Crushed cow bone, Density, Workability*

1. Introduction

Concrete is considered to be a universal construction material for many reasons. It is resistant to water when hardened. It is preferred for the ease with which structural concrete elements can be formed into a variety of shapes and sizes, and it is reasonably low cost to produce. However, in comparison to other materials used in construction industry, concrete consumes a high quantity of natural resources. Mehta and Monteiro (2006) reported that about 11.5 billion tons of resources are being used annually for the production of ordinary concrete consisting of 1.5 billion tons cement, 1 billion tons of water, and 9 billion tons of aggregates. Aggregates consist of fine aggregates and coarse aggregates. Generally aggregate less than 4.75 mm is classified as fine aggregate. The popular and most preferred materials used as fine aggregates are river sand and crushed stones. However, river sand and crushed stone are produced at great cost and at the expense of non-replaceable natural resources, and raises serious environmental concern (OSPAR, 2004). Researchers have been investigating possible alternatives. The materials that have been found as possible alternatives are: recycled glass bottles, recycled fine aggregates, polymer waste material, weathered crystalline rocks, crushed clay bricks, bottom ash, laterite, etc. (Falade et al., 2013a, Mathews et al., 2013, Dahiru and Usman, 2013, Ashiquzzaman and Hussein, 2013, Ganiron Jnr, 2013, Raju et al., 2014, and Otoko, 2014). The present study investigated the use crushed cow bone (CCB) as a partial or full replacement of fine aggregates in the production of normal concrete. Cow bones are waste from abattoirs and slaughterslabs. Annual production of cow bones in Nigeria is about 5 million tonnes, and no efficient disposal system is presently available besides burning and indiscriminate dumping (Falade et al., 2011). This is serious environmental issue that will be solved if found suitable for use in concrete production. Recent studies—Falade et al. (2013b), Ikponmwosa et al. (2013), and Falade et al. (2014)—have investigated using pulverised cow bone as a partial substitute for cement in the production of foamed aerated concrete. But foamed aerated concrete presently has limited application, while cow bones continue to be generated, and thus this application is incapable of solving the environmental and solid waste problems emanating from the slaughterslabs and abattoirs. Also Otunyo et al., (2014) tried using cow bone in lightweight concrete, which by definition is the concrete having a density not greater than 1920 kg/m^3 (ACI, 2003, Falade et al., 2011). An attempt was also made by Bhat et al (2012) to use cow bone as a partial replacement of coarse aggregates in concrete. But the aim of this work is to assess the strength potentials of concrete in which the fine aggregates component has been fully or partially replaced with CCB, without any weight limitations. The parameters investigated include workability, density and the compressive strength.

2. Materials and Methods

2.1 Materials and Mix Proportion

For this investigation, the following materials were used: cement; fine aggregate; coarse aggregates; CCB; and water. Ordinary Portland cement (OPC) of Grade 43, whose production was in accordance with BS 12 (BSI, 1996) and NIS 444-1 (NIS, 2014), was used as the main binder. For the fine aggregates, river sand excavated at the river Ogun bed at Ibafo town in the Ogun State of Nigeria were used. Particles passing through sieve size 4.75mm but retained on sieve size with 0.150 mm aperture, in accordance with BS 882:1992, were used. The coarse aggregates used for this research were crushed granite chippings quarried from Abeokuta of the Ogun State, Nigeria. The coarse aggregates ranged in size from 4.75 mm to 20 mm. The CCB was obtained from Oko-Oba abattoir of the Agege Local government, Lagos State, Nigeria. The bones had been crushed after they were dried and burnt; the muscles, flesh, tissues, intestines and fats having been separated and removed prior to drying and burning. The crushed cow bone was later allowed to undergo sieve analysis so that the fraction passing through 4.75mm but retained on the sieve size 0.150 mm, compatible with the sand to be replaced, was separated, packaged in bags and stored in cool dry place. This was subsequently investigated. Figure 1 is the sample of the crushed cow bone.

Figure 1. Sample of the Crushed Cow Bone (CCB)

The water used for in this study was potable tap water. This was well treated for domestic consumption and maintained for the purpose of this research experiment. A mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) by weight and water/cement ratio of 0.50 were used. The fine aggregates in the mix were replaced with crushed cow bow up to 100% at intervals of 10%.

2.2 Experimental Investigations

2.2.1 Preliminary Investigations

Some preliminary investigations carried out included determination of the particle size distribution of the fine aggregates, CCB and the coarse aggregates. Also, the bulk density, specific gravity, porosity, void ratio and the 24-hr water absorption capacity were determined for the fine aggregates, CCB and the coarse aggregates. All the investigations were conducted using relevant standards.

2.2.2 Main Investigations

Workability Test

Workability properties of the concrete with CCB as partial or full replacement of fine aggregates were assessed through the slump test and the compacting factor tests. The slump test was carried out in accordance with the provisions of BS EN 12350 Part 2: (BSI, 2000). The compacting factor test was done in accordance with the provisions of BS 1881-103 (BSI, 1993). During the investigation, the fine aggregates portion of the mix was progressively replaced by CCB (by weight) up to 100% at intervals of 10%. The mix without CCB served as the control.

Density and Compressive Strength Test

The density and the compressive strength tests were carried out respectively in accordance with the provisions of BS 12350: Part 6 (BSI, 2000) and BS EN 12390-3 (BSI, 2009) using 150 x 150 x 150 mm concrete cube specimens. Tests on the cube specimens were carried out at 7, 14, 28, 56 and 90 days of moist-curing. The specimens were allowed to dry for about 2 hours after taking out of the curing tank. The compressive strength characteristics of each cube were determined on 600 kN Avery Denison Universal Testing Machine at a loading rate of 120 kN/min. Three (3) specimens for each of the curing ages were tested to failure by crushing, and the failure load was recorded. The average failure load of the three specimens was then divided by the area of the specimens to obtain the compressive strength. In order to determine the density, the weight of each of the cube specimens at the point of testing for compressive strength was taken, and later used for the computation of the density.

Specimen Preparations

Concrete samples with a mix ratio of 1:2:4 and water-cement ratio of 0.50 were prepared. The fine aggregate portion of the mix was progressively replaced with CCB up to 100% by weight at intervals of 10%. The sample without CCB (that is, 0% CCB) served as the control. The 150 x 150 x 150 mm cube specimens cast from the concrete samples were compacted using a poker vibrator. After casting, all test specimens were kept in a dry ventilated space and demoulded after 24 hours. To facilitate the demoulding process, the moulds were oiled. The specimens were then lowered into the curing tank filled with water for curing, until the required test date. A total number of 150 cube specimens were prepared and tested.

3. Results and Discussions

3.1 Preliminary Investigations

It can be observed from Table 1 that the weight-related properties of CCB, that is, the bulk density and specific gravity, showed lower values than that of the river sand. What is suggested is that a larger volume of CCB will result for a unit replacement by weight of river sand. The parameters that measure the internal structures like the void ratio, porosity and the water absorption showed higher values than the river sand. This suggests that concrete with CCB may require more water and develop lower compressive strength in relation to concrete with river sand using the same mix ratio. Also it may consume more cement than fine aggregate (ACI, 1999).

Table 1. Some Physical Properties of the Fine Aggregates and Crushed Cow Bone

Properties	CCB Aggregate	River Sand
Bulk Density (Kg/m3)	20.5	58.16
Specific Gravity (SSD)	1.67	2.63
Void Ratio	0.229	0.223
Porosity	0.186	0.182
24-hour Water Absorption (%)	3%	0.15
Aggregate Crushing Value (%)	30%	23.19
Fineness Modulus	2.44	2.88

Further, the water absorption value for CCB, which is a measure of the total pore volume accessible to water (ACI, 1999) is higher than the sand. This means that part of the mixing water may be absorbed by the CCB and thus deprived the concrete mix of the water necessary to maintain the strength-forming hydration process. Figure 1 shows the results of the particle size distribution for both the river sand and the CCB. It can be observed that the grading for both river sand and CCB are similar. Their grading can be described as uniform, and only a few sizes dominate the bulk material. This similarity is further reinforced from the values of their fineness modulli (see Table 2).

Both the river sand and the CCB with the fineness modulus respectively of 2.88 and 2.44 satisfy ASTM C 33 specifications (ASTM, 2003), for fine aggregates which require fineness modulus not to be less than 2.3 or more than 3.1.

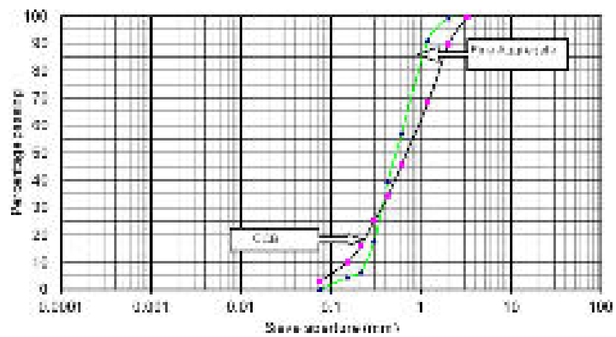

Figure 2. Particle Size Distribution Curve for the Fine Aggregate and CCB

3.2 Workability Test

The results of the slump and the compacting factor tests to assess the workability properties of the concrete mix are presented in Table 2. It can be seen that both the slump and compacting factor values of the concrete samples reduced with an increase in the percent replacement of sand with CCB. For example, the slump decreased by 80% from 25 mm at 0% to 5 mm at 100 % replacement. For compacting factor, there was a reduction of 42.53%. The reduction in slump with increase in quantity of CCB in the mix is due to the cumulative effects of its water-draining characteristics. First a lower specific gravity means more volume for a unit weight replaced (see Table 1), and the resultant larger surface areas means more water will be required to maintain the same workability otherwise there will be reduction in workability.

Moreover, CCB is more porous and had higher water absorption capacity than sand (see Table 1) indicating that part of the mixing water is lost. This results in harsh mixes with an attendant low slump.

Table 2. Workability Properties of the Concrete Specimens

% CCB iIn the Mix	Slump Type	Slump (mm)	Compacting Factor (mm)	Description of Workability
0	True	25	0.87	Very Low
10	True	17	0.82	Very Low
20	True	15	0.74	Very Low
30	True	12	0.71	Very Low
40	True	10	0.66	Very Low
50	Collapse	7	0.63	Very Low
60	Collapse	5	0.60	Very Low
70	Collapse	5	0.60	Very Low
80	Collapse	5	0.55	Very Low
90	Collapse	5	0.55	Very Low
100	Collapse	5	0.50	Very Low

True slump was observed for the specimens up to 40% sand replacement with CCB. The true slump displayed by the sample up to 40% replacement was an indication of cohesiveness of the mix and absence of segregation characteristics (Shetty, 2009). After 40% sand replacement with CCB, the sample did not tend to zero but true slump.Particularly at 70% and above replacement value of sand with CCB, the mixes became progressively vicious so that it was becoming difficult to achieve adequate compaction without much effort. The fact that the CCB is organic may have accounted for this at higher replacement values. Generally, concrete with CCB, irrespective of the level of replacement with sand, resulted in a dry mix and low workability.

3.3 Density

The results of density measurements at the chosen curing ages and for all the replacement of fine aggregates with crushed cow bone are presented in Table 3 with the standard deviation in parenthesis.

Table 3: Density development in kg/m^3 with Curing Ages at all percentage of fine aggregate replacement with

% CCB in Mix	Curing Age (Days)				
	7	14	28	60	90
0	2364.44 ± 9.78	2494.82 ± 10.11	2592.59 ± 10.22	2640.00 ± 10.11	2672.59 ± 10.14
10	2109.63 ± 9.01	2157.04 ± 10.04	2219.26 ± 10.25	2284.44 ± 10.22	2361.48 ± 10.22
20	1774.82 ± 10.20	1819.26 ± 10.23	1845.93 ± 10.27	1928.89 ± 9.87	2050.37 ± 10.17
30	1736.96 ± 10.10	1771.85 ± 9.56	1831.11 ± 10.00	1869.63 ± 9.99	1961.48 ± 10.56
40	1682.96 ± 9.34	1706.67 ± 1056	1745.19 ± 9.89	1810.37 ± 10.21	1860.74 ± 9.90
50	1605.93 ± 9.78	1668.15 ± 9.98	1694.82 ± 9.78	1777.78 ± 10.11	1828.15 ± 9.97
60	1600.01 ± 9.98	1634.23 ± 9.67	1678.99 ± 9.67	1710.12 ± 10.21	1757.47 ± 9.91
70	1578.78 ± 10.23	1609.21 ± 9.78	1634.56 ± 9.89	1678.23 ± 10.01	1699.86 ± 10.01
80	1570.01 ± 10.32	1598.56 ± 10.23	1610.23 ± 10. 23	1645.23 ± 10.05	1667.56 ± 10.16
90	1566.23 ± 10.56	1571.67 ± 10.21	1588.45 ± 10.19	1610.10 ± 9.78	1625.78 ± 10.17
100	1545.56 ± 9.66	1560.32 ± 10.01	1570.98 ± 10.12	1589.10 ± 9.99	1602.56 ± 10.14

3.4 Crushed Cow Bone (CCB)

It can be observed from Table 3 that densities of the specimens increased with curing age at all the replacement levels of sand with CCB. For example, at 10% replacement of fine aggregates with CCB, an increase of 11.94% between the densities of 7- and 90-day curing was recorded. This pattern was observed for all the curing ages. This increase in the density can be explained as the result of the densification effect that the product hydration has on the internal matrix of the concrete specimens, with curing. It can also be observed that the densities of the specimens decreased with increase in the percent replacement of fine aggregates with crushed cow bone. From 0 to 100% replacement, the decrease was 34.63%, 37.46%, 39.41%, 39.81% and 40.04%, respectively at 7, 14, 28, 60, and 60 days curing. This represents an average decrease of 3.46%, 3.75%, 3.94%, 3.98% and 4.04% per each level of replacement.

This decrease can be expected from the results obtained for weight-related properties of CCB and the river sand used as the fine aggregates. As shown in Table 1, CCB has lower values of bulk density and specific gravity when compared with the river sand. This means that more volume will result for a unit weight replacement of sand with CCB. It then follows from density relations, (that is density which equals mass divided by the volume), that the increase in volume with constant mass will result in lower density. In concrete work, concrete is classified into three (3) categories according to its density.

According to Falade et al. (2011), concrete having densities in the range of 300 – 1,950 kg/m3 are classified as lightweight concrete; when the densities are in the range of 2,200 – 2,400 kg/m3, they are classified as normal weight concrete; and concrete with densities greater than 2,500 kg/m3 are classified as heavyweight concrete. As shown in Table 1, replacement of sand by CCB up to 10% resulted in the densities in the range of normal weight concrete. From 20% and above, the resulting concrete specimens had densities in the range for lightweight concrete. Thus, it can thus be concluded that differential densities range or different type of concrete can result from the usage of CCB as partial replacement of sand, depending on the CCB replacement values.

3.5 Compressive Strength

The results of the compressive strength development for all the percent replacements of sand with CCB are presented in Figures 3 and 4, and Table 4. It can be observed from Figure 3 that the compressive strength of the mix decreased with an increase in crushed cow bone. At 28-day curing, the compressive strength decreased from 24,62 N/mm2 for the control specimens to 12.45 N/mm2 at 100 % replacement of sand with CCB (see Table 4). This represents a decrease of 49.43% or an average of 4.94 decreases, for each level of replacement. This pattern was observed at other curing ages.

The results as presented in Table 1 shed some light on this pattern of behaviour. It was found that the weight-related properties of CCB are lower than that of the sand used for this investigation. The immediate effect of this is that for unit weight of sand replaced, more volume than replaced resulted. This inevitably lead to reduced density. In concrete, low density always results in low compressive strength (Sin, 2007). Also, as from Table 1, CCB was found to be more porous than the sand used.

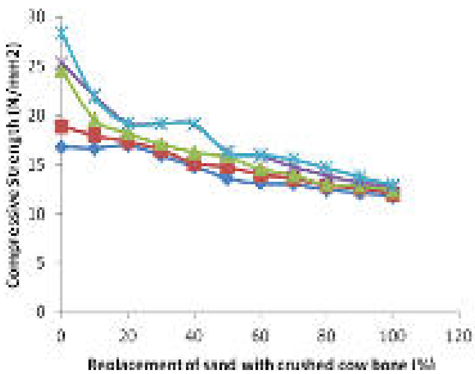

Figure 3. Effect of replacement of sand with Cow Bone on the Compressive Strength

Moreover, this CCB higher porosity when combined with higher water absorption led to the total volume of pores in CCB being more than that of the sand. Neville (2003) reported a direct relationship between the total volume and the compressive strength. With the same water/ cement ratio, the effective water that is available for the strength-forming hydration process in the sample with more CCB is reduced (Neville, 2003). Insufficient water will slow down the formation of the C-S-H gel known to be responsible for the strength development in concrete, and will thus result in reduced strength as the quantity of the CCB in the mix increases.

It can however be observed from Figure 4 that the compressive strength increased with curing age with all the replacements of sand with CCB. This is due to the fact that the longer a concrete is allowed to cure, the more the products of hydration that will be generated. Table 4 shows the statistical analysis of the results of compressive strengths for the concrete specimens at all replacement values of sand with CCB, for curing ages of 28, 60 and 90 days. The figures following "±" represent the standard deviation of the data samples.

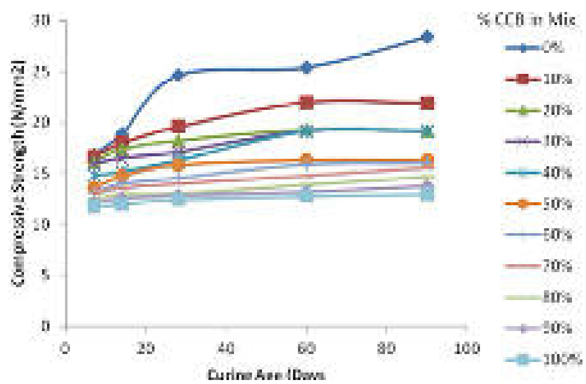

Figure 4. Effect of curing age on the Compressive strength of the Concrete Specimens

Table 4. Compressive strength development in N/mm2 of the concrete Specimens

% CCB in Mix	Curing Age (Days)		
	28	60	90
0	24.62 ± 1.23	25.38 ± 2.23	28.37 ± 2.11
10	22.58 ±1.30 (2.721)	23.98 ± 2.45 (0.989)	25.88 ± 2.14 (2.013)
20	20.22 ± 2. 95 (2.588)	22.28 ± 2.99 (1.794)	24.19 ± 2.99 (2.419)
30	18.11 ± 2.37 (4.751)	20.20 ± 2.78 (3.223)	23.68 ± 2.68 (3.028)
40	16.28 ± 2.34 (6.177)	**19.11** ± 2.56 (4.237)	**21.12** ± 2.10 (6.239)
50	15.83 ± 2.85 (5.337)	16.29 ± 2.78 (5.657)	19.28 ± 2.01 (7.823)
60	14.56 ± 2.71 (6.765)	15.89 ± 2.23 (7.362)	16.01 ± 2.11 (10.131)
70	13.99 ± 2.90 (6.342)	14.78 ± 2.01 (9.122)	15.56 ± 1.99 (11.139)
80	13.01 ± 2.93 (6.851)	13.89 ± 2.23 (8.914)	14.67 ± 1.89 (12.534)
90	12.87 ± 2.83 (7.182)	13.23 ± 2.11 (9.960)	13.78 ± 1.89 (12.349)
100	12.45 ± 2.95 (7.138)	12.78 ± 2.39 (9.117)	12.99 ± 178 (14.947)

As shown in Table 4, the figures in the parenthesis are the computed t-values at 10% confidence interval using a two-tailed test to determine at what percent of sand replacement with CCB is the difference between the compressive strength of the control specimens and specimens with CCB are to be considered significant. At 10% confidence interval, the statistical table t-value is ±2.920 (Kothari and Garg, 2014). Hence, the computed t values for sand replacement with CCB up to 20% for the curing ages of 28 days and above were below the statistical t value, and thus fall within the acceptance region of the normal distribution curve. What this means is that the compressive strengths of the concrete specimens up to 20% sand replacement with CCB are comparable with the compressive strength of the control specimens.

4. Conclusions and Recommendations

Based on the results of this investigation, the following conclusion can be made:

1) There was a reduction in concrete workability with an increase in the percent replacement of sand with CCB. The use of CCB also resulted in harsh mixes with attendant low slump.
2) The density of the concrete specimens reduced as the percent increase in sand replacement with CCB increased.
3) Using CCB as partial replacement of sand can result in different types of concrete based on the density attainable.
4) The compressive strength of the specimens decreased with an increase in the percent replacement of sand with crushed cow bone.
5) The compressive strength of the specimens increased with curing ages.
6) Replacement of sand with CCB up to 20% by weight will result in compressive strength development that is not significantly different from those of the control samples.
7) The use of CCB in the replacement of cement up to 20% by weigh in the production of concrete will have a positive impact on the environment, and encourage the use of bio-concrete in structural engineering.

This paper describes an investigation into the potential use of crushed cow bone as a partial replacement of fine aggregate in concrete, with particular focus the compressive strength and related properties. Evidence shows that compressive strength is the sole measure of concrete quality (Wright and McGregor, 2009). However, durability properties are also important if its usage is to gain wide acceptance. This should be investigated. Usage of CCB as partial replacement of fine aggregates in concrete will help in no small measure to bring about efficient solid waste management systems. This in turn results in a clean environment and promotes sustainable construction by reducing the use of non-renewable natural resources.

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Risk Perception in a Multi-Hazard Environment: A Case Study of Maraval, Trinidad

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Abstract: *An in-depth understanding of perceptions of risk arising from hazards is critical to reducing the socio-economic impacts of hazards. How risk is perceived determines the pivotal decision elements in planning mitigation strategies, which in turn guide policy development and funding allocation. Despite the extreme vulnerability of small island developing states (SIDS) to the impacts of hazards, little is known about how SIDS populations perceive risk in multiple-hazard prone communities. Thus, to determine how risk is perceived and the factors influencing this perception, a survey of 119 persons in Maraval, Trinidad was undertaken. Analysis of variance (ANOVA) and regression analysis showed that risk perception of flooding is influenced significantly by previous experience. Hence, to minimise the development of inappropriate cultural norms, communities must be reminded of the dangers associated with occupying hazard-prone locations. High risk perception towards landslides, storms and earthquakes is significantly affected by low levels of income and education. This suggests that disseminating scientific information through educational programs should change people's beliefs about a hazard, and lead to the adoption of appropriate mitigation strategies. However, this educational initiative should be appropriate, given the preferred data reception mode of each of the income levels. The model did not show any significant relationship between risk perception and demographics such as age, sex or occupation.*

Keywords: *Risk perception, Demographic factors, Disaster, Hazards, Caribbean, Maraval, Trinidad*

1. Introduction

In 2011, 332 disasters were registered globally, less than the average annual disaster frequency of 384 observed between the years 2001 to 2010 (Guha-Sapir et al. 2012). Despite this downward trend in frequency, the economic impacts of disasters, estimated US$ 366.1 billion in 2011, continue to rise (Guha-Sapir et al. 2012). These statistics highlight the importance of understanding the appropriateness of measures used to minimise the socio-economic impact of natural disasters. The usual response focusses on structured engineering measures. However, as a stand-alone measure, these are not sufficient to prevent loss from repeated occurrences, particularly in a multi-hazard environment (Ho et al. 2008). An examination of the complicated interaction between nature and the society, which focusses on local, long-term needs, can reduce the impact of disasters in a sustainable manner (Smith and Petley 2009). This, however, cannot be done without an understanding of the risk exposure of communities.

Risk is the possibility of loss or injury (Webster 2015). Risk may be neutralised through pre-emptive action (Business Dictionary 2013). It can be reasoned that the extent and degree of pre-emptive actions are influenced by how a risk is perceived. Pre-emptive actions will address issues such as who should be targeted, the most appropriate mode of communication, and the most opportune time for action. Risk perception refers to the subjective awareness or discernment of the potential harm or loss caused by a hazard and is based on the integration of risk information such as risk events, risk communication and various influencing factors (Seol 2005). It is therefore an important determinant of an individual's behaviour toward, judgement about and preferences regarding risk (Plapp 2001; Slovic 1992; Oliver-Smith 1996). This information can be important when assessing why some types of adjustment are made whereas others are not, or why one public policy is adopted over another (Drabek 1986).

The emergence of risk perception studies is mainly motivated by the observation that there are significant differences between experts' "objective" assessments of risk and lay persons' "intuitive judgments" of risk (i.e., risk perception): the latter of these two views is usually estimated higher than the former (Barker et al. 2009). Thus, it is essential to understand how an individual perceives risk and its determining factors for improving risk communications and designing effective mitigation policies (Ho et al. 2008). This brings into focus individuals and their social, economic, and demographic characteristics which shape their likely responses. These factors were taken into consideration to determine their effect on the perceived risk for the various hazard exposures in Maraval, Trinidad.

In the Caribbean, there is the anomalous situation where severity of impact is not directly proportional to magnitude of events (Martin, Lewis, and Martin 2012). This demonstrates the need for further studies focusing on non-structural measures. Despite the region's low resilience to disasters (ECLAL 2010), only a few studies have been undertaken on disaster management (Peters and McDonald 2011; Mycoo 2011; Li et al. 2012; Boruff and Cutter 2007; Charles and Vermeiren 2002; Rozdilsky 2001).

An even wider knowledge gap emerges as it pertains to risk perceived by a population, as there is no documentary evidence of any such studies. This work addresses this gap, through the assessment of the risk perceived by the population residing in Maraval, Trinidad. Between 2010 and 2014, this community has experienced approximately 20 incidents of flooding and landslides. The aim of this study was to investigate how the type of natural hazard and the Maraval population's characteristics influence risk perception. The objectives were to:

1. Determine how a population perceives the risks associated with natural hazards—tropical storms, earthquakes, floods and landslides; and
2. Determine the population characteristics that are strongly related to people's attitudes and subsequently their vulnerability to natural hazards.

2. Description of Maraval

A community in the suburbs of the capital, Port of Spain, Maraval, with an estimated population of 10,000 (CSO 2012), has been experiencing rapid population growth fuelled by emigration from adjacent towns. This has resulted in accelerated unplanned settlements especially on the hillsides which trigger a chain reaction of deforestation, soil erosion, landslides and consequently flooding. This problem has been further complicated by the fact that policies governing hillside development, such as the National Hillside Development Policy 2000, have only recently—2014, taken effect. In addition, the National Physical Development Plan has not been updated since the early 1980's and expired in 2000. The result is rapid growth in informal housing through squatting and more illegal development of formal settlements within Maraval.

These dynamic pressures have created unsafe conditions in which buildings with poor infrastructure, which do not adhere to building codes and regulations, are being erected in unsafe locations along the hillsides. This is compounded by low income groups who are without access to suitable land tenure. Disasters are hence being designed by unregulated human action and national disaster legislation is outdated and insufficient to deal with the onslaught. Figure 1 shows a Hazard Map of Trinidad and Maraval.

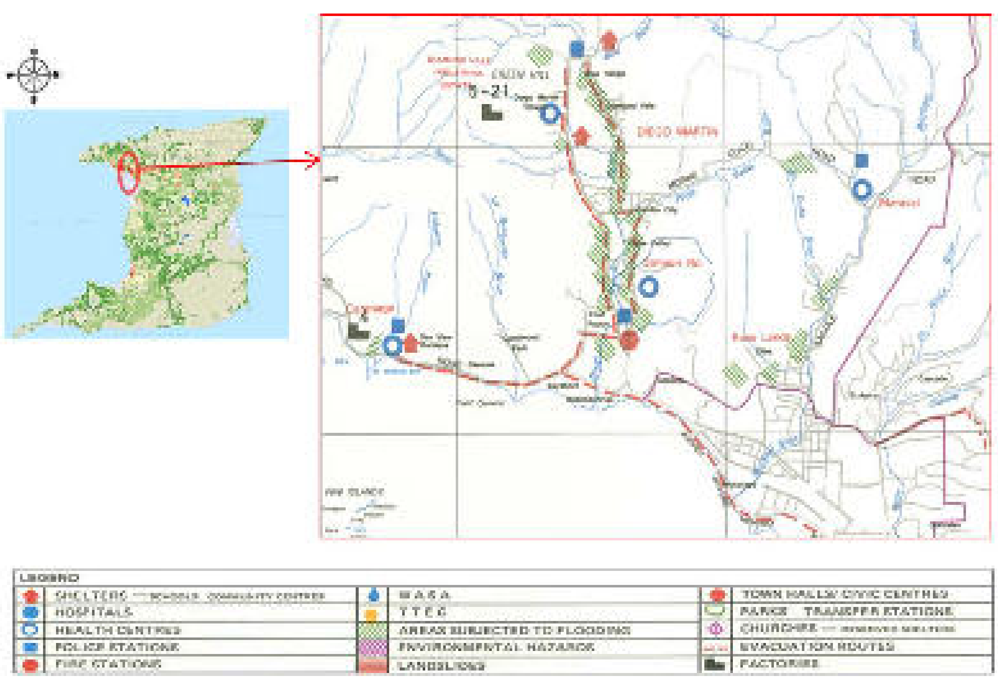

Figure 2. Hazard Map of Trinidad and Maraval Source: ODPM (2015)

Maraval has experienced flooding and landslides of greater frequency and intensity between 2009 and 2011 (La Rose 2011). Between 2010 and 2012 the Office of Disaster Preparedness (ODPM) recorded five (5) landslides in the Upper La Sieva Area, in which homes were destroyed, access roads were blocked and lives were lost (see Figure 2). Flooding was recorded mainly along the Saddle Road: The Maraval River burst its banks causing roads to be washed away and 100 homes built along the river banks were inundated with flood waters and destroyed (La Rose 2011).

Figure 2. Flood damage in Maraval, 2011

3. Decision Theory in Disaster Management

Rational economic decision theory assumes perfect information and perfect markets. This theory should therefore result in consistent preferences. However, in disasters no two situations are the same and information is often unreliable. These imperfect signals limit the applicability of this theory, as it is often the case that the perceived benefits of effective hazard adjustments are lower than their true social benefits. As a result, demand is often insufficiently understood and supply inadequately catered to. This is the consequence of decision makers' inability to cope rationally with low-probability, high consequence events (Mileti 1999). For example, if decision makers purchase insurance only because they are at risk, only those most likely to make claims will purchase policies.

Despite these shortcomings in explaining behaviour, classical decision theory has had significant impacts on decision making models, such as utility theory. The attractiveness in this theory resides in idea that a person's choice is based on a maximisation of preference. However, utility theory is limited to the satisfaction of the Neumann and Morgenstern (1953) axioms of transitivity for accurate predictions. Simon's (1991) concept of "bounded rationality" maintains that people are limited to being able to deal with relatively little information and relatively few concepts. Thus, although they cannot be completely rational in terms of classical theory, they can take a rational approach. The application of subjective estimates of probabilities as surrogates for uncertain or missing data to determine the utility for each alternative choice has been used. Therefore, bounded rationality leads people to underestimate the risks of natural hazards, which in turn lead to under-adjustment, followed by a crisis orientation after a disaster strikes (Mileti 1999).

Subjective expected utility theory may work well in static environments but is poorly suited to extreme environmental decisions, which must be made under conditions of severe uncertainty. Under these conditions decision makers have a tendency to rely on standard operating procedures, incremental changes, and short-term feedback (Kunreuther et al. 1978).

Attitude theory assumes people's behavioural intentions are determined by their belief and attitude towards the behaviour and their subjective norm for that behaviour, including how it is viewed by others (Fishbein and Stasson 1990). It is therefore likely that values, attitudes and practices will lead to great losses for those affected, because neither is readily changeable.

These theories suggest that it is important to assess what people believe about natural hazards and mitigation actions; whether people's beliefs will make a difference in adopting and implementing mitigation; and assuming that belief makes a difference, how beliefs can be changed to increase the adoption and implementation of effective measures.

4. Factors Affecting Risk Perception

Knowledge is the body of truths, information or awareness that humans have acquired or constructed (Savin-Baden and Major 2013). It is this awareness of the elements of the environment through physical sensation which defines how one perceives risk. Since knowledge is acquired through experience and education, risk perception is mainly influenced by people's ability to understand and respond to risk. Past experience of a disaster and cultural values affect how people perceive and understand risk, thus each individual will identify risk differently, as their perceptions are based on their preferred ways of life (Kellens et al. 2011). One's experientially gained knowledge determines the "affect heuristic" of a person. This is a mental shortcut driven by emotion that enables people to make decisions quickly. This is often based on positive and negative feelings associated with particular risks (Alhakami and Slovic, 1994).

Multiple socio-demographic characteristics of people, such as age (Zhai and Suzuki 2009; Armas and Avram 2008), education (Raine 1995), gender (Flynn, Slovic, and Mertz 1994), income, ethnicity (Flynn, Slovic, and Mertz 1994), length of residency as well as religion (Alshehri, Rezgui and Li 2013) also affect risk perception. These various studies often provide conflicting findings on risk perception. Since, there is no definitive, accepted view of factors affecting risk perception further work in this area is needed.

5. Method

Linear regression analysis can be applied to quantify the strength of the relationship between dependent variable Y and the independent variable X_k, to assess which X_k may have no relationship with Y at all, and to identify which subsets of the X_k contain redundant information about Y. The test for significance of regression is a test to determine whether a linear relationship exists between the dependent variable Y and a subset of independent variables $x_1, x_2, \ldots, x_k$. The appropriate hypotheses are:

$$H_0: \beta_1 = \beta_2 = \ldots = \beta_k = 0$$
$$H_1: \beta_j \neq 0 \text{ for at least one } j$$

Rejection of $H_0: \beta_1 = \beta_2 = \ldots = \beta_k = 0$ implies that at least one of the independent variables $x_1, x_2, \ldots, x_k$ contributes significantly to the model. The significance $P \leq 0.05$ was used to express H_1 true. If (H_1) true, (H_0) will be rejected. Standardised β coefficients refer to how many standard deviations a dependent variable Y will change, per standard deviation increase in the predictor variable x_k. Hence, standardisation of the coefficient indicates which of the independent variables has a greater effect on the dependent variable, particularly when the variables are measured in different units of measurement.

5.1 Data collection

119 residents were surveyed to determine whether population characteristics and type of hazard actually influence risk perception. Convenience sampling of respondents was employed, based on their availability. Snowballing was then used in some cases and residents referred interviewers to residents. Similar to studies conducted by Martin and Lewis (2016), the internal reliability of the instrument was tested using Cronbach alpha. The questionnaire which comprised of 4 categories to capture (i) demographics; (ii) past experience; (iii) risk perception; and (iv) mitigation/ preparedness was adapted from Bird (2009), Ogston (2005) and Ho et al. (2008). Table 1 shows a list of risk perception, mitigation/preparedness items.

The questionnaire's quality and appropriateness to the local context were verified through a pilot study, which targeted academics, practitioners, and persons from the community. Respondents were asked to rate the risk level of each of four hazardous events (earthquakes, floods, landslides, and storms) in Maraval. Statistical Package for the Social Sciences (SPSS) was utilised to conduct stepwise regressions. Stepwise regression has the advantage of utilising forward inclusion and backward exclusions of independent variables at the same time to determine the most significant relationship with the dependent variable (George and Mallery 2010; Martin and Lewis 2013).

5.2 Data Analysis

R^2 measures the proportion of the total variation about the mean of the risk perception variable explained by the regression model. R^2 can vary from 0 to 1, with a value of 1 indicating that the prediction explains all of the variations in the data (Draper and Smith 1981). The adjusted R^2 is a modified version of R^2 based on the number of predictors in the model. The adjusted R^2 increases only if the new term improves the model more than would be expected by chance.

Table 1: Risk perception, mitigation/preparedness items

Risk Perception	
The area that I live in may be affected by a natural hazard	1 Strongly disagree----5 strongly agree
The threat posed by each of the natural hazards to your area	1 Unlikely ---------------5 most likely
The frequency of the occurrence of the following hazardous events	1 Never -----------------5 always
The likelihood of occurrence of a disaster when the event occur	1 Unlikely ---------------5 most likely
Damage to property	1 Unlikely ---------------5 most likely
Loss of life	1 Unlikely ----------------5 most likely
Water pollution	1 Unlikely ----------------5 most likely
Damage to crops/livestock	1 Unlikely ----------------5 most likely
Mitigation and Preparedness	
In relation to each hazard/disaster score the level of your knowledge	1 No knowledge -------------5 expert knowledge
What was the source of your information	Brochures, television, internet, at school, a training course
Do you know the mitigation actions you can clearly adopt?	1 Not clear at all-------5 very clear
Having experienced a disaster, how would you score you preparedness if it were to re-occur?	1 Not prepared---------5 very well prepared
Your level of insurance coverage owned	No insurance, contents only, house only, house & contents only, house/ contents/ life
Your awareness in case of an emergency	
Numbers to call	1 Unaware ------------------- 5 fully aware
Organisations to contact	1 Unaware -------------------- 5 fully aware
Shelters to go to	1 Unaware -------------------- 5 fully aware

The between-group degree of freedom is the number of groups minus one, and the within-group degree of freedom is the number of subjects minus the number of groups minus one (George and Mallery 2010). Utilising F statistics tables, and based on the degrees of freedom, the critical F for the evaluation was determined.

Analysis of Variance (ANOVA) was used for comparing sample means to see if there was significant evidence to infer that the means of the corresponding population distributions also differ. The null hypothesis (H_0) and the alternative hypothesis (H_1) were developed in determining the significance as follows:-

H_0 There is no significant difference between the respondent groups and risk perceived.

H_1 There is significant difference between the respondent groups and risk perceived.

Significance $P \leq 0.05$ was used to express H_1 true. If (H_1) true, (H_0) was rejected. Once it was determined that the risk rating differed among the groups within a demographic background item, Least Square Difference LSD post-hoc test was used to determine which groups significantly differed from the others with respect to the mean ratings.

6 Results

6.1 Sample Characteristics

The reliability of the instrument obtained from the Chronbach's alpha is 0.812, values above 0.7 are deemed adequate (George and Mallery 2010). Of the 119 persons sampled, 55% were male and 45% were female. The respondents fell into the following age brackets 16-30 (22.7%); 31-45 (28.6%); 46-60 (27.7%); >60 (15%); and ≤ 15 (6%). 70% of all respondents had attained an education above secondary level. Of this total, 53% were educated at tertiary level. The primary level accounted for 13% and other represented 8%. 38.7% of the respondents were professionals, 21.8% were self-employed, 14% students, 12% retired, and the remaining unemployed. 36.1% of the respondents reported income of US$790-US$1422, 24.4% of persons earned less than US$790, and the remaining population accounting for less than US$1422/month.

To determine the extent to which disasters are on the minds of residents of Maraval, they were asked if they ever experienced a disaster. 60.5% of the respondents had past experiences with a disaster, while 39.5% had no prior experience. Of those who experienced disasters, 75.0% experienced flooding, 33.3% experienced landslides, 8.3% experienced storms and 22.2% experienced earthquakes. Landslides and flooding are localised events, were more frequent than all other hazards in this study, while storms and earthquakes usually affect wider areas. So once earthquakes and storms are experienced by one person it should have been experienced by all, unless there have been no recent events in the area. Hence, those who reported experiencing earthquakes and storms may be older and residing in the community longer than the other respondents. When asked to identify the natural disaster posing the greatest threat, 30.3% indicated that floods posed the greatest threat, 28.6% indicated landslides, 9.2% indicated storms and 5% indicated earthquakes. This sense of dread is being associated with frequency and past experience as the area is known to be frequently affected by floods and landslides.

When questioned about the likelihood of a disaster, most respondents (37.6%) stated that the most likely disaster was flooding, 27.7% indicated landslides, 6.7% indicated storms and 5.9% indicated earthquake. When asked about their level of preparedness for a disaster, 31.9% stated they were unprepared for the onset of another disaster, while 2.5% felt that they were well prepared and the remaining percent was uncertain. This was also reflected in the fact that 52.9% had no insurance at all, while only 0.8% had their house, contents of the home and life insured. When asked to rate their level of knowledge of each type of disaster on a scale of 1 to 5, 12.5% of the respondents indicated they were extremely knowledgeable about floods, 8.4% about landslides, 7.6% about storms and 7.6% about earthquakes. Knowledge is regarded here as facts, information, and skills acquired through experience or education. Most of their knowledge about disasters was received via the television (75.6%) and the internet (42.0%).

6.2 Risk Perception Toward Flooding

Damage to property, frequency of floods and past experience with floods were the three factors that significantly affect risk perception about floods. The R^2 (.373) and the adjusted R^2 (.329) suggest a correlation of risk perception among these three factors. The ANOVA values .000 suggest that the model chosen was significant at the 95% confidence level (see Table 2 and Table 3).

Using β unstandardised and the equation $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$, it can be stated that risk perception towards floods = 2.495 + .396 damage to property - .219 frequency of flood + .723 affected by flood in the past. This implies that risk perception towards floods is directly proportional to the likelihood of damage to property, and past experience with flood. However, it is inversely proportional to the frequency of floods. As the frequency of flood increases, the likelihood of damage to property from flood increases. Consequently, residents may judge that a flood is more likely to occur if they have experienced numerous floods in the past or if they suffered severe losses in a recent flood event.

However, the feeling of dread may be diminished particularly if losses in prior events were not significant. Experience or association-based processing in the context of risk can be beneficial (Slovic and Weber 2002). It enables humanity to evolve and survive over time and remains the most natural and most common

Table 2. Flooding model summary and ANOVA

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
Damage to property	.493	.243	.227	1.069
Frequency of flooding	.559	.313	.281	1.030
Affected by floods in the past	.611	.373	.329	.995

Model	Sum of squares	Df	Mean square	F
Regression	25.343	3	8.448	8.533
Residual	42.572	43	.990	p-value
Total	67.915	46		0.000

Table 3. Regression Coefficients for perceived flood risk

Model	Unstandardised β	Std. Error	Standardised β	t	P-value.
(Constant)	2.495	.498		5.010	.000
Damage to property	.396	.094	.508	4.204	.000
Frequency of flooding	-.219	.099	-.266	-.2.203	.033
Affected by flood in the past	.723	.355	.246	2.038	.048

way to respond to threat, even in the modern world

This system transforms uncertain and threatening aspects of the environment into affective responses (e.g., fear, dread, anxiety) and thus represents risk as a feeling, which indicates whether it is safe to walk down a dark street or drink strange-smelling water (Loewenstein et al. 2001). Continued experiences of threatening situations have led to the development of mitigation strategies as a way to cognitively adapt (Lima et al. 2005), as individuals tend to be better informed and prepared (Baan and Klijn 2004). Generally, regions with low levels of flood risk perception and a low degree of preparedness for coping with flood events tend to experience flood damage levels above average – their vulnerability to flood events is usually high (Messner and Meyer 2005). Hence, a vulnerability factor with regard to risk perception and preparedness of communities and individuals might exist. Of these factors the model suggests that the "potential of damage to property" which has the largest beta (.508) has the most significant influence on risk perception toward floods.

6.3 Risk Perception toward Landslides

The results of risk perception toward landsides show that there are four main factors of significance. They are: "knowledge about landslides", "likelihood of landslides occurring", "level of insurance of house contents" and "income level". The R^2 (.826) and the adjusted R^2 (.802) values suggest a co-linearity between these factors and risk perception toward landslides. That is, an indication that the predictor variables have non-zero correlations with each other (Thomas 2006). The ANOVA value of .000 shows the overall model significance (see Table 4 and Table 5).

The significance of the coefficients and beta (influence) values can be expressed in the following equation: $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4.$ Risk perception toward landslides =-.229 + .514 knowledge of landslides + .579 contents insured + .299 likelihood of landslide occurring - .286 income. This implies that the risk perception toward landslide is directly proportional to one's knowledge of landslides, the extent of insurance of house contents and the likelihood of a landslide occurring but is inversely proportional to income. Knowledge is one of the most influential factors impacting perceived risk towards landslide. The rationalist's viewpoint is that at least some of our knowledge is derived from reason alone, and that reason plays an important role in the acquisition of all of our knowledge.

Table 4. Landslide model summary and Anova

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
Knowledge of landslides	.827	.683	.667	.919
Contents insured	.865	.748	.729	.831
Likelihood of landslide occurring	.896	.802	.781	.745
Income	.909	.826	.802	.709

Model	Sum of squares	Df	Mean square	F
Regression	88.127	5	17.625	35.028
Residual	18.618	37	.503	P-value
Total	106.744	42		.000

Table 5. Regression Coefficients for perceived landslide risk

Model	Unstandardised β	Std. Error	Standardised β	t	P-value
(Constant)	-.229	.571		-.402	.069
Knowledge of landslides	.514	.109	.456	4.728	.000
Contents insured	.579	.225	.199	2.572	.014
Likelihood of landslide occurring	.299	.086	.298	3.482	.001
Income	-.286	.128	-.168	-2.230	.032

There is clearly a limit to what we can learn through abstract thought, which is why empiricists hold that all of our knowledge is ultimately derived from our senses or our experiences. Both views, combined, suggest that perception will affect the stimulus perceived in the first instance, and then the ways in which that stimulus is understood, processed, and finally the response to it. This supports the most influential variable "Contents insured". The equation also reveals that the lower one's income level (social status) is, the greater one's risk perception toward landslides is likely to be. A Marxist view suggests that low-income groups reside in substandard housing and are least able to deal with the adverse effect of hazards. Conversely, higher-income groups can afford mitigation measures, such as retaining walls, to reduce risk.

6.4 Risk Perception Toward Storms

Risk perception toward storms is significantly affected by the likelihood of storms occurring, knowledge of storms and income. The R^2 (.676) and the adjusted R^2 (.636) values suggest a co-linearity between these factors and risk perception toward storms. The ANOVA value of .000 shows the overall model significance at the 95% confidence level. Again, using the equation: $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3,$ risk perception toward storms = .765 + .544 likelihood of the storm + .351 knowledge of storms - .353 income (see Table 6 and Table 7). From this it can be stated that risk perception toward storms is directly proportional to likelihood of storms occurring and knowledge of storms but inversely proportional to income. Therefore, the lower one's income, the greater one's perceived risk posed by storms.

Slovic (1997) states that individuals with high income levels generally have low risk perceptions since high income individuals can afford effective mitigation strategies that would lessen the cost of recovery. On record, there are no occurrences of storm events (of the order of magnitude of hurricanes) experienced by the island. Interestingly, unlike all the other hazards, there was no account of damage to property or importance placed on possible losses through the purchase of insurance. It means that mitigation measures for this hazard are likely to be inexpensive, as the perceived losses are not viewed as important. Knowledge of storms will play an important role for hazards that are very low in probability, as uncertainty in information about preparation, responding, and possible impact, makes responders and citizens vulnerable to injury, death, disruption and other adverse effects of disasters.

Table 6. Storm model summary and ANOVA

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
Likelihood of storm occurring	.711	.505	.486	.920
Knowledge of storms	.773	.598	.566	.845
Income	.822	.676	.636	.774

Model	Sum of squares	Df	Mean square	F
Regression	30.036	3	10.012	16.695
Residual	14.393	24	.600	P-value
Total	44.429	27		.000

Table 7. Regression Coefficients perceived storm risk

Model 3	Unstandardised β	Std. Error	Standardised β	t	P-value
(Constant)	.765	.540		1.417	.169
Likelihood of storm occurring	.544	.106	.615	5.127	.000
Knowledge of storms	.351	.118	.353	2.985	.006
Income	-.353	.147	-.291	-2.406	.024

6.5 Risk Perception Toward Earthquakes

In the case of earthquakes, the model yielded three factors that significantly affected risk perception. These are: "knowledge of earthquakes", "damage to property" and "education". Once again, the R^2 (.585) and the adjusted R^2 (.547) values suggest a co-linearity between these factors and risk perception toward earthquakes. The ANOVA value of .000 shows the overall model significance at the 95% confidence level (see Table 8 and Table 9).

Using the equation: $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$, risk perception toward earthquake = 1.177 + .702 knowledge of earthquakes + .344 damage to property - .680 education. This implies that as one's knowledge of earthquakes and damage to property increases, risk perception toward earthquake increases, but the lower the level of education the higher one's perception of risk toward earthquakes. That is, risk perception toward earthquakes is inversely proportional to educational level. This may seem conflicting with past risk perception findings (Pilisuk and Acredolo 1988), but persons of low levels of education are usually those of lower social and economic status and are unable to afford appropriate mitigation measures. Since, residents with lower education and income levels are more vulnerable to the negative impacts, their awareness is higher. Education, when it is confined to school education, can provide useful information. However, other sources of information exist, and family and community education may play the most vital role in decision making and actions taken (Shaw et al. 2004). This informal social influence on hazard adjustment is prevalent when people do not have an opportunity to learn directly from their physical environment or their own experiences (Mileti 1999).

Table 8. Earthquake Model Summary and ANOVA

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
Knowledge of earthquakes	.604	.365	.346	1.020
Damage to property	.691	.477	.446	.939
Education	.765	.585	.547	.849

Model	Sum of squares	Df	Mean square	F
Regression	32.575	3	10.858	15.065
Residual	23.064	32	.721	P-value
Total	55.639	35		.000

Table 9. Regression Coefficients for Perceived Earthquake Risk

Model	Unstandardised β	Std. Error	Standardised β	t	P-value
(Constant)	1.177	.537		2.191	.036
Knowledge of earthquakes	.702	.131	.671	5.368	.000
Damage to property	.344	.098	.417	3.506	.001
Education	-.680	.235	-.368	-2.891	.007

6.6 Demographic Factors and Risk Perception

No significant relationship was found between demographic factors of age, sex or occupation and risk perception. This is rather contrary to previous findings noted by Peacock et al (2005) and Kellens et al. (2011).

7. Discussions

7.1 Past Experience

From the model, having been affected by flooding in the past was the most significant factor influencing risk perception. This is further supported by the fact that the other two factors, "frequency of flooding in your area" and "most likely impact of flooding being damage to property" are related to past experience with flooding. This study has drawn a similar conclusion to that of Ho et al. (2008), that is, victims with more experience of disasters felt their life was more seriously threatened and had a greater sense of fear than those with less experience resulting in a higher risk perception. Experience influencing risk perception was only directly observable with flooding hazards.

Hence, the type of hazard and the frequency of occurrence is a significant factor in determining how an individual will perceive related risk. Further, Ogston (2005) identified several determinants of the perception of flood risk and disaster preparedness. These include past experience with hazard events, the length of time that an individual has lived in a community, the levels of education and the age of the individual. Ogston (2005) highlighted that recent experience with disaster leads to individuals being more knowledgeable and more sensitive to that type of extreme hazard event. Victims with more disaster experience perceived a higher occurrence rate of disasters, and saw them as being more life threatening, and had a greater sense of dread (Ho et al. 2008).

Since experientially derived knowledge is often more compelling and more likely to influence behaviour than abstract knowledge (Epstein 1999), people must be reminded of their own experiences in order to convince them of the need to adopt mitigation measures. The literature has shown that the continued experience of threatening situations has led to the development of mitigation strategies as a way to cognitively adapt to the situation (Lima et al. 2005).

7.2 Social Factors

Low levels of education and low income are two characteristics associated with low social status. The model yielded results which indicate that risk perception towards landslide, storms and earthquake is significantly affected by income and education, since the β (standardised) values in each of these cases were negative. Negative values imply an inverse relationship, i.e. high risk perception is significantly affected by low levels of income and education.

Education has been found to play an important role in accounting for a sense of control over hazards. People with more years of education had a higher sense of controllability, regardless of the type of hazard and were more likely to adopt preparatory measures than those with lower levels (Ho et al 2008). It is this knowledge coupled with experience which is emphasised in the concept of bounded rationality, which explains that the choice and decisions of people often undercompensate in their responses when faced with hazards (Winchester 1996; Smith 2001).

7.3 Economic Factors

Economic factors are related to income. The negative β (standardised) value shows an inverse relationship. High perception of risk toward storms and landslides is significantly influenced by low income levels. Although most households adopt extremely limited mitigation strategies, low income households have significant vulnerabilities due to their ill-preparation and are constrained by their socioeconomic conditions. Local communities need to pay extra attention to developing specific adjustment measures and encouraging mitigation activities for lower-income households (Sah 2007).

7.4 Demographic Factors

The model did not show any significant relationship between demographics such as age, sex, occupation and risk perception. However, it can be argued that social and economic statuses are both subsets of demographics. In that case, demographic factors do significantly influence risk perception. However, not all demographic factors will fall into this category, according to the model, since no correlation was found between sex, age or occupation.

This finding should be accepted, as it was previously noted by Nordenstedt and Ivanisevic (2010) that other underlying factors, such as value, are more likely to account for demographic variations in risk perception. Nordenstedt and Ivanisevic (2010) argue that demographic factors are insufficient to explain the complex structure of social groups, which in turn might lead to ineffective decision-making. Drabek (1986) and Gardner et al. (1996) believed otherwise, and showed correlations between risk perception and factors such as age, gender, socio-economic status, race and ethnicity. As explained, men tend to judge risk as being smaller than do women (Flynn et al. 1994; Slovic 1997). Females are physically more vulnerable than males and thus females are more sensitive to risk (Ferraro 1995) and appear to be more risk-averse (Peacock et al. 2005).

8. Conclusion

In designing strategies to reduce vulnerability and to improve disaster preparedness of a community, policy makers should involve the people living in the disaster-prone area. Secondly, the risk perception of the targeted group, as well as the influencers of their risk perception should be known (Plapp 2001). The degree of public awareness of risk is a necessary condition to engage in disaster risk reduction. People are more vulnerable when they are not aware of the hazards that pose a threat to their lives. The adjustments people make in response to threats depend on how they perceive those threats and the associated risks (Pan 2012). Knowing how risk is perceived can help government understand how to initiate behavioural change towards hazards and through what medium this initiative would be most appropriate.

It is against this background that this study gains particular significance: the purpose of this study was to determine whether risk perception of natural hazards such as floods, landslides, storms and earthquake is influenced by economic, demographic and social factors or past experience with disasters. The study revealed that risk perception is influenced by three of these factors – social, economic, and past experience. The results also revealed that having knowledge about a type of hazard had a significant effect on risk perception of that hazard. In advising the government on where to place its efforts, the main area would be education about natural hazards, since the findings showed that knowledge of a natural hazard significantly affects risk perception. Government should embark on an education campaign through its schools from primary level upward. Disseminating scientific information would presumably change people's beliefs about a hazard and in turn lead to the adoption of appropriate mitigation strategies. Television and internet should be the main media through which this education and information dissemination occurs, since the study showed that the knowledge gained by most respondents concerning natural hazards and their effects was via television and the internet. Thus, the level of risk awareness depends largely upon the quantity and quality of available information.

In addition, this study has shown that the factors that had a significant effect on risk perception of natural hazards are the frequency of the event, and perceptions about the damage that the hazard will most likely cause. Perception is the individual and private mental process of organising all the received external impulses (Armas 2008) which in risk analysis, involves a high degree of insupportable decision-making which is often subjective and blind to certain realities.

People's ideas about risk and their practices in relation to disasters are the tools used to measure and chart vulnerability. In order to entirely assess a region's vulnerability, one must first understand the risk perception of its people. This is the initial stage in developing and improving the adaptive capacity of the region or community (Meheux et al. 2007). If a set of variables are correlated to a phenomenon (such as perception), it does not necessarily imply that these variables are the causes of that phenomenon. This can be illustrated in the results reported—risk perception is significantly related to the income or education level of respondents because those with low income and/or educational levels tend to live in vulnerable neighbourhoods (the cause of the higher degree of risk perception).

Even though no relationship was found between demographic factors and risk perception, there were conflicting views within the literature, thereby prompting further investigation. The view from the Caribbean region, in particular Maraval, Trinidad, was explored on risk perceived by portions of its population and the relationship between perceptions and respondents' characteristics. In addition, a person's inaction towards a hazard even when their perception is high is not well understood, and as such further work is needed to investigate this anomaly.

Nevertheless, this work relies on internal knowledge of the respondents which was assumed to be equal in contribution. Further, the use of snowballing may have resulted in respondents referring others, with a similar mindset to their own. The influence of NGOs has been assumed constant.

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A Study of Stakeholder Perception Regarding Quality of Education in Civil and Environmental Engineering at The University of the West Indies

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Abstract: *This study evaluated the quality of the undergraduate programmes in the Department of Civil and Environmental Engineering at The University of the West Indies. The research utilised questionnaires which were administered to undergraduate and recently graduated students as well as to five companies that employed graduates of the programmes. The results showed that the majority of undergraduates and graduates are generally appreciative of the programmes but also have some major concerns especially regarding the lack of practical content in the course material and the high work load due to the condensed length of the programmes. The majority of the employers agreed that although graduates had a positive work ethic, they were found to be lacking critical workplace skills and, to a lesser extent, technical skills. The findings indicate that efforts must be made to strengthen the link between theory and practice in the curriculum and serious consideration be given to the extension of the programme to a 4-year period.*

Keywords: *Engineering education; education quality; programme evaluation; student feedback; employer feedback*

1. Introduction

The concept of quality is one which is often difficult to explain; therefore, when evaluating quality, stakeholders should define the criteria as clearly as possible. Harvey and Green (1993) describe five interrelated ways of thinking about quality: as exceptional (excellence in achievement of standards); as perfection (product is provided exactly to specification and consistently free of defects); as fitness for purpose (meeting the needs of the customer); as value for money (direct relation to cost); and as transformative (causing a fundamental change of form). In education, quality can be viewed in two ways, firstly, as achieving fitness for purpose and secondly as being transformative. Most educational institutions are systems that involve students receiving a 'packaged' education for which the students are required to pay. It is justified, therefore, to think of quality in education as being both an issue of meeting customer needs as well as ensuring that participants evolve to become effective graduates.

For the majority of the 20th century, the quality in engineering programmes in the United States was measured by the success of its students in passing undergraduate courses in engineering, mathematics and science (Schachterle, Demetry and Orr 2009). However, in the late 1990s, many engineering professionals and faculty became concerned with the increasing complexity and narrower focus of the courses necessary to satisfy accreditation demands, as well as the increasing pace with which course content became outdated when compared to industry trends. This led to a reform in the accreditation protocol that evaluated the methods used to prepare engineering graduates for their profession (Schachterle, Demetry and Orr 2009).

Two common methods for evaluating quality in higher education include: firstly, the planning, validation and review of courses and secondly, the use of student feedback on the perception of teaching quality (Ellis 1993; Leckey and Neill 2001). Student feedback is increasingly acknowledged as playing a major role in developing quality in higher education. Indeed the evaluation of teaching performance, course effectiveness and the overall student experience through the completion of evaluation questionnaires has become a common practice throughout higher education institutions (Leckey and Neill 2001). It must be noted, however, that higher education institutions also rely on other methods of evaluating the quality of their programmes. Indeed Levy (2000) lists a number of groups as key sources of evidence of the quality of education being promoted within a given institution. These include past and present students and employers as well as staff members, external examiners, external advisers, subject peers, and accreditation bodies.

Feutz and Zinser (2010) highlight four (4) key stakeholders in the educational institution who all play a part in ensuring that the education programmes being implemented are indeed relevant. For instance, lecturers want to know that their teaching is effective and meaningful, whereas students want the education to prepare them for the world of work. Sponsors want to ensure that their funding is justified. Employers also demand qualified and competent employees. Employers are especially affected by the level of quality in an education system both as graduate 'consumers' and as collaborators in research activities (Harvey and Green 1993). Taking this into consideration, the study focussed on the perspectives of two stakeholders that are affected by the educational process: students and employers.

Educational institutions can adopt different approaches in their quest to obtain quality. However, the three main methods identified and defined by Woodhouse (1999) are: assessment, audit and accreditation. Assessment involves evaluation that results in graded judgment on quality, while auditing aims to check how well an institution is fulfilling its own objectives. Both of these processes are commonly conducted internally as the criteria are set by the institution itself. Accreditation, the most widely used of the three, is an evaluation of an institution or programme by an external and independent agency to determine whether it meets the set standard and thereby qualifies for a certain status.

The University of the West Indies, St. Augustine, Trinidad & Tobago, has employed all of the above approaches. However, this study focuses on the internal quality systems. Therefore, emphasis is placed on the mandate for the development and implementation of a full system of quality audit and quality assurance at the University. A consequence of this is the implementation of a quality assurance review for the University's Department of Civil & Environmental Engineering (hereinafter referred to as the Department) in February 2016. This study assesses the current quality of education provided in the Department from the students' and employers' perspective. This study determined whether the quality of education in the Department is effective in meeting the educational needs of the students and effective in producing qualified graduates for employment. Therefore, the information gleaned from this study can inform the upcoming review process and accreditation visit.

This paper begins with a review of related literature on education quality followed by a description of the methodology used to collect and analyse the data. This is followed by a presentation and discussion of the results. The paper concludes with recommendations that could be implemented by the Department.

2. Literature Review

2.1 Role of student feedback in quality assurance

Feedback can be obtained using formal methods such as questionnaires and staff-student committees, or informal methods such as casual conversations or comments. The advantages of formal methods, especially the questionnaire, are that they provide an opportunity to obtain individual feedback from a large population and can document the learning experiences of the student population in a relatively systematic manner (Richardson 2005). Harvey (2003) defines student feedback as the expressed opinion of students about the service they receive. In a higher educational institution, feedback can be given on a wide variety of components inclusive of perceptions about learning and teaching, learning support facilities (e.g. libraries and available technology), learning environment (e.g. laboratories and lecture rooms), and other support facilities (e.g. health facilities and student services).

Much of the available literature on this topic (Leckey and Neil 2001; Harvey 1997; Harvey 2003; Harvey 2011; Williams 2011) focuses on student feedback on the quality of teaching as this is one of, if not the most, essential aspect of a student's academic experience. Although achieving quality assurance in an institution consists of more than students' evaluations of teaching effectiveness, such evaluations are still important for various reasons. They can be used as feedback to improve teaching strategies; to measure teaching effectiveness for use in administrative decisions; to assist prospective students in the selection of a course or programme; and as a source of data for research in teaching and the educational environment (Leckey and Neill 2001).

The concept of student feedback involves more than just the compilation of results. It also includes ensuring that students are informed of what actions have been taken to improve the unsatisfactory areas (Harvey 2003). Richardson (2005) asserts that students and staff need to feel a sense of ownership of the feedback data and be involved in and informed about its analysis to be more likely to act on its findings and to be willing to participate in further evaluations in the future. The collection and analysis of the findings by an external party, as suggested by Harvey (2003), would serve to disengage the two main stakeholders that will be affected by the results.

Many institutions put considerable effort into collecting student feedback without having an established system of analysis for the data collected and having no approach as to how to remedy the issues raised in the findings (Harvey 1997). Students are less likely to be enthusiastic about continuing to give feedback if there is no evidence of any action being taken in response to their opinions. This makes it difficult to get students to actively participate in further evaluations for quality assurance (Leckey and Neill 2001; Harvey 2003; Harvey 2011).

2.2 Role of Lecturers in Quality Assurance

In the context of considering students as customers in the process of education, both lecturers and administrators represent service providers. Most studies (Sander et al.

2000; Hill, Lomas and MacGregor 2003; Voss and Gruber 2006) agreed that students desired lecturers who were knowledgeable, enthusiastic and approachable. Another study (Greimel-Fuhrmann and Geyer 2003) listed qualities such as the ability to give clear explanations; creativity in teaching; willingness to understand students' problems; fairness; and a sense of humour as being important to students as well. However, the study also found that students perceived the lecturers' ability to give clear explanations, solid examples and feedback on their learning progress to be more valuable than friendliness, patience or overall classroom management.

In order to achieve quality as perceived by students, lecturers would do well to heed student needs and expectations and, where possible, to use that information in their teaching methods and programme design (Voss and Gruber 2006). However, it is important to note that the lecturer's role consists of more than satisfying the students' expectations – the qualities highlighted are tools with which lecturers can equip themselves for achieving the ultimate goal of assisting the students' growth in knowledge, skill and passion within their various fields.

2.3 The attitude of staff towards student feedback

It should be noted that staff members are more than likely the persons who will have to respond in some way to the changes called for in the students' evaluations. However, staff members tend to be sceptical about the effectiveness of student evaluations. There are various reasons for this.

Firstly, students are not equipped to make accurate assessments on effective teaching, yet often times their responses (usually anonymous) are unchallenged. This breeds contempt for students among staff members. Secondly, if the student feedback method is one that is imposed on the staff, there will be no sense of personal engagement in seeing the process through and staff morale will suffer as a result. Moreover, it is often the case that student feedback conveying poor performance leads to some administrative action while good performance is not recognised (Leckey and Neill 2001). This does not encourage lecturers to improve their teaching performances. Instead it may instill apprehension when teaching for fear of not meeting student expectations.

2.4 Role of employers in higher education quality

Employers' expectations are becoming increasingly relevant as employability is now being considered a relevant quality indicator in higher education. Therefore, employers' perspective is one that also deserves attention in the context of enhancing quality (Romenti et al. 2012). In the design of an educational programme, the quality of the degree is related to achieving the right balance between developing a theoretically sound programme and incorporating the core competencies to become a professional (Harvey 2004; Kalanova 2008). To achieve such a balance, there must be constant communication between educators and professionals to combine their perspectives in developing educational objectives. As a result, students are trained to face professional challenges in the 'real' world (Romenti et al. 2012).

2.5 Graduate employability and its effect on higher education quality

One of the main methods that can be used to measure a higher educational institution's effectiveness is the success of the graduates that it produces. Teichler (2009) states that graduate employment and work became key indicators of quality in the 1990s and since then universities have been more attuned to the requirements of the industry with respect to ensuring that the education provided does indeed equip students with the tools to succeed in the working world. According to Yorke (2004), the term 'employability' embodies the skills, understandings and personal attributes that make graduates more likely to gain employment and to be successful in their jobs. For many professions, graduates gain most of these skills and knowledge in higher educational institutions.

The questions that follow such a statement are: What are these skills and attributes that make one a successful employee? And, who determines what they are? The second question is more easily answered – employers determine which attributes an employee should possess based on profession and position in the organisation. The findings of a study conducted in the United Kingdom entitled "Employers' perceptions of the employability skills of new graduates" stated that employers expected graduates to have technical and discipline competencies from their degrees as well as a range of broader skills and attributes inclusive of communication, team-work, critical thinking, problem solving and management skills (Lowden, et al. 2011). The study also highlighted that in cases where partnerships between higher educational institutions and employers were implemented, employers could contribute positively towards course design making courses more attuned to fostering employability attributes (Lowden, et al. 2011).

3. Methodology

3.1 Setting of Hypotheses

The focus of this study was on the assessment of education quality in the Department from the students' as well as the employers' perspectives. A number of hypotheses were formulated based on these two sample groups and were tested in the study.

The hypotheses from the undergraduate students and recent graduates' perspectives were:

1. The Department is providing undergraduate programmes of good quality.
2. The Department has adequate academic resources to support the delivery of undergraduate programmes.
3. The Department provides a rewarding learning experience for students in the undergraduate programmes.

The hypothesis from the employers' perspective is expressed by the following:

4. The Department is producing employable graduates from its undergraduate programmes.

3.2 Population and Sample

The target population for the survey consisted of:

- Civil and Environmental Engineering graduates of The University of the West Indies, graduating within the period of 2012 to 2014
- Current undergraduate students from levels 1 to 3 in the Civil & Environmental Engineering Department of The University of the West Indies
- Employers of Civil & Environmental Engineering graduates from The University of the West Indies

Each undergraduate is estimated to have cohort of 40 students. The overall average response rate ranged between 70% and 83% which indicates a good representative sample. In the case of the graduates, an average of 35 students is estimated to graduate each year (UWI 2016). Questionnaires were sent to all the graduates for each of the three years (2012, 2013, 2014) but only a 20% response rate was achieved. Reminders were sent to those who did not respond, however, minimal improvement was noticed.

The questionnaire format of the survey has some disadvantages such as misinterpretation of questions by the respondents and untruthful responses which can affect the overall accuracy of the results. However, the structure of the survey questions was simplified to mitigate these possibilities. Rowley (1995) points out that there is the possibility of receiving inaccurate information, another limitation, as questionnaires are usually administered at the end of an activity or experience, any improvements made as a result of the survey's findings will usually not benefit the persons from whom the feedback was taken. It can, however, still be used to improve the experience for future participants.

3.3 Design of Data Collecting Instruments

The administered survey consisted of three sets of questionnaires, one for each respondent group: undergraduate students, recent graduates, and employers. These were distributed to the respective respondents in hard and soft copy form where necessary over a period of about three months and were completed anonymously.

The structure of the student feedback questionnaire was the same for both undergraduate and graduate students except for a few questions. Questions 1 to 5 sought general information about the student which included year level, gender, student status (full time/part time), GPA, and specialisation/major. Graduate students were also asked if and where they were employed in order to determine some of the organisations to which the employer questionnaires could be distributed.

Question 6 tested hypotheses 1 and 2 and consisted of a total of 18 items that were divided into 3 sections whose content is described in Table 1. The sections consisted of a programme component scale which comprised 10 items, a resource component scale which comprised 7 items and a potential for employability scale. Cronbach's alphas for the 10 programme items and 7 resource items were found to be $\alpha = 0.87$ and $\alpha = 0.73$ respectively – indicating the scales' high reliability. Some of the items evaluated included: teaching and assessment methods, pace of learning, quality of computer and library resources and laboratory equipment. These were measured using a 5-point Likert scale consisting of the following response choices: Excellent, Very good, Good, Fair and Poor.

Question 7 sought the students' rating of their overall learning experience in order to test Hypothesis 3. It was also measured using a 5-point scale consisting of the following responses: Excellent, Good, Satisfactory, Mediocre and Poor/Disappointing.

Table 1. Description of scales used to measure student academic experience

Scale	No. of items	Description	Sample item
Programme	10	Measures student perception of overall effectiveness of academic programme	General course content
Resources	7	Measures student perception of study support and resources available	Online resources
Potential for employability	1	Measures undergraduate student perception of degree enabling them to find work/ whether graduate student has found work in his/her chosen field of study	My degree has allowed me to find work in my chosen field

Questions 8 and 9 were open-ended questions which sought to determine what students valued and disliked most about the programme respectively and Question 10, also an open-ended question, focused on how students thought the programme could be improved.

The structure of the employers' perception questionnaire consisted of three sections A, B and C. Section A comprised general questions about the name and type of the company or organisation to which the employer is affiliated, as well as the employer's contact information. Section B was designed to test hypothesis 4 and comprised 19 statements which evaluated the on-the-job performance of the Department's recent graduates. These were scored by the employer using the 5-point Likert scale consisting of five responses, each with a different weighting for statistical analysis purposes: Strongly agree (SA) = 5, Agree (A) = 4, Undecided (U) = 3, Disagree (D) = 2, Strongly disagree (SD) = 1. Cronbach's alpha for the 19 items was found to be 0.83 – indicating high reliability. Some examples of the statements to be evaluated by the employers included:

- Graduates are technically competent for the demands of the job
- Graduates display the ability to evaluate issues critically and analytically
- Graduates have difficulty applying theoretical concepts to practical situations
- Graduates display initiative

In Section C, the employer was given the opportunity to offer any other comments he/she believed would help in evaluating the performance of graduates.

3.4 Statistical Analysis

Statistical analysis of the data was performed using the IBM SPSS software package, specifically using the One Sample t-test. The t-test was used to analyse Question 6 to 8 in the student feedback survey, as well as Section B in the employer survey whose responses were in the form of the 5-point Likert scales. In each of the scales used, the most positive response (Excellent, Strongly Agree) was assigned a test value of 5, while the most negative response (Poor/Disappointing/Strongly Disagree) was assigned a test value of 1. The scale items in the student feedback survey each focused on an aspect of the quality of education offered and in the employer survey, they assessed employers' perception of various skills possessed by graduates. These were collectively used to determine whether to accept or reject the hypotheses.

The t-test compared the responses obtained to the hypothesis test value, depending on the item, in order to determine whether there is a significant difference between the responses obtained from the test groups and the expected hypothesis response. For the first three hypotheses, a test value of 3 was used which represents the "good" and "satisfactory" responses. For the fourth hypothesis based on the employers' perspective, a test value of 3 which represents the "Undecided" response is used. This is a two-tailed test which analyses whether responses skewed to the left or right of the test value – a negative t-value would indicate a poor job/experience while a positive t-value would indicate an excellent job/experience.

Further analysis was conducted using the responses to the open-ended questions posed in both the student and employer surveys. The responses were examined to see whether they support a rejection of the proposed hypotheses.

4. Results and Analysis

4.1 General Data

There were 93 responses from the undergraduate group, 19 responses from the graduate group and 5 responses from employers. The background information acquired from each of these three (3) groups is summarised in the Tables 2, 4 and 4. The results from the study will be presented by addressing each hypothesis.

Table 2. General data from Undergraduate population sample

Undergraduates						
# of Responses	**No. of Full-time**	**Male**	**Female**	**1st -Year**	**2nd -Year**	**3rd -Year**
93	93	58	35	32	33	28

Table 3. General data from Graduate population sample

Graduate									
# of Responses	Male	Female	Year Graduated			GPA Scores			
			2012	2013	2014	0 - 1.99	2.0 - 2.99	3.0 - 3.59	3.60 - 4.30
19	11	8	7	7	5	1	9	8	1

Table 4. General data from Employer population sample

Employers	
Type of Company	**No.**
Consultant Companies	2
Contractor companies	2
Government operated Consultant and Project Management Organisation	1

Hypothesis 1: The Department is providing undergraduate programmes of good quality

In both Tables 5 and 6, the test value of 3 represents a "good" rating, with any rating more than the test score indicating a positive response (very good or excellent) and any rating less than the test score indicating a negative one (mediocre or poor).

Table 5 shows the results of the one sample t-test conducted to determine whether the quality of the undergraduate programmes was "good" from the views of students. The mean response (M= 2.60, SD= 1.02) was lower than the test value of 3. The results indicated an overall statistically significant difference between means ($P < 0.05$) and, therefore, we can reject the null hypothesis.

An analysis of the individual components, however, shows that the respondents viewed the general course content of the programme to be of good quality, $t(92) = 5.34$, $p = 0.00$. In the case of quality of teaching, although it was rated as fair, the mean score of 2.89 was not significantly different from the test value ($P < 0.05$). On the other hand, for all other components, the respondents' ratings were significantly different from the test value, with negative t-values indicating ratings of fair or poor. Students especially highlighted the following as major areas in which the programme was lacking: opportunities for internship ($t(87) = -10.973$, $p = 0.00$), perception that they would obtain employment with ease, ($t(88) = -6.732$, $p = 0.00$), and feedback on performance/concerns, ($t(92) = -5.301$, $p = 0.00$).

Table 6 shows the results of the one sample t-test conducted to determine whether the quality of the undergraduate programmes was "good" from the views of recent graduates. The mean response (M= 2.75, SD= 0.90) was lower than the test value of 3.

Table 5. One-sample t-test results for undergraduate evaluation of programme quality

Programme Components	N	M	SD	t	df	*P**
General course content	93	3.53	0.95	5.34	92	**0.00**
Quality of teaching	93	2.89	1.06	-0.98	92	0.33
Teaching methods	93	2.66	1.05	-3.17	92	**0.00**
Tutorials	85	2.52	1.02	-4.36	84	**0.00**
Required pace of learning	91	2.63	1.09	-3.26	90	**0.00**
Assessment methods	91	2.70	0.97	-2.91	90	**0.00**
Feedback on your performance/concerns	93	2.41	1.08	-5.30	92	**0.00**
Opportunities for internship	88	1.89	0.95	-10.97	87	**0.00**
Perceived ease of obtaining employment after graduation	89	2.31	0.96	-6.73	88	**0.00**
Link between theory and practice	90	2.49	1.08	-4.48	89	**0.00**
Test Value = 3	91	2.60	1.02			
**Significant at 0.05 level*						

Table 6. One-sample t-test results for graduate evaluation of programme quality

Programme Components	N	M	SD	t	df	*P**
General course content	19	3.58	0.69	3.64	18	**0.00**
Quality of teaching	19	3.16	0.69	1.00	18	0.33
Teaching methods	19	2.68	0.82	-1.68	18	0.11
Tutorials	18	2.67	1.14	-1.24	17	0.23
Required pace of learning	19	2.74	0.56	-2.04	18	0.06
Assessment methods	19	2.53	0.70	-2.96	18	**0.01**
Feedback on your performance/concerns	19	2.42	1.07	-2.36	18	**0.03**
Opportunities for internship	19	2.11	1.10	-3.54	18	**0.00**
Perceived ease of obtaining employment after graduation	19	3.00	1.20	0.00	18	1.00
Link between theory and practice	19	2.63	1.07	-1.51	18	0.15
Test Value = 3	19	2.75	0.90			
**Significant at 0.05 level*						

Statistically, the hypothesis is also to be rejected if any of the components fail to meet the required test value of 3 ("good"). According to the results, there are components for which this condition prevails, e.g. assessment methods, $t(18) = -2.96$, $p = 0.01$. Therefore, according to the graduate group, Hypothesis 1 is to be rejected.

An analysis of the individual components highlights a few areas which the graduate respondents viewed as good. Similar to the undergraduate group, the graduates indicated that the general course content of the programmes was significantly better (M=3.58, SD= 0.69) than good, $t(18) = 3.64$, $p = 0.00$. The graduates also rated the following areas as good: quality of teaching, t(18) = 1.00, p = 0.33, and perceived ease of obtaining employment after graduation, t(18) = 0.00, p = 1.00. Conversely, of the components which were rated below the test value, only a few differed significantly from the test value. These included: Assessment methods (t(19) = -2.53, p = 0.01), Feedback on performance (t (18) = -2.36, p = 0.03) and opportunities for internship, t(18) = -3.54, p = 0.00.

Hypothesis 2: The Department has "adequate" academic resources to support the delivery of undergraduate programmes.

In both Tables 7 and 8, the test value of 3 represents a "good" rating, with any rating more than the test score indicating a positive response (very good or excellent) and any rating less than the test score indicating a negative one (mediocre or poor).

Table 7 shows the results of the one sample t-test analysis performed to determine whether according to the undergraduate respondents, Hypothesis 2 is to be rejected. Statistically, the hypothesis – if taken to represent an overall evaluation of the programmes' resource quality by the respondents – is to be rejected if the rating for any of the components fails to meet the test value of 3 – indicating a "good" rating. The results show that this is the case for the second component: textbook availability and accessibility – t(92) = -2.75, p =0.01. Therefore, according to the undergraduate group, Hypothesis 1 is to be rejected.

In analysing the components individually, results indicate that except in the area of textbook availability and accessibility, where t(91) = -2.75, p = 0.01, the ratings for all other components are above the test score. However, this result is only statistically significant in the case of the evaluation of library resources, t(92) = 2.59, p < 0.01. In all other cases, the lack of statistical significance (p > 0.05) indicates that the respondents' ratings differed only slightly from the test value of 3.

Table 7. One-sample t-test results for undergraduate evaluation of resource quality

Resource Components	**N**	**M**	**SD**	**t**	**df**	***P***
Support from lecturers outside of classroom time	92	3.07	0.97	0.64	91	0.52
Textbooks (availability and accessibility)	92	2.68	1.10	-2.75	91	0.01
Online resources	93	3.19	1.05	1.79	92	0.08
Library	93	3.27	1.00	2.59	92	0.01
Computers	92	3.05	1.05	0.50	91	0.62
Lab and Lab equipment	91	3.04	1.02	0.41	90	0.68
Test Value = 3	19	3.30				
**Significant at .05 level*						

Table 8. One-sample t-test results for graduate evaluation of resource quality

Resource Components	**N**	**M**	**SD**	**t**	**df**	***P***
Support from lecturers outside of classroom time	19	3.21	1.08	0.85	18	0.41
Textbooks (availability and accessibility)	19	3.21	0.92	1.00	18	0.33
Online resources	19	3.32	0.82	1.68	18	0.11
Library	19	3.53	0.77	2.97	18	**0.01**
Computers	19	3.16	0.69	1.00	18	0.33
Lab and Lab equipment	19	3.37	0.68	2.35	18	**0.03**
Test Value = 3	19	3.30				
**Significant at .05 level*						

The results of the one sample t-test analysis performed to test whether, according to the graduate group, Hypothesis 2 is to be rejected is shown in Table 8 above. Statistically, the hypothesis is to be rejected if any of the components' ratings falls below the test value of 3. The results show that this is not the case and therefore according to the graduate group, Hypothesis 2 cannot be rejected.

Analysis of the components at an individual level showed statistically significant differences from the test value in the evaluation of library resources (p = 0.01) and evaluation of lab and lab equipment quality (p = 0.03). In both cases, the mean scores were higher than the test value (although not reaching a value of 4), thereby indicating that graduates found these resources to be "good". For all other outlined resource components, however, although their mean scores were above the test value, there was no significant difference between the scores and the test value. This indicates that very few respondents' ratings differed from the actual test value, notably on the more positive side.

Hypothesis 3: The Department provides a sufficient learning experience for students in the undergraduate programmes.

In both Tables 9 and 10, the test value of 3 represents a "satisfactory" rating, with any rating more than the test score indicating a positive response (good or excellent) and any rating less than the test score indicating a negative one (mediocre or disappointing).

The one sample t-test was used to determine whether, according to the undergraduates, Hypothesis 3 is to be rejected. The results show that in the opinion of undergraduate students, the learning experience provided is above "satisfactory" level with a highly statistically significant mean score of 3.35, t(90) = 3.78, p = .00 (i.e. $p < 0.005$). This indicates that the hypothesis cannot be rejected.

Table 9. One-sample t-test results for undergraduates' rating of overall learning experience

	N	M	SD	t	df	*P**
Overall Experience Rating	91	3.35	0.89	3.784	90	0.00
Test Value = 3						
**Significant at .05 level*						

Table 10. One-sample t-test results for graduates' rating of overall learning experience

	N	M	SD	t	df	*P*
Overall Experience Rating	19	3.58	0.84	3.012	18	0.007
Test Value = 3						

The results of the one sample t-test used to evaluate Hypothesis 3 from the graduates' perspective are shown in Table 10. The analysis shows that graduates' rating of their overall learning experience is greater than the test value 3 with a statistically significant mean score of 3.58, t(18) = 3.01, p = 0.007. This indicates that graduates do find the quality of their learning experience to be at least above "satisfactory" level thereby indicating that the hypothesis cannot be rejected.

Hypothesis 4: The Department is producing employable graduates from its undergraduate programmes.

The scales displayed in Tables 11 and 12 show the results of the one sample t-test analysis performed to evaluate hypothesis 4. Employers were to evaluate each statement using the following responses with assigned test values: Strongly Disagree (1), Disagree (2), Undecided (3), Agree (4) and Strongly Agree (5). The test value of 3 which represents the "undecided" response was used in order to determine whether the employers' responses for each statement swung to the left (agree) – indicated by a positive t-value or to the right (disagree) – indicated by a negative t-value. A t-value of 0 indicates that the mean response concurred with the test value of 3.

Tables 11 and 12 show employers' views on several qualities and attributes which graduates may or may not have displayed in their time as employees. Out of the 14 components there were seven (7) for which employers gave a mean response that concurred with the test value 3 = "undecided". These components therefore can have no bearing on the outcome of the hypothesis test. Statistically, the hypothesis is to be rejected if any of the components' mean scores fell below the test value of 3. Therefore, in analysing the other 7 components for which the mean score was not the test value, the results show more than one area in which the criteria is not met. Therefore, on this basis, according to the employers, the hypothesis is to be rejected.

An analysis of the components individually showed firstly that employers were clearly undecided on several of the components, e.g. graduates showing leadership qualities, graduates having difficulty applying theoretical concepts, among others.

Table 11. One-sample t-test results for employer evaluation of graduates' job performance - part (i)

Performance	N	M	SD	t	df	*P**
Graduates display a positive work ethic	5	4.00	0.71	3.16	4	**0.03**
Graduates are technically competent for the demands of the job	5	3.20	0.84	0.53	4	0.62
Graduates show leadership qualities in the way they undertake various tasks	5	3.00	1.00	0.00	4	1.00
The computer skills of graduates are satisfactory	5	4.40	0.55	5.72	4	**0.00**
The majority of graduates display a laid-back attitude to their work	5	1.80	0.45	-6.00	4	**0.00**
Graduates are familiar with the most current trends in their field	5	2.40	0.55	-2.45	4	0.07
Graduates are receptive to new ideas and changes within the department/organisation	5	4.00	0.71	3.16	4	**0.03**
Graduates take responsibility for their own learning and development at the workplace	5	2.60	1.34	-0.67	4	0.54
Graduates are able to organise and manage their priorities in a timely manner	5	2.60	0.89	-1.00	4	0.37
Graduates display the ability to evaluate issues critically and analytically	5	2.60	0.89	-1.00	4	0.37
Test Value = 3	5	3.06				
**Significant at .05 level*						

Table 12. One-sample t-test results for employer evaluation of graduates' job performance - part (ii)

Performance	N	M	SD	t	df	P*
Graduates demonstrate the ability to balance theoretical knowledge with technical competence	5	2.60	0.55	-1.63	4	0.18
Graduates are innovative in their approach to solving problems	5	3.00	1.22	0.00	4	1.00
Graduates understand the core principles of their discipline	5	3.20	1.30	0.34	4	0.75
Graduates have difficulty applying theoretical concepts to practical situations	5	3.00	1.58	0.00	4	1.00
Graduates use their creativity when faced with work-related challenges	5	3.00	1.22	0.00	4	1.00
Graduates display initiative	5	3.00	1.22	0.00	4	1.00
The areas of specialisation that graduates bring to the workplace are too narrow in scope	5	3.00	1.41	0.00	4	1.00
When necessary, graduates exhibit supervisory skills in managing staff	5	3.00	1.00	0.00	4	1.00
Test Value = 3	5	2.98				

**Significant at .05 level*

Secondly, there were some statements whose mean responses were not significantly different from the test value (i.e. $p > 0.05$) indicating that a very small portion of the respondents gave a score that varied from the test value. Some of these statements included: graduates being technically competent for the demands of the job and understanding the core principles of their discipline, graduates being familiar with the most current trends in their field, and graduates taking responsibility for their own development.

Notably, given all of the statements, only 4 had statistically significant different responses ($p < 0.05$) from the test value and all four indicated something positive about the graduates attributes. Three of the four statements showed that the employers agreed that graduates displayed a positive work ethic, $t(4) = 3.16$, $p = 0.03$, that their computer skills were satisfactory, $t(4) = 5.72$, $p = 0.00$, and that graduates were receptive to new ideas and changes within the organisation, $t(4) = 3.16$, $p = 0.03$.

The remaining statement indicated that employers did not agree that the majority of graduates employed by their organisation displayed a laid back attitude towards their work, $t(4) = -6.00$, $p = 0.00$.

5. Discussion of findings

5.1 Quality of undergraduate programmes

In evaluating the quality of the programme, the undergraduate and graduate respondents were in agreement that the department was lacking in many of the components identified. Firstly, on a positive note, both groups were in agreement that the general course content of the programme was good. However, they agreed that the department needed to improve on the following areas:

- Assessment methods
- Feedback on performance/concerns
- Link between theory and practice
- Opportunities for internship
- Required pace of learning
- Teaching methods
- Tutorials

This assessment by the undergraduates and graduates suggests a serious need for review by the Department. Lecky and Neill (2001) identify student evaluation of teaching quality as an important method of measuring its effectiveness. It seems that although students find that the content of the curriculum is sound, the way in which it is delivered to the students and assessed is not as effective. This implies that the Department may have changed its methods of teaching and the types of assessments used to test students' understanding of the curriculum. Lecturers would also have to formulate means of efficiently providing feedback on coursework and other concerns.

The lack of internship opportunities within the department is one which, if improved, can affect other areas positively as well. The exposure of students to work experience in the industry would help to address the issue of strengthening the link between theory and practice. The very practical nature of the industry requires the need for interaction between students and the workplace to allow them to fully grasp not only the application of the theory, but the magnitude of the consequences that would follow lack of understanding.

The two respondent groups disagreed on two areas: the quality of teaching in the programme as well as the perceived ease of obtaining employment. The graduates felt that both of these areas were good while the undergraduates did not. Firstly, it should be noted that all of the graduate respondents were employed in the civil engineering field. It is possible that for this group of graduates, finding employment was not too difficult. On the other hand, many of the undergraduates may not have any prior working experience and would base their perception on other factors. Some of these factors may include the requirement for experience for many of the positions available or too few employment opportunities. Additionally, exposure to internship opportunities would also give undergraduate students a more realistic view of the likelihood of obtaining employment after graduation.

The difference in responses between the undergraduate and graduate respondents on the quality of teaching may be due to a difference in perspective. That is, graduates performed the evaluation from a more reflective viewpoint. All graduates indicated that they were currently employed and may therefore have experienced situations that helped them have a better appreciation for their experience within the programmes upon meeting the demands of industry. Contrastingly, it may be that the undergraduates are unfamiliar with the expectations of industry, which promotes self-learning in comparison to their previous experience at the secondary level. It is important to note however, that there is an expected difference in view between the graduate and undergraduate group based on time and experience. Such a difference, even between year levels would make achieving quality somewhat challenging for the Department, as the needs of the different year groups may vary and make it difficult to satisfy everyone. A third stakeholder is therefore needed to further define the quality to be attained, which is where employer feedback becomes relevant.

5.2 Resources supporting the delivery of undergraduate programmes

The results, according to the undergraduate group, imply that the resources provided by the Department are adequate except in the availability and accessibility of textbooks. The issue of textbook availability may be due to factors such as an increase in student intake so that resources have to be shared among a larger group. In this case, the Department must either ensure that the study material is enough for the current student enrollment or only accept numbers for which it can comfortably provide. It may also be possible that the undergraduate students are simply not seeking out the material, even though it has been made available to them. These statements can be applied to all resources, not just textbooks. The mean scores awarded by the graduate group in this category indicate that they were also pleased with the quality of the resources provided by the department. The university library has a vast resource of electronic books, providing the students with sufficient material to engage in the necessary learning. However, additional marketing of these resources could be improved to remind the students of their availability.

The results demonstrate that the Department's challenges rest mainly with its programme components. This can be viewed either positively or negatively. On the one hand, the issues lie mainly with only one element of the Department, on the other, it is the element that poses more difficulty to implement changes. Improving programme components involves the difficult task of changing the culture of how things are done which can be quite challenging. This may require additional training of staff in current teaching and learning methods.

The overall higher scores awarded by the graduate group may be accounted for by the fact that the quality of material resources such as lab equipment, books and computers decreases with time. Therefore, there is the possibility that what may have been working well during the time in which the current graduates were enrolled would not be as adequate for the undergraduate class. In such a case, it is more a matter of the Department implementing maintenance procedures to ensure continued quality of their facilities and acquiring new resources when necessary.

5.3 Learning experience in undergraduate programmes

Despite the issues identified in previous paragraphs, it appears that the undergraduate group still thought the overall experience was generally satisfactory. Therefore, it could be inferred that the Department's programme and resource components, despite students' dissatisfaction in some areas, are still able to provide students with an adequate educational experience. If, however students are the customers of the educational system as alluded to by Harvey and Green (1993), then is the aim of the Department to provide merely satisfactory service or to strive to achieve the highest standards of quality? It can be argued that the provision of a quality education can be costly – involving the investment in better facilities, perhaps more staff and the spending of valuable time to design programmes of excellence. Moreover, it is highly difficult to develop educational programmes that will please all stakeholders. Taking these into consideration, the undergraduates rating of the department as more than satisfactory can be considered an achievement, especially in light of the fact that there are still areas to improve.

One can also argue that the fact that the student responses are negative for many of the components, while claiming to have a satisfactory experience does not add up. Perhaps, for a significant number of the sample group, their capacity to judge the quality of the education is not yet developed. Lecky and Neill (2001) suggest that this is one reason for staff scepticism toward student evaluations of education quality. Many of them may not have experienced working in the industry and so would not know whether the perceived hardships of their programmes could in fact be a norm in industry. Their lack of experiences would render them more likely to evaluate based on how they feel. This is not to say that there is no truth to their indications, but rather to suggest the chance of misjudgement.

In the case of the graduates, there was no contradiction between the evaluation of the programme and resource components and the rating of overall experience. The graduates' perspective, no doubt influenced by experience and hindsight, also deemed the learning experience provided by the Department as satisfactory. It can be argued that the graduates' perspective is more reliable because of their interaction with industry conditions and more than likely, greater maturity. However, this can be countered by the fact that there was a much smaller number of respondents from the graduate group than the undergraduate, and so their responses may not be a statistically realistic representation of the graduates' views.

5.4 Employability of graduates from undergraduate programmes

The results for this hypothesis were statistically inconclusive. However, it is important to note that since there were only five employers evaluating the statements, even small deviations from the test value could be considered significant. Whilst the sample size in this group was small, it should be noted that the respondents are the main employers for graduates of the Department. Therefore, for the purpose of discussion, a review of some of the responses that deviated from the test value, without regarding significance, is noteworthy. Firstly, some of the employers agreed with the following statements:

- Graduates display a positive work ethic
- Graduates are technically competent for the demands of the job
- The computer skills of graduates are satisfactory
- Graduates are receptive to new ideas and changes within the organisation
- Graduates understand the core principles of their discipline

Moreover, it can be said that some of the employers disagreed with the following statements:

- The majority of graduates display a laid-back attitude to their work
- Graduates are familiar with the most current trends in their field
- Graduates take responsibility for their own learning and development at the workplace
- Graduates are able to organise and manage their priorities in a timely manner
- Graduates display the ability to evaluate issues critically and analytically
- Graduates demonstrate the ability to balance theoretical knowledge with technical competence

Studies conducted by Feutz and Zinser (2010) and Harvey and Green (1993) acknowledged that within the education system, besides students, employers are one of the most important stakeholders as they receive the finished 'product' of the educational process – the graduates. Therefore, their opinion should weigh heavily in determining whether university programmes equip graduates with the skills to be useful in industry. Concerning the quality of graduates produced by the Department, the representative sample of employers indicated some areas of concern, some of which concur with those of the graduate and undergraduate groups.

One such area concerns the relation of theory to practice. Although employers were undecided in whether graduates had difficulty applying theoretical concepts to practical applications, it can be said that some agreed that graduates did not demonstrate the ability to balance theoretical knowledge with technical competence. Recall that both the graduate and undergraduate group indicated that one of the issues they encountered within the programme was a weak link between theory and practice. This indicates that the Department must include more practical components within its programme - a venture in which the professional community can participate. One of the suggestions made by students was that they be given the opportunity to interact with industry professionals on a more frequent basis. This will enable them to keep abreast of industry trends, as well as to attain a deeper appreciation of the practical applications of concepts learned in their courses.

It can be argued that some of the employers indicated that the graduates possessed some positive attributes as well. These include: having a positive work ethic, being receptive to new ideas and changes, having satisfactory computer skills and not displaying a 'laid-back' attitude on the job. Moreover, some also indicated that graduates seemed to understand the core principles of their discipline. Some of these attributes such as knowledge of the core principles can be directly improved by the Department's programmes. Those addressing attitude and ethics, are more complex. The Department can attempt to impart the importance of possessing these attributes to its students, perhaps through an ethics course or allowing students to select electives offered on industry preparedness.

Other areas in which some employers expressed concern included:

- Graduates not taking responsibility for their own learning and development at the workplace
- Graduates not being able to organise and manage their priorities in a timely manner
- Graduates not displaying the ability to evaluate issues critically and analytically

The last statement is of great concern, as one of the goals of higher education that is to develop critical and analytical thinking among students. Such skills are vital in the engineering profession and should be constantly nurtured in all engineering programmes. This implies that the Department must find ways in which to challenge students to assess problems, not just through final year projects but throughout the progression of the programme. It must be mentioned that this can also be developed through work experience which can be facilitated through summer internships or a co-operative programme.

Graduates taking responsibility for their own learning and development and managing their priorities efficiently are attitudes that should be constantly cultivated. Again, the Department can arrange for students' interaction with persons from industry who may help in this regard. Some employers also suggested the implementation of reasonable but strict time constraints as it pertains to handing in of assignments and projects to encourage proper time management.

6. Further Views

As mentioned earlier, the latter section of the questionnaires consisted of open-ended questions that aimed at determining what undergraduate and graduate students valued and disliked about the programmes as well as their recommendations. Employers were also asked to give any recommendations they believed to be helpful in evaluating graduates of the Department.

6.1 Undergraduates

When asked what they valued most about being a student in the programme, some of the main responses from the undergraduates were that the programme provided relevant theoretical and practical knowledge about the civil engineering from lecturers who are regionally well known in their fields and have a vast wealth of experience. Secondly, students appreciated the dedication and approachability of some of the lecturers – qualities which were indicated to be of value to students in various studies (Voss and Gruber 2006; Hill et al. 2003; Sander et al. 2000). Thirdly, they also valued the opportunity of getting to work with other students from various backgrounds all attempting to grasp the concepts taught.

When asked what they disliked most about being in the programme, one frequent response was the lack of "student-friendly" teaching methods/approaches used by some of the lecturers – the course material is explained in a manner which students found difficult to understand. Notably, one study (Greimel-Fuhrmann and Geyer 2003) found that students highly valued lecturers' ability to provide clear explanations and examples, more than even friendliness and patience. Many of the students indicated that their main dislike was the heavy work load in the programme's limited time period. Students explained that they found it difficult to fully grasp course material and even enjoy learning as they were under constant pressure with limited time to produce quality assignments, review course material and attend classes.

The students were also asked to suggest ways in which they think the programmes should be improved. Some of the responses included different teaching approaches by lecturers which should incorporate more practical exercises and better explanation of course material; the introduction of more tutorials and interactive classroom sessions; the provision of internship opportunities; as well as the opportunity to select electives, perhaps from other faculties. The major call for improvement, however, concerned the length of the programme itself – many students felt that extending the programme to a 4-year period would allow students to grasp course material much more effectively.

The fact that students appreciate the knowledge and experience of the Department's lecturers is a good indicator that the lecturers themselves are not a part of the identified problems. In fact, the 3-year programme length may very well be a hindrance to lecturers as well and increased contact time in a 4 –year programme may allow for the lecturers to deliver course material in more detail; and the freedom to incorporate more practical components. Furthermore, the implementation of internship opportunities and electives can only be possible if more time is allotted to the programme.

6.2 Graduates

When asked what they valued most about having been a student, many of the graduates appreciated that lecturers were very approachable and available to offer support. Another recurring response was that students appreciated the laboratory sessions incorporated into the programme as they involved practical work that helped them to better understand the theoretical concepts.

When asked what they disliked about being a student in the programme, some of the recurring points were:

(i) Students found it difficult to relate the theoretical concepts of the course material to their practical applications.

(ii) Many students felt that there was too much course content to be covered each semester and not enough time available. This resulted in them merely cramming information for the purpose of passing assignments and exams instead of actually understanding the course material.

(iii) There was often little to no feedback on assignments, projects and exams from some lecturers which left students in the dark about their progress.

It is important to note that, once again, the approachability and dedication of (some) lecturers have been highlighted. This is a great achievement that the Department would do well to recognise, reward and encourage. It is an attribute which can be a deciding factor in getting students to enrol in programmes. This emphasises the relevance of student feedback not only as a means of identifying areas needing improvement but areas in which the Department excels.

Some recommendations suggested by the recent graduates can be summarised in a few main points. Firstly, similar to the undergraduate students, many of the graduates thought the programme should be extended to a 4 year period to encourage actual learning as students' main goal rather than just the passing of exams. Moreover, graduates highlighted that the extension of the programme may help alleviate the pressure that many students experience and it would also make the programme more accommodating to differences in learning pace among students. In fact, previous studies conducted within the Department have shown that on average, students take 3.6 years to complete their degree due to failing prerequisite courses. The Department's programmes already make provisions for students who take more than 3 years to graduate – it is possible that this can be extended to its entire student body. The extension of the programme may first of all, reduce failure rate as students would have less courses to focus on per semester as well as allow for students to re-take courses and still graduate with their cohort.

Many students advocated for the implementation of course content and delivery methods which were more related to practice such as case studies, field trips and interaction with industry professionals as well as the inclusion of more tutorial sessions. However, as indicated by Romenti et al (2012), the implementation of such methods would require the forging of relationships between educators and professionals in order to create opportunities for each party to involve the other in relevant activities.

6.3 Employers

Some of the employers held further opinions regarding the performance of graduates as employees. One of the employers implied that the performance of the graduates is based on attitudes developed at home and not necessarily at the university and therefore, it is not a problem to which the Department can provide a solution. Employers suggested that certain skills such as ethical conduct and time management be emphasised within the Department's programmes to better prepare students for the work environment. Another suggestion is that undergraduates be given more opportunities to visit construction sites in order to see the implementation of what they learn first-hand. This presents another opportunity for collaboration between industry and academia.

One of the employers indicated that most graduates still need a lot of on-the-job training and therefore they should be expected to be lacking in some areas. However, the real issue is that of application and attitude to improvement in their work as many graduates seem to lack understanding of basic concepts as well as initiative and leadership qualities. This opens the door to a whole other research area in relation to whether it is the responsibility of the Department to provide its students with the means of obtaining so called 'soft' or non-technical skills such as leadership, managerial abilities, communication and teamwork. In their study, Lowden et al. (2011) pointed out that employers expect graduates to possess these skills and attributes and therefore it suggests that the Department must accommodate the learning of such skills within its programmes. This can be more efficiently achieved by partnering with employers in the industry to assist in including components in the curriculum that foster these skills.

7. Conclusion

Students are considered to be important stakeholders in the quality assessment process. Therefore, an effort must be made to continually obtain their views. However, the collection of their opinions is not the end of the process. The gathered data must be properly analysed, clearly reported and actions need to be taken in the areas that need improvement and change. Furthermore, students must be informed of the results and actions to make them feel more involved in the institution's pursuit of quality (Harvey 2003). Additionally, employers are also key stakeholders and the design of programmes must take employers' perspectives into consideration to ensure that the academic objectives are in alignment with the requirements of the professional world (Kalanova 2008).

Before outlining the overall findings of the study, it is important to note that there are a few limitations in this study that may have had the potential to cause imprecise or misleading results. The statements or phrases in the scale sections of the questionnaire were open to interpretation, as is often the case with that method of surveying. This could have affected the accuracy of the results, although, in the case of the undergraduate group, the large sample number would have reduced the effects. For the employer and graduate group however, it is a different case. The low response rate from both graduates and employers can also be viewed as another limitation. The small sample number may have a significant effect on results as it may not provide an accurate representation of the views of the entire population of graduates and employers.

This study sought to determine whether the quality of the programmes provided by the Department was good according to the key stakeholders—undergraduates, graduates and employers. The findings showed that all groups had positive and negative assessments of the programmes. The undergraduates felt that although the resources were adequate, areas such as performance feedback and provision of internship opportunities needed improvement. Graduates on the other hand, indicated that overall, both the programme and resources were good. Employers identified some positive attributes which graduates possessed such as good work ethic and computer skills.

However, they highlighted other areas in which graduates were not as prepared. The findings suggest that although the Department is providing an educational experience of some quality, there is still much room for improvement.

One of the main suggestions was the need for the extension of the degree to four years in order to facilitate more effective learning and to allow for increased opportunities for students such as co-op learning and electives. The research suggests that it would be fruitful for the Department to explore how they may address the deficits identified by stakeholders. The process would be a long and challenging one, but the promised benefits to students and lecturers of the Department alike are worth the attempt.

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Development of Brown Paper Pulp Filled Natural Rubber Composites for Structural Applications

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Abstract: *To improve the flexural properties of materials for structural applications, composite materials from paper pulp can be bonded with natural rubber. Paper pulp exhibits some bonding potentials which can further be enhanced for some tailored applications by mixing it with another bonding agent. This study describes the influence of natural rubber on the flexural and water absorption properties of paper-pulp-filled natural rubber composites for structural applications. This research was done using pulverised brown paper pulp as the filler and natural rubber was used as the bonding agent. A measured volume of natural rubber was mixed with a known quantity of paper pulp and the mixture was poured into a detachable mould and compacted for about 10 minutes to produce the composite. The developed composites were detached from the mould and allowed to cure in air at room temperature for 27 days. Flexural and water absorption tests were done on the samples. The composite developed from the mixture of 70 wt % brown paper pulp and 30 wt % natural rubber gave the best result for flexural properties, while the sample with 60-40 wt % emerged the best composition for the water absorption property.*

Keywords: *Brown paper pulp; natural rubber; flexural properties; water absorption; structural application*

1. Introduction

Composites are materials that have combinations of two or more materials that result in better properties than those of the individual components used alone. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. They are generally made in two phases: the reinforcement and the matrix. The reinforcing phase provides strength and stiffness while the matrix performs several critical functions, including maintaining the fibres in the proper orientation and spacing and protecting them from abrasion and the environment (Campbell, 2010).

Paper is a wood-based product without which modern civilisation would not have evolved, and would not have been sustained and advanced. Paper pulp can also be used for diverse purposes such as in the preparation of cellulose derivatives like cellulose nitrate, cellulose acetate, regenerated cellulose and many more (Akpabio et al, 2012). Pulps are manufactured from raw materials containing cellulose fibres usually from wood, recycled paper and agricultural residue (Bajpal, 2012). The difference between white paper pulp and brown paper pulp is due to the removal of lignin from the pulp of brown paper which is known as delignification. Lignin provides the mechanical support for stems and leaves and supplies the strength and rigidity of plant walls (Okon and Aniekan, 2012). Generally, paper and pulps have been useful in producing consumer products like books, newspaper print, wall paper, postal products, artwork materials, cardboard, tissue paper and packaging materials amongst others.

Natural rubber is most often produced from the milk-like fluid from latex of certain tropical trees. The latex is a colloid state dispersion (Renner and Pek, 2011). Natural rubber is scientifically unique because of its elasticity which is due to an entropy change resembling that of ideal gas. It differs from energetic elasticity and standard organic, inorganic or metallic solid materials. However, the mixtures of natural rubber latex and paper pulp when prepared by iso-static compression have a high degree of flexural properties. They are polymeric materials displaying excellent physical properties for structural applications. Cellulose, hemicellulose, and lignin are the main constituents of paper that contribute to the tensile, flexural and impact properties of the composites developed from them (Sridah and Prompunjai, 2010).

Waste papers are solid wastes in the environment. Solid waste generation is a growing problem at local, regional and global levels. Solid wastes are those organic and inorganic waste materials, produced by various activities of the society, which have lost their value to the first user. Improper disposal of these solid wastes pollutes all segements of the living environment (air, land and water) (Okoro et al, 2015). To reduce the amount of solid waste in the environment, the use of waste paper in different end use materials is being investigated, as it this case in this research. Recycling of waste paper helps reduce the amount that would otherwise be sent to landfills or incinerators. The use of these waste papers for an engineering application reduces the problem of littering. Paper dumped in landfills currently accounts for 25 % of methane gas released from landfills. Also, municipal landfills account for one third of human related methane emissions of 1.6 million tons of greenhouse gases (Ogunwusi and Ibrahim, 2014).

Furthermore, dry construction methods are needed for saving costs. The use of dry construction methods with appropriate standardised components to reflect the designer's specification would reduce or completely eliminate wastages; and reduce labour requirements, cost and time for construction. The dry construction method is therefore cost-effective and preferred above the conventional method (Adedeji, and Ajayi, 2008). The use of waste paper for the development of structural products, as a dry construction method, will be very cheap, as waste paper which constitute the bulk of the material can also be readily sourced free or at a reduced cost from newspaper companies, offices and schools.

In this work, brown-paper-pulp-filled composites were developed using natural rubber as a binder to produce composite materials that will be used in structural applications like ceiling sheets and partitioning boards. The use of this waste paper will help in reducing waste and burning that was associated with the disposal of waste paper in Nigeria. Processing of this waste paper by grinding with a laboratory milling machine is a better option for the conversion of this material to engineering use. It is safe because there is no environmental pollution that emanates from this operation. Since the papers are readily available and cheap, only the milling process involves the use of energy which therefore makes the production of this product easy and cheap.

2. Experimental

The materials used for this research work include: waste newsprint paper, rubber latex, and ammonia solution and cellophane sheets.

2.1. Preparation of Materials

Natural rubber was tapped from the stems of trees at the Federal College of Agriculture, Akure, and was preserved with ammonia solution. Natural rubber is a thermoplastic material that is highly cross-linked, the property that makes it elastic. It has good frictional property, resistance to abrasion and fatigue. Waste newspaper prints used as brown paper were sourced from newspaper vendors. The papers were later sorted in order to remove contaminants, and afterwards the sorted papers were soaked in water for 2 weeks in order to ensure easy pulverisation in the milling machine. During the grinding process, water was added so as to promote a stress-free milling operation and to form slurry. The pulverised paper was squeezed to remove the water and sun dried for 5 days to obtain fine particulate material.

2.2. Development of Composites

The composites were developed by forming homogeneous pastes from the mixture of natural rubber and brown paper slurry in predetermined proportions as shown in Table 1.

Table 1. Mixing proportions of brown paper pulp with natural rubber

Compositions\Samples	Control	A	B	C	D	E	F	G	H
Paper in slurry (%)	100	95	90	85	80	75	70	65	60
Natural rubber (%)	-	05	10	15	20	25	30	35	40

Paper slurry was formed by blending 1 kg of the sun dried particulate paper with 2 litters of water followed by mixing in a bucket to form the slurry. The composition of the mixture was 500 g of the brown paper slurry and 200 g of the natural rubber. This was chosen after preliminary investigation into how best to blend these two materials.

Each representative samples were produced by pouring the homogenous pastes into the flexural mould and compressed with a cold compression moulding machine at ambient temperature for about 10 minutes until they are compacted. The samples were de-moulded after compaction and allowed to dry further at room temperature in the laboratory for 27 days as shown in Figure 1. This curing time was in agreement with the conventional curing time for cementiteous based composites (Oladele and Afolabi, 2015).

2.3. Property Tests

The dried composite samples were made to undergo both flexural and water absorption tests. These tests are very important based on the environmental challenges they are to be subjected to in service. This material is for use as structural material, namely portioning boards, which are likely to experience flexural or bending challenges when sudden load hits them. Also, water can come in contact with the boards, therefore, this test is also essential.

Figure 1. Samples of compacted brown paper samples mixed with natural rubber

2.3.1. Flexural Test

The flexural test was carried out by a Testometric Universal Testing Machine in accordance with ASTM D790. To carry out the test, the grip for the test was fixed on the machine and the test piece, with dimensions of 150 x 50 x 3 mm, was hooked on the grip and the test commenced. As the specimen was stretched the computer generated the required data and graphs. The Flexural Test was performed at the speed of 100 mm/min.

2.3.2. Water Absorptive Test

Since this material is likely to come in contact with water as a building material, it was necessary to carry out water absorptivity test to determine the extent to which the formed composites can absorb water.

In determining the water absorption property of the composite materials, each of the composites was weighed (g) in air with the aid of an electronic weighing balance and then immersed in 700 cm^3 of water. This test was done for 6 hours for the various samples of paper composite boards. Every hour the composite samples were removed, cleaned, and then weighed again. The water absorption capacity was found out according to the procedure described in the ASTM D 570 standard. The data collected was used to determine the % water absorption using:

$$\%\ Water\ Absorption = \frac{Final\ Weight - Initial\ Weight}{Initial\ Weight} \times 100 \quad (1)$$

3. Results and Discussion

3.1. Flexural Test Results

Figure 2 shows the bending strength at peak results for the samples. An evaluation of the influence of natural rubber on the developed paper pulp composites revealed that the addition of natural rubber increased the bending strength property of most of the samples produced as compared to the control sample.

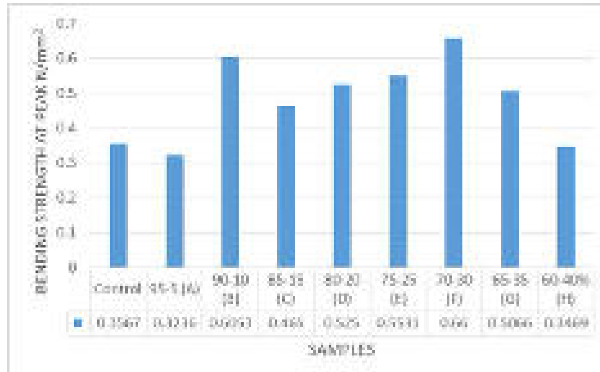

Figure 2. Variation of bending strength at peak with samples

According to the results, the bending strength at peak can only be enhanced within a given range of the proportions of the paper pulp and the natural rubber which can be taken to be from 90/10 to 65/35. The addition of natural rubber below 10 wt% shows that the material is not enough to bring about the desired improvement. This is because there is not enough material to aid proper wetting and bonding while the addition in excess of 35 wt% was too much and give higher ductility. With the exception of samples B within this range of optimum performance, the responses of the materials show a progressive increase in the bending strength at peak from sample C- F before experiencing a decrease in G. However, sample F, with composition 70-30 %, exhibited the best bending strength at peak performance with a value of 0.66 N/mm^{2,} closely followed by sample B with composition 90-10 % having a bending strength at peak value of 0.61 N/mm^2. These showed that the best performances based on the likely sources of enhancement were seen to arise from the two extremes.

The response of the developed materials to bending modulus was presented in Figure 3. All the developed composites except sample G possess better bending modulus than the control. The two samples with the best bending strength at peak happened to be the ones with the best bending modulus. However, a contrary trend to the bending strength at peak was observed between them—there is a progressive decrease in the bending modulus from sample C-E. From the results, it was observed that natural rubber indeed enhanced the bending modulus property of most of the composite samples when compared to the performance of the control sample. The consistency of sample F with composition 70-30 % was obvious as it exhibited the best performance in this category with a value of 34.37

N/mm^2 followed by sample B, composition; 90-10 % with a value of 26.31 N/mm^2. This further confirms the importance of adding natural rubber to brown paper pulp in the development of paper-based composites for structural applications.

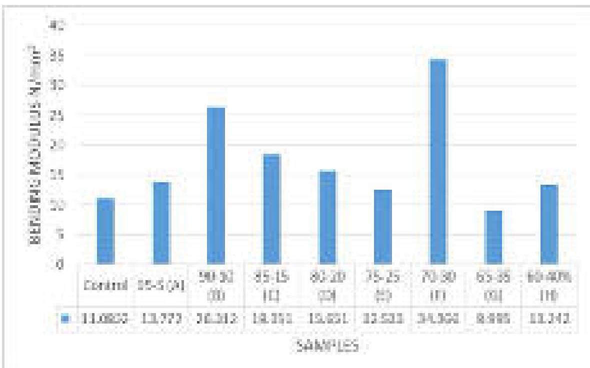

Figure 3: Variation of bending modulus with samples.

The results of the flexural properties tests show that sample F is the best brown paper composite produced. This is as a result of its flexural properties—good strength and stiffness. With these results, it is obvious that the addition of natural rubber to brown paper pulp with 70 % paper and 30 % natural rubber composition is a potential means for the development of low cost and environmentally friendly structural material. The results on the bending properties have shown that bending strength at peak increases within the range that produce the best results while the bending modulus was observed to decrease within the same range. These responses show that the two properties were inversely proportional.

3.2 Water Absorptivity of the Composite samples and the control

The results of the water absorption properties were as shown in Figure 4. It was observed from the plot that, as the natural rubber content increases, the water absorption tendency for the developed composites decreases. The control sample as well as samples A, D, F and H, possess % increase without attaining saturation within the 6 hours. However, samples B, C, E and G attain saturation state at 4, 3, 4 and 4 hours, respectively. The rate of water absorption was high for samples A-F, while that of samples G-H was low.

This suggests that as the natural rubber content increases, the rate of diffusion of water molecule within the pores of the paper-pulp-based composites reduces, thereby giving rise to a considerably low amount of water being absorbed by samples G with composition 65-35 % and sample H with a composition of 60-40 %. This test was essential, since paper tends to dissolve in water and contamination with water in service cannot be ruled out.

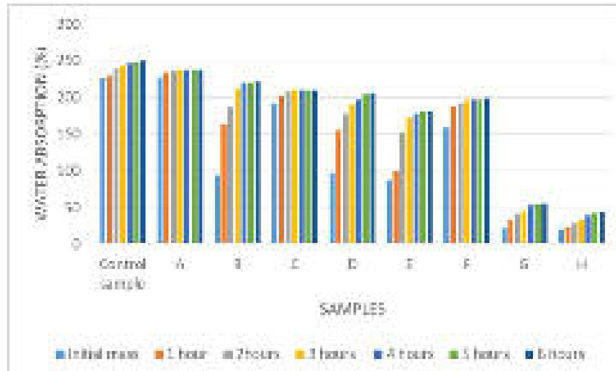

Figure 4. Percentage water absorption test on the samples for 6 hours

4. Conclusions

The results of the research into the influence of natural rubber on the flexural and water absorption properties of brown-paper-based composites have revealed the possibility of binding paper pulps made from brown paper with natural rubber to produce composite materials for structural applications. These materials are readily available and can be sourced locally at affordable rates. Also, they are environmentally friendly and can be easily processed. From the results, the following can also be deduced:

- Natural rubber can be used as binder for brown-paper-pulp-composite materials since the addition of natural rubber gave better flexural and water-repelling properties.
- The best composition for optimum flexural properties was 70-30 wt % paper pulp-natural rubber content, while the sample with the best water repellent property was obtained from 60-40 wt % paper pulp-natural rubber content.
- The work revealed that these materials can be blended together to develop strong and light weight composite materials for structural applications in low cost buildings.

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Mechanical and Microstructural Characteristics of Rice Husk Reinforced Polylactide Nano Composite

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Abstract: *The application of polylactides in tissue engineering is attracting significant interest. Using renewable; low cost; health and environmental friendly agro waste as reinforcement in electrospun polylactide nano composite fibres reduces the need for petroleum based fillers and enhances the strength of polylactides. In this paper, the morphological, mechanical and water permeability properties of electrospun treated and untreated rice- husk reinforced polylactide- nano- composite fibres are presented. The treated rice- husk particulates were ground, subjected to steam explosion and chemical treatment to remove its lignin and hemi-cellulose contents so as to increase the crystallinity of the filler. The addition of 4wt. and 6 wt. % untreated rice- husk filler increased the tensile strength by 95% and 43% respectively. Young's modulus, fracture stress, water permeability and other properties are also enhanced. This work shows that; the mechanical properties and biodegradability of scaffolds for tissue engineering can be improved by reinforcing polylactide with rice-husk instead of petroleum- based polymeric- nano- fiber composites.*

Keywords: *Nano-composite, fibre, polylactide, rice- husk, mechanical properties, morphology*

1. Introduction

There is a growing awareness that the world's petrochemical resources are not only finite (Howard *et al.,* 2009), but costly to produce; contribute to climate change (Skjærseth and Skodvin, 2001); increase carbon footprint; (Gentner et *al.,* 2014) and pose waste management problems (Malmasi et *al.,* 2010). All these result in an increased demand for polymeric composites produced from sustainable and ecologically friendly raw material and not from petrochemicals (Kim and Netravali, 2010; Mukherjee and Kao, 2011).

Polylactide or polylactic acid (PLA) is a bio-degradable, thermoplastic aliphatic polyester obtainable from renewable resources such as corn starch (Todo and Takayama, 2011). To produce a fully bio-degradable and renewable nano-composite, cellulose based reinforcement which is renewable and biodegradable is used. Cellulose is cheaply sourced, readily available and has good mechanical properties (e.g. high modulus, ~140 GPa), compared to inorganic reinforcing fillers (Sturcova et *al.,* 2005). Applications of PLA are restricted to low performance articles such as plastic bags, packaging for food, disposable cutlery and cups; slow release membranes for drug delivery; and liquid barrier layers in disposable nappies. The inherent brittleness of PLA leads to relatively poor impact properties performance. The limited supply and higher cost of PLA compared with commodity polymers such as polyethylene and polypropylene are of concern (Perego and Cella, 2010). To address these shortcomings, nano-fibres are added as reinforcements in PLA to form polymer composites. This process often helps to improve the polymer's mechanical and physical properties, making it suitable to a wide range of applications.

PLA is a resorbable polymer which degrades on exposure to body fluid (Armentano et *al.,* 2010). Addition of fibres, coatings and coupling agents can be used to control the degradation rate (Zeeshan et *al.*, 2015). When agro-waste fibres are added to PLA, its load bearing capacity, resorbability and some mechanical properties are enhanced. This makes it suitable for tissue engineering application, since the composite is both biodegradable and biocompatible. Such applications include the development of fracture fixation, interference screws, scaffolds and bone graft material (Zeeshan *et al.*, 2015).

Agro-waste such as rice husk contains natural fibres which are readily available, cheap, and biodegradable. This natural waste can be used to produce nano-fibres that can serve as reinforcing agents in polymer composites, through an electro spinning process (Dashtbani and Afra, 2015). This will lead to the production of polymer composites of improved mechanical and impact performance with enhanced biodegradability. The advantages of using natural fibres as reinforcement over glass fibres, talc or carbon fibres include lower density of the polymer composite, retention of biodegradability of the composite, superior performance, improved waste management of agro-waste fibres, lower cost and ease of acquisition of the abundant agro-waste fibres (Pertinakis, et *al.,* 2013). The fibrous nature of cellulose is another advantage because it can align and orient along the matrix axis with resultant improvement in mechanical properties and weight reduction. Cellulose is non-abrasive and , easy to process, which allows for high filling levels and this in turn yields significant savings (Eichhorn et *al.,* 2010).

Interfacial interactions or adhesion between polymer matrices and cellulose fibres depend on the strength of the molecular interactions that occur at the interphase between them. The stronger the molecular interaction, the stronger the resulting interfacial adhesion and the optimal load transfer performance. These can be achieved by modifying the surface of the cellulosic fibres through esterification, acetylation, and the use of coupling agents or compatibilisers (Huda et *al.,* 2006). Natural nano-composites can be found in the structure of abalone shell and bone. Interphases in nano-composites play a dominant role and affect their macroscopic properties. The reinforcing material can consist of nano materials in zero, one or two dimensional form.

Electro-spinning has been recognized as an effective technique for the fabrication of polymer-nano-fibres. Various polymers have been successfully electro-spun into ultrafine fibres using either solvent solution method or in melt form. Using solvent solution, PLA can be successfully electro-spun into ultra-fine fibres. Some amazing characteristics such as very large surface area to volume ratio, flexibility in surface functionalities, and superior mechanical performance, are achievable provided the diameters of polymer fibre materials measure nano-meters (Zeng et *al.,* 2003). One of the most promising uses for electro-spun nano-fibres is for developing nano-fibrous cellular scaffolds for tissue engineering. This is based on the biomimetic principle that electro-spun nano-fibres can mimic the physical structure of the native extracellular matrix (ECM), as most tissues and organs are fibrous in form with fibre dimensions down to nanometer scale (Laurencin et *al*., 1999).

Nano fibrous scaffolds can promote cell growth and also function well in the synthesis of genuine extracellular matrices over time (Laurencin *et al*., 1999). Dimensional stability of nano-composite fibres for scaffold tissue engineering is useful since they should be able to withstand the stresses of shrinkage and swelling due to changes of temperature and moisture (Matoke et *al.,* 2012).

The study on the effect of different solvent systems on fibre morphology and diameter of electro-spun PLA nano-fibres done by Casasola et *al*.,(2014) revealed that only acetone was able to produce a sufficient quantity of fibres to form nano-fibre mats with a minimum mean diameter. The fibre diameter is 757 nm with bead string morphology attributed to its relatively high conductivity and dielectric constant when compared to single solvents like Tetrahydrofuran (THF) and 1, 4-dioxane (DX). The single solvent did not produce continuous nano-fibres but produced droplets probably due to their high surface tension and low conductivity (McCullen et *al.,* 2007).

Green nano-composites composed of cellulose nano- fibre (CNF) and PLA were made using a solvent casting method. The CNF was surface modified and followed by esterification to improve the dispersion and its interfacial adhesion with the PLA. The results revealed uniform distribution of nano-particles in the polymer matrix at 1 and 3wt. %, but at 5wt. % the, CNF was easily agglomerated, thus causing a reduction in the mechanical properties of the nano-composite. The results of water vapour permeability (WVP) tests showed that the use of acetylated nano-fibres had no significant changes on the permeability of the films. Nano-composites with 1wt .% CNF does not produce significant alteration in tensile strength and elastic modulus but over 60% increment in elongation.

However, nano-composites with 3 and 5wt. % CNF showed significant changes in tensile strength, elastic modulus and elongation percentage. There is slight increase in glass transition and melting temperatures of PLA reinforced with CNF (Ali et *al.,* 2014). Baumgarten's (1971) study, of the effect of varying solution and process parameters (solution viscosity, flow rate, applied voltage) on the structural properties of electro-spun fibres using a poly (acrylonitrile) /dimethyl formamide (PAN/DMF) solution, determined that fibre diameter had a direct dependence on solution viscosity. The results indicated that the higher the viscosities, the larger the fibre diameters. The fibre diameter does not monotonically decrease with increasing applied electric field. Although it initially decreases with an increase in the applied field reaching a minimum and then increases when the applied field is further increased.

By varying the solution and processing parameters, electro-spun fibres with diameters ranging from 500 to 1,100 nm were produced. Properties of PLA composites reinforced with microcrystalline cellulose (MCC) from oil palm biomass have also been studied (Haafiz et *al.,* 2013). There was an improvement in the thermal stability of the PLA/MCC composites, while there was no improvement in both tensile strength and elongation at break of the composites when compared to virgin PLA. However, the Young`s Modulus increased from 3.9- 4.6 GPa with MCC loading. This was attributed to increase in hydrogen bonding, a stiffening effect, and high crystallinity index of MCC. The decrease in tensile strength of the PLA/MCC composites with MCC loading was attributed to aggregation of the MCC. The aggregation was due to Van der Waal's forces causing pronounced filler-filler interaction than filler-matrix interaction. Poor interfacial adhesion between the matrix and filler generated numerous voids at the filler-matrix interface. Decline in elongation with MCC loading was attributed to the stiffening action of the filler by restricting the segmental chain movement of PLA during tensile testing.

Petinakis et *al.,* (2009) studied the effect of wood flour content on the mechanical properties and fracture behaviour of PLA/wood-flour composites. The results indicated that enhancements in tensile modulus could be achieved, but the interfacial adhesion was poor. The incorporation of ligno-cellulosic materials into biodegradable polymer materials, such as PLA, has the effect of improving mechanical properties such as tensile modulus. But the strength and toughness of these bio-composites were not necessarily improved. This was attributed to the hydrophilic nature of natural fillers. The incompatibility with the hydrophobic polymer matrix will cause fibres agglomeration resulting in low impact properties, particularly at high fibre loadings.

The incorporation of 1wt. % cellulose nano-crystals (CNC) loading into electro-spun PLA fibres has resulted into about 37% improvement in strength and Young`s Modulus (Xiang *et al.,* 2009). It was suggested that the addition of CNCs could reduce the diameter of electro-spun fibres and thus improve fibre uniformity. The enhanced electric conductivity of electro-spinning in the presence of CNCs was given as the propelling force, which tends to increase the mechanical properties of mats. The smaller fibre diameters yielded higher overall relative bonded areas between fibres by increasing its surface area, bonding density and distribution of bonds.

This study was aimed at producing biodegradable, health and environmental friendly, renewable and low cost polylactide nano-composites for application in scaffold tissue engineering using treated and untreated rice-husk particles as fillers. The electro-spun nano-composite fibres were characterized for mechanical, water absorption and morphological responses**.**

2. Experimental Methodology

Industrial PLA obtained from Suzhou, China was used. The agro waste (rice-husk) was from a rice plantation in Abakiliki, South East, Nigeria. The exterior of rice husk is composed of dentate rectangular elements. These elements are themselves composed mostly of silica coated with a thick cuticle and surface hairs. The mid region and inner epidermis contain little silica. Amorphous silica is concentrated at the surfaces of the rice husk and not within the husk. The solvent used in the electro-spinning process was Dichloromethane manufactured by Shandong Jinhao Int`l Trade Co. Ltd, CAS number 75-09-2, 96% pure with concentration of 14.9M.

2.1 Fibre processing for untreated and treated rice-husk

The rice-husks (RH) were collected; washed; dried in sunlight for 5 days at an average daily temperature of 29^0C; cut into small pieces; ground to pass a screen of 10 mm in a mechanical crusher; and sieved using a sieve size of 105 μm to get the untreated RH particulate.

For the treated RH particulate, in addition to grounding, it was subjected to steam explosion at a temperature of 175 ^{0}C and a pressure of 1bar in an autoclave (SM280 E). The resulting fibre was hydrolysed in 2 % solution of NaOH overnight, neutralized in acetic acid and bleached with 8 % solution of hydrogen peroxide. Further acid hydrolysis was undertaken with a mixture of 10 % (w/w) nitric acid and 10 % (w/w) chromic acid at a temperature of 60^0C for 15 minutes. The resultant treated RH was sieved to 105 µm. The RH was treated to remove the lignin, amorphous and hemi-cellulose contents from it. This would also increase the crystallinity of the nano- fibre.

2.2 Preparation of PLA - Rice husk composite solution

The pulverized and sieved (treated and untreated) RHs were dissolved in Dichloromethane after they were weighed. Different grams of PLA were also dissolved in dichloromethane solvent to form the polymer solution. The different solutions of PLA- RH were mixed accordingly using 3 - 8wt. % RH as shown in Table 1.

Table 1. Solution formulation of PLA: Rice husk nano-composite fibre

S/N	PLA wt. %	Rice husk wt. %	PLA (g)	Rice husk (g)
X(control)	100	0	20	0
U1 and T1	97	3	16.2	0.5
U2 and T2	96	4	24	1.0
U3 and T3	95	5	28.5	1.5
U4 and T4	94	6	31.3	2.0
U5 and T5	93	7	33.2	2.5
U6 and T6	92	8	34.5	3.0

2.3 Electro-spinning of the rice-husk reinforced polylactide nano-composite fibres

In the trial test it was discovered that above 10 wt.% RH were formed in the PLA droplets instead of fibres on the collector plate independent of the voltage applied (0-30 KV), the flow rate and tip-to-collector distances. Therefore, the optimal level of the rice husk in the PLA is 8 wt. %; as above this content level the chances of droplets formation increases.

The solution samples of PLA- RH in different wt. % (from 3 - 8wt. % in increments of 1wt. %) were poured into a burette inclined at 30^0 to the horizontal surface. The flow rate was maintained at 0.01ml/s with a constant voltage of 26KV from the high voltage source. The distance from the tip of the spinneret to the collector was kept constant at 24.5cm. During electro-spinning, at a room temperature of 23^0C, the PLA- RH solution was involved in an electric field. The polymer filaments were formed from the solution between two terminals bearing electrical charges of opposite polarity. One of the terminals was placed at the tip of the spinneret attached to the tip of the burette, and the other onto a collector (aluminium foil on a metal sheet and grounded). As the charged polymer composite solution jets were ejected out of the metal spinnerets, the solution jets evaporated to become nano-fibres, which were collected on the aluminium foil collector.

2.4 Characterisation

In this study all tests and measurements were done thrice to ensure reproducibility. Mechanical tensile testing was done using 2cm by 2cm samples on a Double column Instron Universal tensile testing machine model 3369 located at Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. The computerized mechanical testing machine had a load capacity of 50KN, and the mode of operation was by continuous loading. The loading rate / strain rate used was 5mm per minute. The mechanical properties results were obtained from this test.

The morphology of the nano-fibres were studied using an ASPAX 3230 Scanning Electron Microscope (SEM) operated at an accelerating voltage of 15KV, located in the Materials Laboratory of Kwara State University, Malete, Kwara State, Nigeria. Backscattered electrons were used for the acquisition of the images. The samples were sputter-coated with a thin layer of silver to prevent the material from becoming charged by the electron beam during the analysis. The micrographs of treated and untreated PLA-RH electro-spun nano-fibres with 4, 6 and 7wt. % untreated RH and 5, 6 and 7 wt. % treated RH reinforced samples were taken. These were samples with the two highest values and the lowest value in ultimate tensile strength (UTS) respectively. The average diameters of fibres and beads were determined using an image analyser software program called ImageJ. It is a Java-based image processing program which can analyse, process, and read many image formats including TIFF, PNG, GIF, and JPEG.

A water absorption test was done on all samples to know the rate at which the nano-composite fibres absorb water. The samples were first dried;weighed using Unic Bloc Digital weighing balance (UW 1020H) with tolerance of 0.001g; and then immersed in distilled water at room temperature (23^0C) and at 70^0C. At room temperature, the samples were placed in different beakers containing a constant volume of distilled water for five days (120 hours), with water absorption rates taken at 24 hour intervals. At 70^0C, the test was done for two hours with the absorption rate taken at 30 minute intervals. The samples were periodically taken out of the water, wiped with tissue paper to remove surface water, and then weighed. The % water absorption or % weight gained (W %) was calculated using Equation 1:

$$W(\%) = \frac{W_2 - W_1}{W_1} \times 100\% \quad ----------(1)$$

Where W_2 and W_1 are weight gained after exposure and dry weight respectively.

3. Results and Discussions

3.1 Microstructural responses

The extent of dispersion of the fillers into the PLA- RH nano-composite fibres, bead formation and diameter in nanometres of the fibres, were observed using the SEM. The presence of numerous beads in the morphologies is attributed to low solution viscosity and agglomeration of fillers as shown in Figure 1. This is in keeping with the studies done by Zeng et *al*., (2003). The 6 wt. % treated RH and 7 wt. % untreated RH- PLA nano-fibres exhibited the least UTS due to large diameters.

The 4 wt. % untreated RH showed the best dispersion of filler and less bead formation, with the highest UTS, Young`s Modulus and fracture stress due to efficient load transfer from PLA to filler irrespective of its diameter size (see Figure 2) . This agrees with the work of Seong et *al.,* (2012). The larger nano-fiber diameter at 6 and 7 wt. % untreated RH and 5 and 6 wt. % treated RH (see Figure 3) is attributed to solution viscosity, as higher viscosities gave larger fibre diameters. Baumgarten (1971) reported the effect of varying solution concentration and process parameters on the structural properties of electro spun fibres using a poly (acrylonitrile) /dimethyl formamide (PAN/DMF) solution. It was deduced that fibre diameter had a direct dependence on solution viscosity as higher viscosities gave larger fibre diameters.

3.2 Mechanical Responses

The effect of treated and untreated RH on the tensile strength of electro-spun PLA nano-composite fibres are shown in Figure 4. The tensile strength for untreated RH decreased for 3, 7 and 8 wt. % RH loading of the reinforced nano-composite fibre. However, a 95% and 43% increase in strength occurred at 4 and 6wt. % RH loading compared to the virgin PLA. The tensile strengths decreased for treated RH reinforced PLA nano-fibres that are 45, 13 and 45% for 3, 4 and 6 wt. % RH loading respectively. But slight strength increases occurred at 5, 7 and 8 wt. % RH loading, which is inferior to the virgin PLA. Lignin content in the untreated RH filler is capable of enhancing adhesion between the hydrophilic natural fibre and the hydrophobic matrix polymer (Salmah et *al.,* 2013). The removal of the amorphous and lignin contents from the filler led to an increase in crystallinity and decrease in tensile strength of the rice-husk (Akpan et al.., 2014).

The morphological observation indicates better dispersion of the filler at 4 and 6 wt. % untreated RH loading with less beads or agglomeration of the fillers as

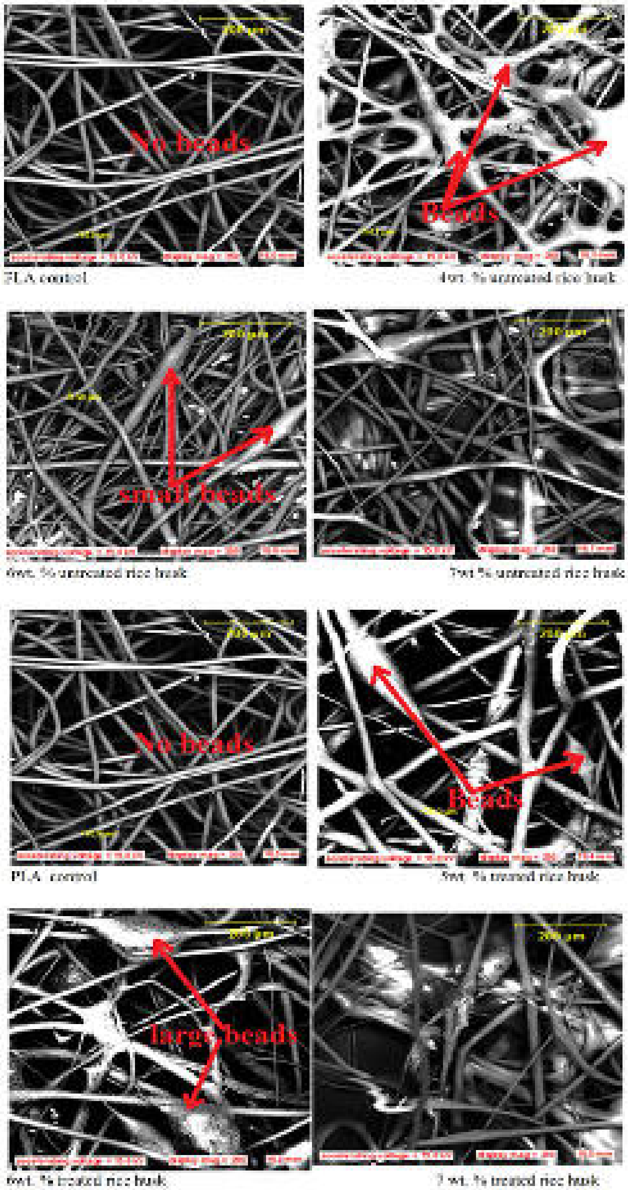

Figure 1. SEM micrographs of reinforced PLA nan- composite fibres at 250x magnification

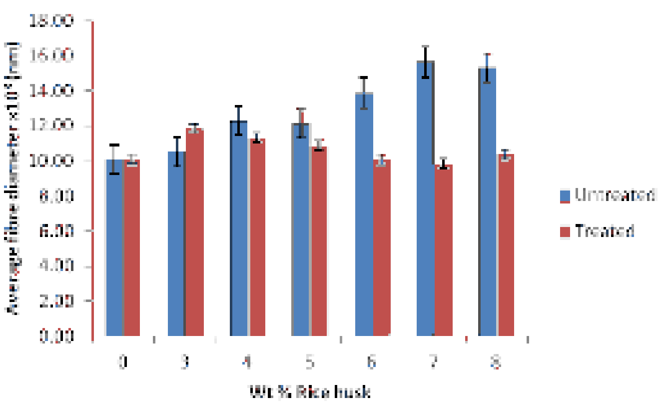

Figure 2. Comparison of average diameter of nano-composite fibres

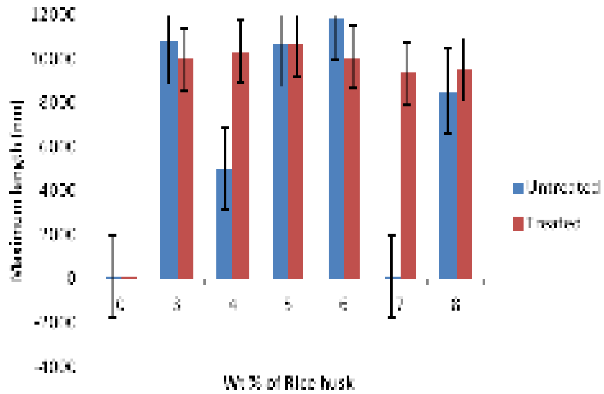

Figure 3. Comparison of maximum length of nano-composite fibres

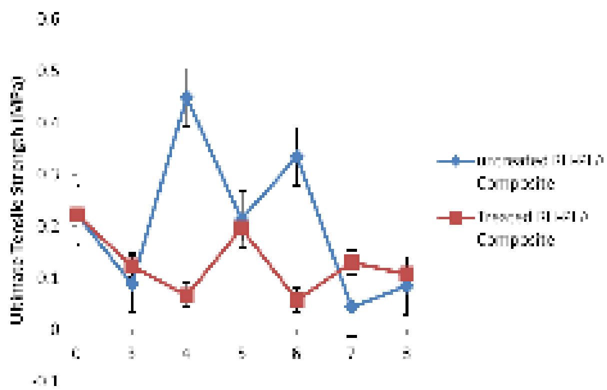

Figure 4. Ultimate Tensile Stress of rice-husk reinforced PLA nano-composite fibres

compared to 7 wt. % untreated RH which had more beads and agglomeration of filler as shown in Figure 2. Thus, there is poor filler-matrix interface alignment and reduction in stress transfer to the filler. This finding agrees with studies by Haafiz et *al*., (2013).

Young's Modulus of the PLA-RH nano-composite fibers increased for both treated and untreated RH loading, compared to the unreinforced PLA. The untreated filler nano-fibre composite showed 1000, 700 and 350% increase at 4, 5 and 6 wt. % RH loading respectively. There were 125, 100, 212, and 174% increases in Young's Modulus for 3, 4, 5 and 7 wt. % RH loadings respectively as shown in Figure 5. This increase in Young Modulus is attributed to the stiffening effect and high crystallinity index of the filler due to the presence of cellulose in the RH fillers, with significant increase in untreated ones due to amorphous content (Haafiz et *al.*, 2013; Akpan et *al.*, 2014). The high increase in Young's Modulus at 4 and 5wt. % untreated RH and 5wt. % treated RH loadings was as a result of efficient stress/load transfer from the PLA matrix to the filler material due to good dispersion and adhesion between the matrix and the filler.

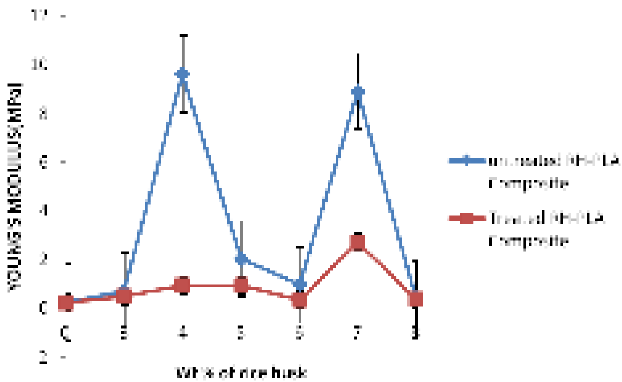

Figure 5. Young`s Modulus of rice-husk reinforced PLA nano-composite fibres

Gorga and Cohen (2004) reported that as the content of the filler is increased in a polymeric matrix above a critical level, the filler aggregates and reduces the effective stress transfer resulting in a modulus decline. This was also observed in the SEM micrographs in Figure 1; with 4wt. % untreated and 5wt. % treated RH reinforced nano-composite fibres showing less bead formation, which could be caused by adequate filler-matrix adhesion and dispersion with subsequent increase in the Young's Modulus.

Figure 6 shows the ductility for 3- 8 wt. % treated and untreated RH reinforced PLA nano-composite fibres. There was a drastic decrease in ductility for both treated and untreated RH fillers when compared with the unreinforced PLA. There were 89, 91, 89, 61, 100 and 77 % decrease at 3 – 8 wt. % untreated RH respectively. For the treated 3- 8wt. % RH loadings there were 72, 91, 77, 83, 94 and 66 % decrease in ductility respectively.

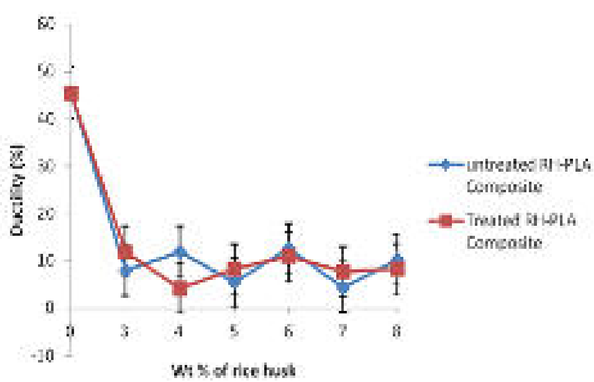

Figure 6. Ductility of rice- husk reinforced PLA nano-composite fibres

This result could be attributed to the stiffening action of the RH filler by restricting segmental movement of PLA during tensile testing and/or poor dispersion / interaction between PLA and RH. These led to agglomeration and substantial local stress concentrations, with subsequent reduction in ductility of the nano-fiber composites. The study by Pei et *al.*, (2005), reported that ductility can be affected by the filler volume fraction; the level of the dispersion of the reinforcement in the matrix; and the interaction/adhesion between the reinforcement and the matrix.

Impact, given by the energy at break, also decreased drastically for both treated and untreated RH reinforced nano-composite fibres at all wt. % and is inferior to virgin PLA (see Figure 7). There were 90, 91, 91, 56, 90 and 89 % decline at 3, 4, 5, 6, 7 and 8wt. % untreated RH respectively. For treated RH, there were 96, 89, 87, 91, 90 and 91% decline for 3, 4, 5, 6, 7 and 8wt. % respectively. There was a slight increase in energy at break at 6 wt. % untreated RH, possibly due to better filler-matrix adhesion which was observed in the micrograph, with very few beads or agglomeration of the filler. The drastic reductions in impact resistance for both filler types could be attributed to the stiffening action of the fillers through segmental chain movement restriction of the PLA, including possible agglomeration of filler thus leading to substantial local stress concentrations with resultant decrease in energy at break (Pie et *al.,* 2005).

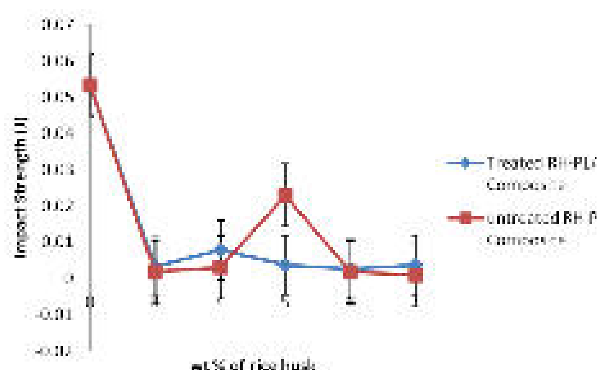

Figure 7. Impact responses of rice-husk reinforced PLA nano-composite fibres

Fracture stress (Tensile stress at breaking) increased for both treated and untreated RH reinforced PLA nano-composite fibres. Results show that the untreated RH PLA nano-composite fibre being higher, when compared with treated RH reinforced PLA and the virgin PLA (see Figure 8). There were 67, 1250, 400, 500, 150 and 10% increase in fracture stress at 3, 4, 5, 6, 7 and 8wt. % untreated RH respectively. For 3 - 8 wt. % untreated RH reinforced PLA there were 10, 150, 100, 150, 150 and 10% increase in fracture stress respectively compared to the unreinforced PLA.

This result was attributed to the dispersion and adhesion properties between the filler and PLA and this was higher in the untreated fibers especially at 4wt. % (see Figure 1).

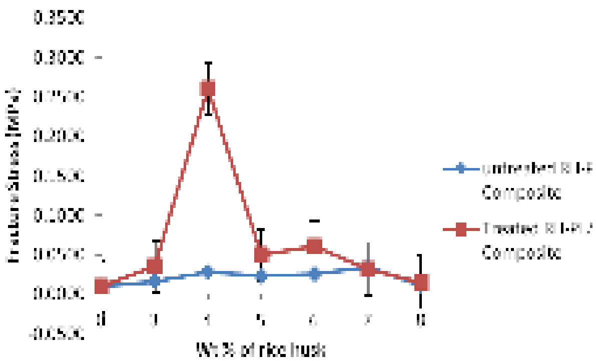

Figure 8. Fracture stress of rice-husk reinforced PLA nano-composite fibres

Thus, there was increased filler-matrix interface with efficient load/stress transfer to the filler (Haafiz et *al.,* 2013; Zhou and Wu, 2012). The slight increase in fracture stress for treated RH reinforced PLA nano-composite fibres compared to the virgin PLA and the untreated RH could be attributed to the removal of the amorphous content from the treated RH, thus increasing its crystallinity with subsequent reduction in its toughness (Akpan et *al.,* 2014).

3.3 Water absorption of nano-composite fibres

The effect of water absorption is important where the application requires the material to be in contact with water like in tissue engineering and drug delivery systems. The effects were observed for both treated and untreated RH reinforced PLA nanocomposite fibers at 23^0C and 70^0C as shown in Figures 9-12. It was observed that water absorption increased with increase in RH filler loading for both treated and untreated RH. As the filler loading increases, the formation of agglomerations increases which subsequently increases the water absorption of the fibers.

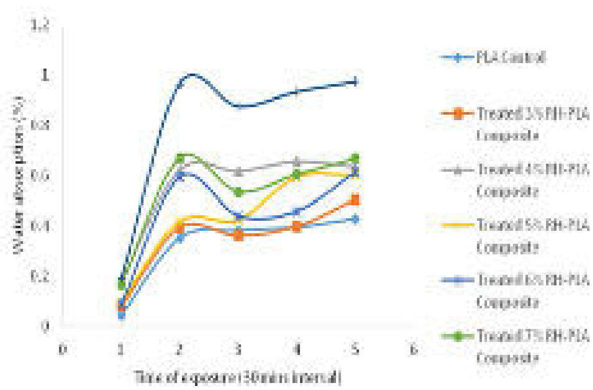

Figure 9. Water absorption of treated rice-husk reinforced PLA nano-fibres at 70^0C

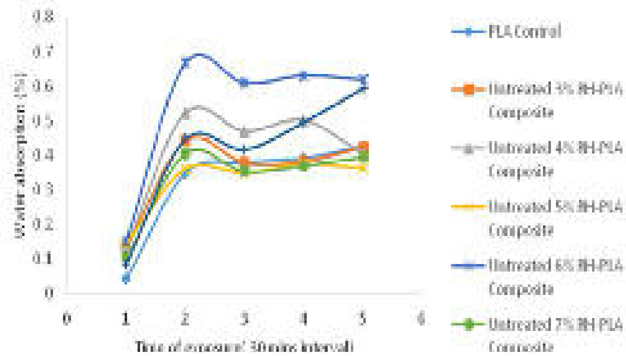

Figure 10. Water absorption of untreated rice- husk reinforced PLA nano-fibres at 70^0C

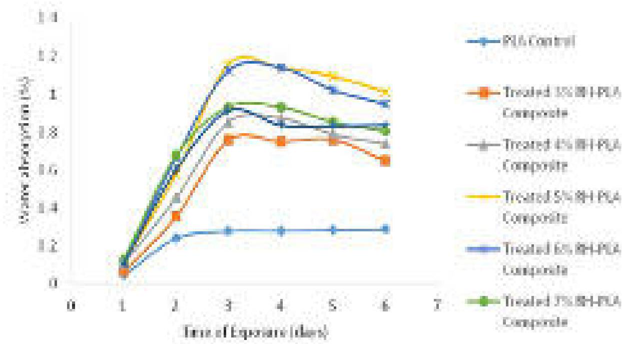

Figure 11. Water absorption of treated rice-husk reinforced PLA nano-fibres at 23^0C

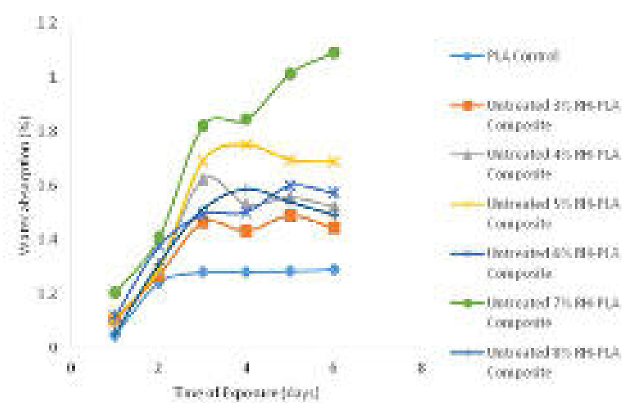

Figure 12. Water absorption of untreated rice- husk reinforced PLA nano-fibres at 23^0C

Dimensional stability of nano-composite fibres for scaffold tissue engineering is relevant since they should be able to withstand the stresses of shrinkage and swelling due to changes of temperature and moisture (Matoke et *al.,* 2012).

3.4 Summary

As a biopolymer the studied composites demonstrate low solubility in water and high water uptake characteristics that are very important for use as absorbent materials in horticulture, healthcare and agricultural applications (Petersen et *al*., 1999). Scaffold design and fabrication are subjects of biomaterial research, tissue engineering and regenerative medicine research (Langer and Vacanti, 1993). Scaffolds play a unique role in tissue regeneration and repair. Scaffolds are porous solid biomaterials designed to promote cell-biomaterial interactions, cell adhesion, and ECM deposition. They permit adequate transport of gases; and nutrients, for cell survival, proliferation, and differentiation. Scaffolds, sustain biodegradation at a controllable rate similar to the rate of tissue regeneration with minimal or no inflammation or toxicity (Langer and Tirrell, 2004).

The results of this study on polylactide rice-husk nano-fibre composites indicate that this material can be considered for use in scaffolds as their strength, rate of degradation, porosity, and microstructure, as well as their shapes and sizes, can be more readily and reproducibly monitored (Fuchs, Nasseri, and Vacanti,2001).

In view of the properties studied and discussed in this work an optimal level of properties performance was achieved with the rice-husk reinforced PLA nano-composite fibre at 4 wt. % and 5 wt. % for untreated and treated rice-husk reinforcement respectively.

4. Conclusion

The study on the reinforcement of PLA using rice-husk as filler for the production of nano-composite fibres has shown that the mechanical properties of electro-spun PLA nano-fibre can be improved by reinforcing with 3 - 8 wt. % rice-husks. Untreated rice-husk fillers improved the mechanical properties than the treated ones due to the presence of amorphous content together with the cellulosic content. Improved dispersion and adhesion between 4 -6 wt. % untreated rice-husks as seen in the micrographs led to more efficient stress transfer to the filler which is the load bearing entity, with subsequent improved mechanical properties.

Water absorption also improved with increase in wt. % for both the treated and untreated rice-husk reinforced PLA nano-composite fibres. Thus the mechanical properties and biodegradability of scaffolds for tissue engineering, can be improved by reinforcing PLA with rice-husk in place of petroleum based polymeric nano-fibre composites, thereby reducing their adverse effect on the environment.

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Physical and Mechanical Properties of Porous Kaolin Based Ceramics at Different Sintering Temperatures

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Abstract: *In this work, kaolin based ceramics using styrofoam, sawdust, and powdery high density polyethylene as pore formers were experimentally investigated. Prior to batch formulations, the kaolinite used was wet beneficiated. This was followed by mixing starting materials with pore formers, producing green bodies which were then uni-axially compacted into standard sample dimensions and fired at various sintering temperatures of 850°C, 1000°C and 1150°C for 2 hours in a furnace. The physical and mechanical properties of the sintered samples were investigated and the generated data analysed. It was observed that the apparent porosity and water absorption of the samples decreased with increased sintering temperature, while the bulk density, apparent density and cold crushing strength of the samples increased with increased sintering temperature. It was concluded that the samples which were sintered at 850°C with 5% wt pore former of powdery high density polyethylene gave the optimum properties in terms of the porosity and mechanical strength of the samples.*

Keywords: *Sintering temperature, Kaolin based ceramics, Pore formers*

1. Introduction

Porous ceramics have attained increasing importance in industry recently due to their numerous applications and utilisation involving different materials like metals, polymers, composites, semiconductors and biomaterials (Muhammad, 2008). Porosity can affect performance properties, strength (both flexural and compressive), and density of materials. There has been a long tradition in producing porous materials mainly for structural applications which include concrete, cements, bricks and refractories (Nettleship, 1996). In all applications of porous material, transport through the pore phase is very important and can be achieved if the materials contain more than 10% connected porosity and pore volume. This type of porous ceramic finds key applications as supports for heterogeneous catalysts, membranes for bioreactors, environmental filters for hot flue gases and diesel engine emissions.

The development of porous ceramic materials has presented a new challenge to several industries, because porous ceramics are specifically more durable in extreme environments and their surface characteristics permit them to fulfil very specific requirements. With the incessant demand for porous ceramics in industrial applications, a number of technologies have been developed lately for fabricating these materials and their pore characteristics, and for identifying pore-related properties. A tailor-made porous ceramic can be made through a critical understanding and interpretation of the relationship between various pore-related properties and optimising them for specific uses. Nowadays, different porous ceramics with more delicate and uniform pore structures, having wide pore size range (few micrometers to a few nanometers) can be prepared for diverse purposes via varied physical and chemical processing (Bilung, 2012). Figure 1 is a pictorial view of well distributed pores in a ceramic body.

Porous ceramics with well-defined macroscopic shapes and also high mechanical stability can be fabricated using novel processing routes, while retaining the inherent porosity of the porous powder from which they are produced (Sheng, 2001; Dibandjo et al, 2008). Sintering is a thermal process that transforms a compact powder into a bulk material, and is used in mass-producing complex-shaped components. Sintering is one of the most important technological processes in the powder metallurgy and ceramic industries. A rational theory of sintering should predict the routes for production of the required structure of a sintered body in order to provide the desired physio-chemical and physio-mechanical properties (Olevsky, 1998).

Figure 1. Image of porous ceramics
Source: Abstracted from Sheppard (1992)

Nigeria and Ghana are endowed with large deposits of ceramic raw materials such as pegmatite; alumina; montmorillonite and illite; mica; clay; feldspar; quartz; and bauxite. Clay mineral deposits have been found in most regions of Nigeria and Ghana and are mainly high grade clays containing kaolinite $Al_2Si_2O_5(OH)_4$. With the growing demand for porous ceramics in industrial applications, several technologies have been developed for fabricating these materials while also attempting to control their pore characteristics and properties (Sheppard, 1992; Montonnaro et al., 1996).

Numerous pore-forming agents have been investigated such as:

- Starch (Sheffler, 2005; Zivcova et al., 2012; Khatab et al., 2012; Garrido et al., 2011; Chen et al., 2011; Zivcova et al., 2009; Zivcova et al., 2010)
- Graphite (Gregorova et al., 2006; Sarikaya and Dogan, 2013; Sanson et al, 2008; Ding et al., 2007)
- Lycopodium (Boaro et al., 2003; Zivcova et al., 2007; Zivcova et al., 2008)
- Sucrose (Sarikaya and Dogan, 2013; Ray et al., 2010; Wang et a.l, 2005)
- Polymethyl methacrylate (Zeng et al., 2007; Yao et al., 2005; Kumar et al., 2005).

Even though starch is the most frequently used pore forming agent, possibly due to its biological origin and availability, the difficulties in maintaining the pore structure formed by the starch burn out, and the narrow size range of commercially available starch types (typically between 5 and 50 μm) limits its application when large pores are desirable (Gregorova and Pabst, 2007). Svinka et al. (2009) studied the production of porous alumina ceramics by the slurry casting method and investigated pore formation by elimination of hydrogen as a result of a chemical reaction of aluminium powder with water. The purpose of their study was to determine various ways of producing high porosity alumina ceramics having high mechanical strength and other properties significant for refractory ceramics.

The commercial ceramic supports are traditionally manufactured from compounds such as alumina (Al_2O_3), cordierite ($2MgO.2Al_2O_3.5SiO_2$), and mullite ($3Al_2O_3.2SiO_2$) (Zhong, et al., 2002; Saffaj, et al., 2004; Mohammadi and Pak, 2003), all of which have a relatively elevated cost. More recently, different processing routes for kaolin based ceramic and membrane supports have been proposed (Bouzerara et al, 2006) in order to decrease cost of manufacturing supports and to evaluate the feasibility of using local natural resources (Bouzerara et al., 2006; Zhou et al., 2008).

Therefore, this work investigates the physio-mechanical properties of low-cost kaolin based ceramics using styrofoam, sawdust, and high density polyethylene as pore formers at varying temperatures for its possible application as catalyst supports amongst others. It is important to highlight the use of powdery high density polyethylene (PHDPE) as a pore former, because to the best of our knowledge PHDPE has not been explored as a pore former in castable ceramics.

2. Experimental Procedure

The clay materials that were used in this study were obtained from Kankara and Kibi Kaolin deposits in Nigeria and Ghana respectively. The sawdust used was obtained from a local sawmill in Ghana. The styrofoam and powdery high density polyethylene powders were processed at the Materials Laboratory of the University of Ghana.

2.1 Raw material beneficiation and powder preparation

The mined kaolinite containing impurities was removed by washing, sieving and drying of the slurry in a Plaster of Paris (POP) mould. The washing was done by adding water to a constantly stirred kaolin blunger. The slurry was then passed through a sieve cloth to eliminate coarse grained impurities. The slurry filtrate was poured into a plaster of Paris (P.O.P) mould. The water was then separated from slurry by capillary action. Next, the solid was further dried in an electric oven for 7 hours. The dried samples were fed into a Thomas Hammer Mill (Arthur H. Thomas Co, USA), to break the soft lumps into powder.

Pellets were made by dry pressing in a hydraulic press (Carver Press USA) at a load of 3.5 MPa, with a 25% pump speed and dwell time of 90 seconds. A high carbon, high chrome steel die (12.5 mm diameter) was used. The pellet thickness was 6 mm. Acetone was used for cleaning the die to prevent contamination and sticking and 5% stearic acid solution was used for lubrication.

2.2 Characterisation Techniques for Kaolin

The essential properties of the raw material such as particle size ranges were experimentally determined. A laser method, low-angle laser light scattering (LALLS), was used for the particle size analysis with levels of sensitivity in the 0nm to 1000nm micron range using a nanoparticle analyser (Horiba Scientific, SZ-100). 10mg of the kaolin samples (from Kankara and Kibi) plus freshly deionized water (10mg of kaolinite + 10 ml of water) were subjected to continuous ultrasound treatment in an ultrasonic bath for 15 mins to ensure dilution and homogenous dispersion. The pore formers comprising saw dust, styrofoam and high density polyethylene were prepared using an analytical mill to reduce the sizes.

X-ray diffraction (XRD) was performed on powders of kaolin clay to determine their phase compositions. This was done on an empyrean diffractometer (Bruker AXS, D8 Advance) with theta/theta geometry, operating a Cu Kα radiation tube (λ = 1.5418 Å) at 40 kV and 30 mA. The XRD patterns of all the randomly oriented powder specimens were recorded in the 10.0°- 90° 2θ range with a step size of 0.017° and a counting time of 14 s per step. The surface morphology of the kaolin was investigated using an ultra-high vacuum and high resolution FEI, Xl-30 scanning electron microscopy. Samples were metalized with gold/platinum coating prior to the analysis. Images were acquired at magnifications of 8000 and 15000 X.

2.2 Sintering of compacted pellets

The compacted pellets were sintered in a muffle furnace at 850°C, 1000°C and 1150°C. At each sintering temperature, the holding times for different batches were 2 hours. The samples were heated at 5 ^{0}C/min till final sintering temperature. The furnace was switched off for cooling and the samples were taken after the furnace temperature reached below 100 °C.

2.3 Physical Properties' Test

Physical properties tested for were apparent porosity; bulk density; apparent density; percentage water absorption; and total shrinkage. The test specimens were dried at 100°C for 24 hours to ensure total water loss, and later fired up to 850°C, 1000°C and 1150°C in an electric furnace. Their fired weights were measured and recorded. They were allowed to cool and then immersed in a beaker of water. Bubbles were observed as the pores in the specimens were filled with water. Their soaked weights were measured and recorded. They were then suspended in a beaker one after the other using a sling. Each specimen was lightly wiped with a moistened smooth cotton cloth to remove all excess water from the surface, and then the saturated weight, W, was recorded.

The apparent porosity (the amount of void or pores within a volume of porous solid) of the kaolin based ceramic bodies was calculated using Eq. (1):

$$\text{Apparent Porosity} = \left(\frac{\text{W-D}}{\text{W-S}}\right)\times 100 \tag{1}$$

Their respective bulk densities, apparent densities and percentage water absorption were calculated using the formulae proposed by Chesti (1986):

$$\text{Bulk Density} = \frac{\text{D}}{(\text{W-S})}\times 100\left(\text{g/cm}^3\right) \tag{2}$$

$$\text{Apparent Density} = \frac{\text{D}}{(\text{D-S})}\times 100\left(\text{g/cm}^3\right) \tag{3}$$

$$\text{Water Absorption} = \frac{\text{W}}{(\text{W-S})}\times 100 \tag{4}$$

Where: D = Weight of fired specimen, S = Weight of fired specimen suspended in water, and W = Weight of soaked specimen suspended in air.

Also the total shrinkage was calculated for each test specimen using the following formula taken from Norsker (1987):

$$\%\text{Total Shrinkage} = \frac{(\text{OL-FL})}{(\text{OL})}\times 100 \tag{5}$$

Where: OL means original length; DL stands for dry length and FL is fired length.

2.4 Mechanical Property Test

The mechanical property tested for was cold crushing strength. It was used to determine the compression strength at failure for each sample which is an indication of its probable performance under load. The standard ceramic samples were dried in an oven at a temperature of 110 ^{0}C and allowed to cool. The compressive strength testing was carried out on a hydraulic testing machine (Carver Press, USA). The compressive strengths of the porous clay ceramics were obtained by compressive loading of samples prepared according to ASTM C133-97 (2003); and the cold crushing strengths, of standard and conditioned samples, were calculated from the equation:

$$\text{CS}=\frac{\text{P}}{\text{BW}} \tag{6}$$

Where: P is load at failure; and B and W are the respective width and breadth of the specimens.

Table 1 shows the batch formulations of clay (Kankara and Kibi) and pore formers (sawdust, styrofoam and powdery high density polyethylene in four different ratios (clay-to-pore formers) by weight.

3. Results and Discussion

3.1 SEM Images of Kaolin

The SEM images of the beneficiated Kankara and Kibi kaolin respectively scanned at 8000x and 15000x shown in Figures 4 and 5, reveal the platelet structure of kaolinite clay reported in the literature (Abo-El-Enein, 2013; Bergaya et al., 2013) which normally portrays booklets morphology. . The average particle size was estimated as 2.0 µm for both the raw and beneficiated kaolin.

Figure 6 shows the XRD pattern of the beneficiated Kankara and Kibi kaolin. It could be seen from the XRD pattern that the peaks at Bragg's angles of 12.35, 19.89, 20.38, 24.88, 34.94, 35.95, 36.06, 38.35, 45.24, 54.88 and 62.37° responsible for the kaolinite mineral were more prominent after beneficiation. The XRD pattern was dominated by the kaolinite peaks after beneficiation of the kaolin.

Table 1. Composition of test Samples by weight (Total weight = 100g)

Sample code.	Kaolin (g)	Plasticizer (Kibi Kaolin) (g)	Saw dust (g)	Styrofoam	High Density Polyethylene (HDPE)
0% CS	80	20	-	-	-
5%SD	75	20	5	-	-
10%SD	70	20	10		
15%SD	65	20	15		
20%SD	60	20	20		
5%SYF	75	20	-	5	-
10%SYF	70	20	-	10	-
15%SYF	65	20	-	15	-
20%SYF	60	20	-	20	-
5%HDPE	75	20	-	-	5
10%HDPE	70	20	-	-	10
15%HDPE	65	20	-	-	15
20%HDPE	60	20	-	-	20

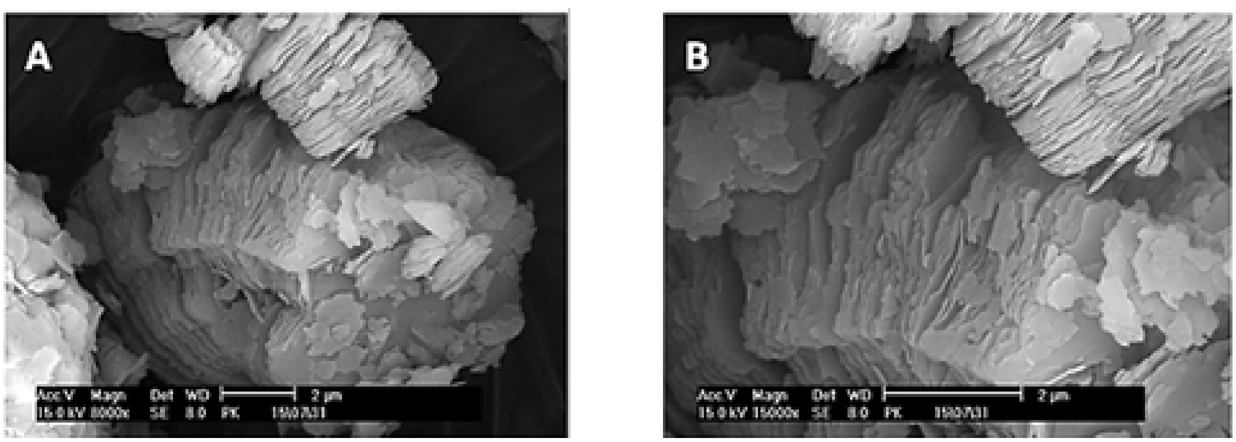

Figure 4.SEM images of Beneficiated Kankara Kaolin: A) 8000X; B) 15000x

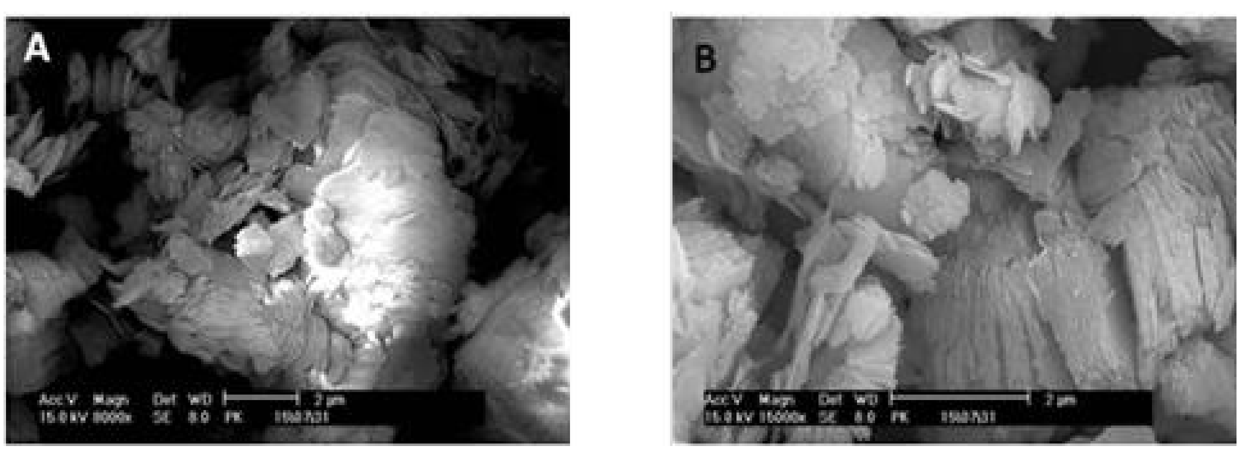

Figure 5. SEM images of Beneficiated Kibi Kaolin: A) 8000X; B) 15000x

3.2 Particle size distribution

The ranges of particle size of the samples after particle size analysis are shown in Figure 7. There is a wide range of particle sizes (0nm-8000nm) in the samples which is necessary for close packing configuration (Kingery, 1976; Richerson, 2006).

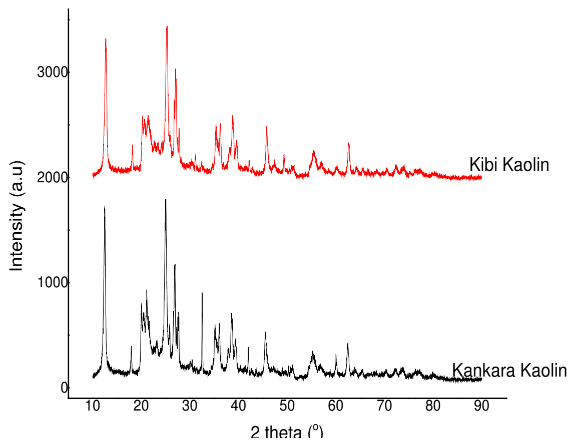

Figure 6: XRD pattern of kaolinite (Kankara and Kibi).

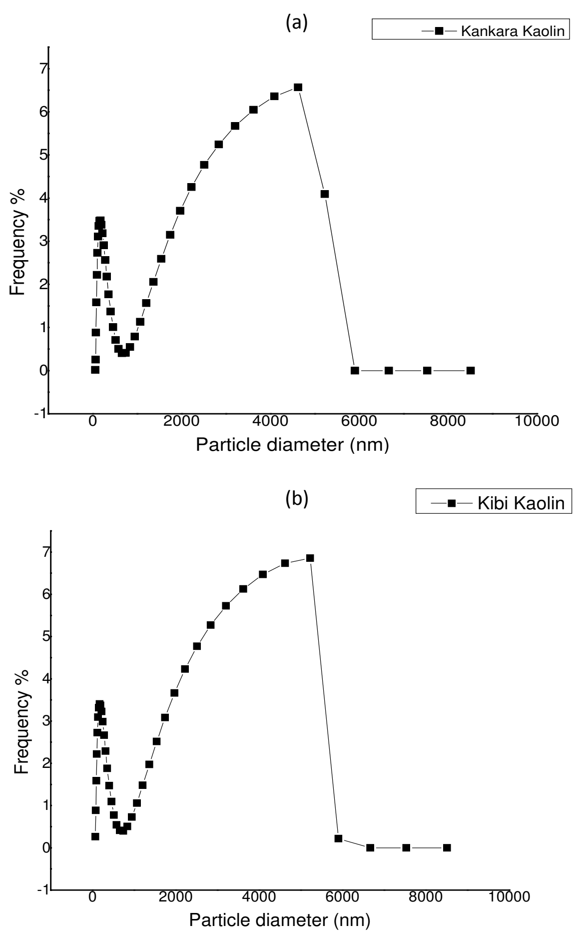

Figure 7: Particle size distribution of Kankara and Kibi Kaolin

3.3 Effects of Sintering Temperature on the Porous Kaolin based Ceramics

3.3.1Shrinkage

The shrinkage plots for the control and porous samples with different fractions of pore formers (SD, STY, and HDPE) are shown in Figure 8. The plot shows that shrinkage increases with increasing sintering temperature. The onset of shrinkage marks the start of the densification process. The control sample showed reduced shrinkage because of the absence of pores in the sample. Thus, the addition of pore formers creates voids in the green (unfired) compact of kaolin-based ceramic which requires higher sintering temperatures for its removal and shrinkage tendency. Thus, at a particular temperature, samples containing pore formers will be more porous than samples without pores. The control samples and samples with saw dust, styrofoam and HDPE at various composition of pore formers had shrinkage values ranging from 7.50-14.25%, 10.00-16.75%, and 12.50-20.00%; 7.50-12.50%, 9.50-10.00% and 11.75-12.50%; 7.50-13.75%, 10.00-17.00% and 12.50-19.75% for sintering temperatures of 850°C, 1000°C and 1150°C, respectively . These values are all within tolerable limits for kaolin-based porous ceramics.

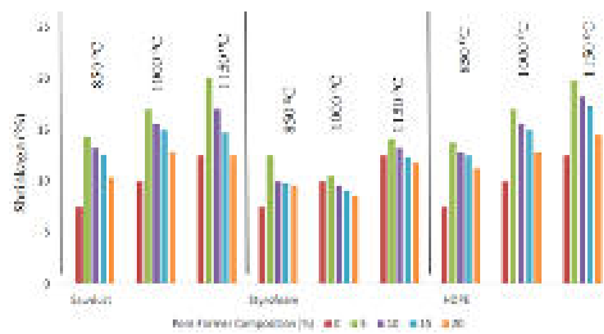

Figure 8. Variation in shrinkage values of fired samples (fired at 850°C, 1000°C and 1150°C) due to change in sintering time and percentage of pore formers

3.3.2 Apparent porosity and water absorption

The porosity and water absorption rate, which are the void contents and the weight of the moisture in the pores as a fraction of the weight of the sintered specimen, is an effective index of the quality of porous ceramics. From Figures 9 and 10, the effects of sintering temperature on the apparent porosity and water absorption of the sintered clay-based ceramic are clearly shown. All the plots show a similar trend, that is an increasing porosity and water absorption trend with pore former content. The control samples showed significant reduction in apparent porosity, this is due to the absence of pore formers. However, the absolute value of porosity and water absorption decreases with an increase in sintering temperature and time. This implies that at higher sintering temperature and/or longer holding time, the pore mobility increases. This causes reduction in porosity and water absorption. These results are in agreement with Surabhi (2012).

From Figure 9, it is observed that the apparent porosity of the sintered sample decreases with increases in sintering temperature. This is due to the fact that voids exist between particles of the newly formed green (unfired) ceramic, much of these inter-particle voids are eliminated during firing/sintering to produce sintered ceramic. However, it is often the case that this pore elimination process is incomplete and some residual porosity will remain. A lot of factors determine the amount of these pores that will be eliminated during sintering, these include, the temperature at which the ceramic is sintered; the higher the sintering temperature, the higher the amount of the pores that will be filled/eliminated during the sintering operation. Moreover, the composition of the ceramic raw materials from which the ceramic is fabricated together with the sintering temperature equally affects the elimination of the pore during sintering.

Control samples and samples with saw dust, styrofoam and HDPE at various composition of pore formers had apparent porosity values ranging from 30.87-51.97%, 30.22-51.16%, and 28.63-47.00%; 30.87-48.82%, 30.22-44.40% and 28.63-39.19%; 30.87-57.06%, 30.22-54.36% and 28.63-51.66 % for sintering temperatures of 850°C, 1000°C and 1150°C respectively. However , samples with saw dust, styrofoam and HDPE as pore formers had water absorption values ranging from 19.87-54.34%, 18.75-52.58%, and 17.07-42.10%; 19.87-61.96%, 18.75-51.56% and 17.07-42.10%; 19.87-69.70%, 18.75-61.54% and 17.07-53.84 % for sintering temperatures of 850°C, 1000°C and 1150°C, respectively. These values are all within tolerable limits for kaolin-based porous ceramics.

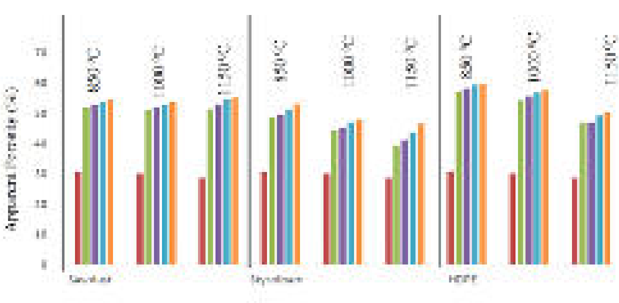

Figure 9: Variation in Apparent porosity values of Fired Samples (fired at 850°C, 1000°C and 1150°C) due to change in sintering time and percentage of pore formers

The results (see Figure 10) show that as the percentage by mass of pore formers increased, the water absorption of the porous ceramic samples increased. A near-linear dependence of porosity and water absorption on the pore former contents (from 5 to 20 wt%) in the samples was observed. Furthermore, the amount of water absorbed by the porous ceramics decreased with an increase in the heating temperature. The decline in the rate of water absorption with increasing heating temperature suggests that local liquid-phase sintering occurred, which contributed to a decrease in pore volume and the water absorption rate. Water absorption values of the samples show that the sintering behaviour of ceramics is affected by the formation of a transitory liquid phase, which improves the densification of the sintered samples. The bonding capacity of the mixture is related to the amount of the pore formers added to the mixture.

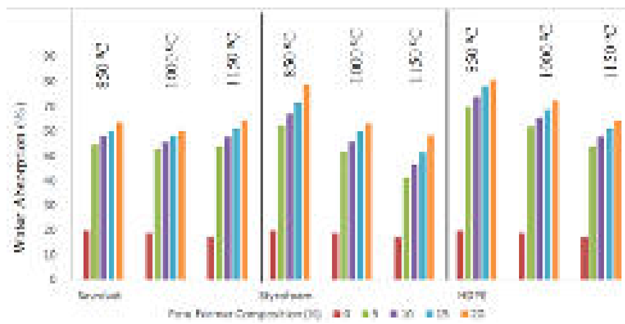

Figure 10. Variation in water absorption values of fired Samples (fired at 850°C, 1000°C and 1150°C) due to change in sintering time and percentage of pore formers

3.3.3 Apparent and Bulk density

Figures 11 and 12 show the variation of apparent and bulk densities in the sintered control and porous kaolin-based ceramics as a function of pore former content for different sintering temperatures. All the plots show similar trends, that is a decreasing bulk density trend with pore former content. However, the absolute value of apparent and bulk densities increase with an increase in sintering temperature. This implies that at higher sintering temperature, the pore mobility increases. This causes a reduction in porosity and an increase in bulk density.

Control samples and samples with saw dust, styrofoam and HDPE at various compositions of pore formers had apparent density values ranging from 1.90-2.34 g/cm^3,1.93-2.31g/cm^3 and 1.97-2.3431g/cm^3; 1.44-2.24g/cm^3, 1.47-2.31 g/cm^3 and 1.49-2.34g/cm^3; 1.85-2.24g/cm^3, 1.89-2.31g/cm^3 and 1.92-2.34g/cm^3 for sintering temperatures of 850°C, 1000°C and 1150°C, respectively. While bulk density values ranged from 0.86-1.55g/cm^3, 0.89-1.61g/cm^3 and 0.98-2.75 g/cm^3; 0.66-1.55 g/cm^3, 1.47-2.31g/cm^3 and 0.79-2.75g/cm^3; 0.81-1.61 g/cm^3 and 0.88-2.75g/cm^3 for sintering temperatures of 850°C, 1000°C and 1150°C, respectively. These values are all within tolerable limits for kaolin-based porous ceramics.

Contrary to the relationship which existed between the sintering temperature and the shrinkage, water absorption and apparent porosity as discussed above, it is observed that the bulk density of the clay-based ceramic samples increased with increases in the sintering temperature. This is expected because as the inter-particle voids/pores are progressively filled up with increasing sintering temperatures, the volume of the ceramic samples can be said to reduce with increased sintering temperature. This behaviour is also due to the reduced porosity of the sample as explained above which leads to an increase in the amount of matter in the sample per unit volume (Aramide, 2012).

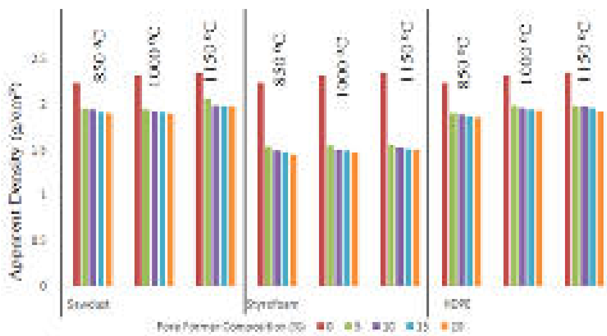

Figure 11. Variation in apparent density values of fired Samples (fired at 850°C, 1000°C and 1150°C) due to change in sintering time and percentage of pore formers

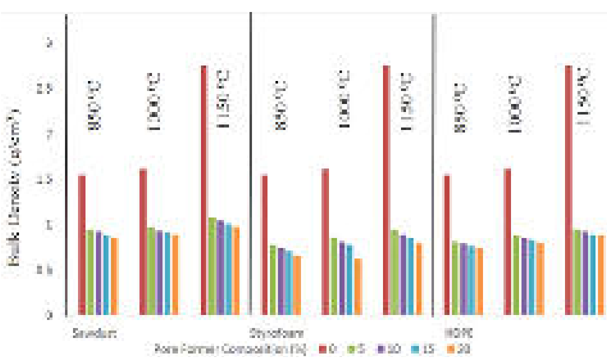

Figure 12. Variation in Bulk density values of fired Samples (fired at 850°C, 1000°C and 1150°C) due to change in sintering time and percentage of pore formers

3.3.4 Cold crushing strength

Figure 13 shows that the cold crushing strength is higher for the control sample in comparison to samples with pore formers due to higher porosity in the latter samples. Higher porosity implies less load bearing capacity and thus weak samples. Control samples and samples with saw dust, styrofoam and HDPE at various compositions of pore formers had cold crushing strength values ranging from 15.01-24.40 MPa, 15.23-29.70 MPa and 18.20-33.10 g/cm^3; 15.00- 24.40 MPa, 15.95-29.70 MPa and 17.01-33.10 MPa; 16.05-24.40 MPa, 16.85-29.70 MPa and 17.25-33.10 MPa for sintering temperatures of 850°C, 1000°C and 1150°C, respectively. Therefore, the strength decreases at higher pore former content. As the sintering temperature increases, the strength increases because at higher sintering temperature, the porosity of the samples decreases, that is the samples densify. This increases the load-bearing capacity or, in other words, the strength increases.

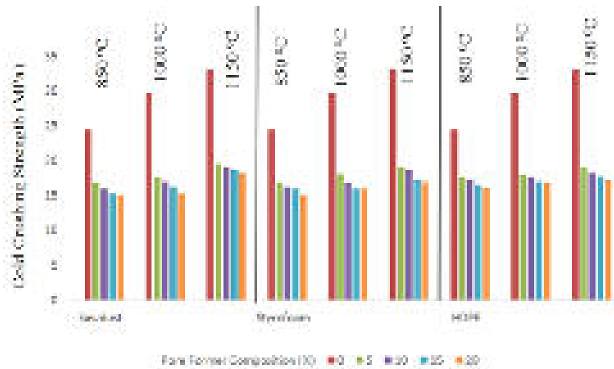

Figure 13. Variation in cold crushing strenght values of fired Samples (fired at 850°C, 1000°C and 1150°C) due to change in sintering time and percentage of pore formers

It is critical to note that, for this study, a sintering temperature of 850°C and a 5% weight pore former addition by mass can be suggested as the optimum conditions for the specific batches. This is in terms of the porosities and water absorption of the ceramic bodies vis-à-vis their mechanical strength. However, properties of ceramic bodies for the other conditions investigated are tolerable and of huge significance considering potential high temperature applications of these substrates.

4. Conclusions

This study examined the physical and mechanical properties of low-cost kaolin-based ceramics in the preparation of porous substrates. Based on the physical and mechanical properties of the sintered samples at different temperatures, it can be concluded that:

i. Samples with high density polyethylene as a new pore former considered in this study resulted in highly porous bodies, confirming that the choice of pore formers is critical to achieving porous ceramic bodies. Formulations containing 80% kaolin can be used for the production of ceramics with porosities as high as 59.84% if the right pore formers are used.
ii. Apparent porosity, and water absorption of the samples decrease with increased sintering temperature.
iii. Bulk and apparent densities and cold crushing strength of the samples increased with increased sintering temperature.

iv. Samples with 5% wt pore former (HDPE), sintered at 850^{o}C gave the optimum properties in terms of the porosity, water absorption and mechanical strength of the samples.
v. The physical and mechanical properties of all samples fired at different sintering temperatures (water absorption, bulk density, apparent density and linear shrinkage) were all within tolerable limits for kaolin-based ceramics.

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A Biosensor for Automated Feature Extraction and Non-invasive Cardiovascular Diagnosis Using Photoplethysmography Waveforms

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Abstract: *Indices derived from the morphological features of photoplethysmography waveforms are increasingly being investigated and linked to cardiovascular diseases, and may eventually be used to enhance patient risk assessments. These indices can be retrieved faster than the results for cholesterol tests (i.e., which are typically required for many risk assessments), are non-invasive, and may be less costly. This paper presents an overview of the development of a non-invasive, continuous, compact and portable device used to acquire the cardiovascular data necessary for assessment and diagnosis in real-time. Typically these indices are not evaluated in real-time, but are instead assessed offline and manually, once the waveform is retrieved. The system presented performs real-time, automatic feature extraction for cardiovascular diagnosis by identifying the 'a', 'b' and 'e' waves derived from the second derivative of the photoplethysmogram waveform, followed by calculating indices associated with these waves. Results demonstrate the feasibility and utility of such a system as an enabler of personalised cardiovascular care systems. Results from demonstrative tests with test subjects are comparable to those in the literature. This paper also offers valuable insights into the challenges in deploying automated, non-invasive, continuous monitoring systems for extraction of cardiovascular health indicators beyond heart rate and blood pressure.*

Keywords: *Automatic feature extraction, biosensor, cardiovascular diagnosis, medical device, photoplethysmography*

1. Introduction

Cardiovascular disease (CVD) is one of four main types of non-communicable diseases (NCDs) which are the leading causes of death globally (WHO, 2014). In a comparison of NCDs that are categorised as leading causes of death in the years 2000 and 2012, heart disease contributed significantly to the number of deaths per year (WHO 2014). There was an alarming increase of deaths from CVDs, such as ischaemic heart disease, hypertensive heart disease and stroke, from 12.5 million in 2000 to 15.2 million in 2012 (WHO 2014). The Caribbean is one of the most affected regions of the Americas, as chronic diseases are now the main cause of early death. In 2008, the Caribbean region was ranked the third in the number of deaths from NCDs compared to the total number of deaths in that region (THCC, 2014).

Given the impact upon the region, it is necessary to reduce the incidence of CVDs and healthcare costs. A key strategic intervention is predicting the likelihood of developing CVDs and associated complications. To assess a patient's risk of developing a CVD, multivariable risk prediction approaches have been developed which incorporate risk factors such as age, sex, and blood pressure ~~etc.~~ (D'Agostino et al., 2008). These assessments, as well as monitoring the disease, can be important to reversing the epidemic which has led to a rise in deaths and disabilities from NCDs. Emerging evidence has shown that clinical decisions based on CVD risk assessment, which includes prescribing the relevant drugs, has led to improved management of CVD risks. For example, initial risk assessment and targeted treatment can lead to a reduction in the risk of CVDs such as cardiovascular heart disease (CHD) (Heart Foundation, 2015).

Photoplethysmography (PPG) is an optical measurement technique that can be used to capture cardiovascular data. Indices calculated from the physiological features identified from the PPG waveform are being correlated with the risk of CHD in individuals (Elgendi, 2012). Other risk assessments, such as the popular Framingham risk model and other models discussed in Bitton and Gaziano (2010), typically use age, gender, cholesterol and systolic blood pressure to calculate the risk score (D'Agostino et al., 2008). To obtain a cholesterol reading a sample of blood is required from the patient, whereas the PPG waveform, from which the indices are calculated, is retrieved non-invasively (Lai and Insoo, 2015). In addition to using non-invasive measurements, PPG devices can be used to continuously monitor patients and provide these indices, shortly after measurement. This is in contrast to typical assessments, for which there are long delays in obtaining the results, for example the cholesterol test (Mayo Clinic 2015).

Consequently, using PPG-based devices with appropriate signal processing techniques to estimate alternative risk indices, such as those proposed in Elgendi (2012), would also increase the frequency of risk evaluations for CHDs. This facilitates increased personalised and data-driven treatment for persons who may have or may develop CVDs. Furthermore, the ability to track progression of CVDs would help determine the degree to which intervention such as lifestyle changes or medication are lowering the impact CHDs.

PPG-based devices offer several advantages in addition to low manufacturing costs. They can also be wearable devices, such as wrist wearable units (e.g., watches) (Ahanathapillai et al., 2015), and they can be integrated with mobile devices, such as smart phones (Lai and Insoo, 2015). Wearable devices are becoming more popular since this increases the ability for patient self-monitoring (Lewy, 2015). This can save on the cost associated with tests required by the Framingham model as well as the inconvenience of going to the laboratories or healthcare facilities to have tests done (Mansor et al., 2013). Such devices are also advantageous for providing healthcare professionals with important patient data in cases where access is a challenge, such as in remote or under-resourced communities, or even between patient visits or routine follow-up.

PPG waveforms offer tremendous potential for determining key health indicators. For example, there has been considerable work on developing portable PPG-based devices which capture the PPG waveform for estimating heart rate or blood pressure automatically, for example finger oximeters (DMG, 2015). These waveforms have also been used to automatically estimate blood oxygen content (Covidien, 2014). However, further automatic feature extraction required for cardiovascular diagnosis is limited. Either the waveforms are not accessible to the end user, or if they are then the indices are calculated offline by visual inspection of the waveform to manually identify the relevant morphological features (Gonzalez, 2008).

This paper builds on the existing work in PPG-based diagnosis and presents the development of a compact, portable device for automatic feature extraction of relevant cardiovascular metrics for cardiovascular assessment and diagnosis in real-time. The development of this device is aimed at making cardiovascular diagnosis more affordable, and accessible, particularly to those in resource-constrained or remote locations. To the best of the authors' knowledge such functionality has not been realised in current commercial devices, and therefore a gap currently exists. Given the incidence of cardiovascular diseases in the Caribbean and globally, this device has tremendous potential for integration into a personalised health care strategy for the diagnosis and treatment of cardiovascular diseases.

The paper is organised as follows. Section 2 provides a brief introduction to PPG, and describes the technique by which the PPG waveform is retrieved. The indices developed from the PPG waveform, some of which will be derived by the system, are discussed in Section 3. Section 4 presents the technical system which retrieves the PPG waveform continuously and non-invasively; acquires the necessary physiological features; and calculates the values of the indices in real-time. The method by which the system is tested is described in Section 5. An analysis of the results retrieved by the system is discussed in Section 6. Recommendations for future works based on issues discussed in Section 6 are presented in Section 7, followed by concluding statements in Section 8.

2. Photoplethysmography

For the PPG technique, the volume of pulsating blood (i.e., the blood volume pulse – BVP) at a part of the body is estimated by detecting the amount of reflected or transmitted light when a light source illuminates the measurement site. Typically the light source is a light emitting diode (LED) and the detector is a photodiode or phototransistor. For both reflection type and transmission type of the PPG measurement techniques, the principles of light absorption, light transmission and light dispersion determine the sensed PPG waveform. For both techniques a decreased volume of blood in the area in which the sensor is placed results in an increase in the intensity of the received light by the photodetector. Increased blood volumes result in decreased received light intensity.

Since PPG-based techniques are optical in nature, it is expected that performance would depend upon the properties of chosen wavelengths for system operation. It has been observed that the dominant absorption peak corresponding to red blood cells is in the blue region of the spectrum, followed by the green-yellow region (between 500 and 600 nm) (Tamura et al., 2014). Red wavelengths could be used for retrieving the PPG waveform since they sufficiently penetrate various measurement sites (Elgendi, 2012). However, infrared (IR) or near-IR light have longer wavelengths than the red, green and blue (RGB) wavelengths and hence are better for measurement of deep-tissue blood flow (Tamura et al., 2014). Wavelengths shorter than that of the RGB wavelengths are strongly absorbed by melanin. In recent literature green light is becoming increasingly popular, although it is less penetrating than IR, due to its higher signal to noise ratio compared to IR wavelengths (Tamura et al., 2014).

PPG waveforms can be separated into a slowly-varying baseline (referred to as the DC component in the literature) and a pulsatile component (referred to as the

AC component in the literature). The DC component arises from lower frequency biological signals including those due to respiration, thermoregulation and the sympathetic nervous system. The AC component arises due to changes in the blood volume at the measurement site with each heartbeat. Figure 1 illustrates an example of a PPG waveform.

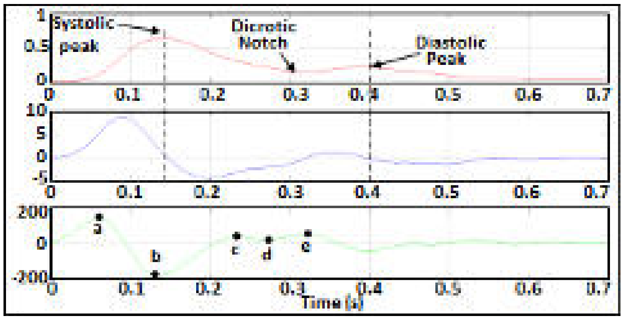

Figure 1. Example PPG waveform (upper figure) with critical points of the second derivative of the PPG waveform (lower figure)

The AC component is superimposed onto the DC component and contains the information needed for cardiovascular diagnosis. The AC component of the PPG waveform has 2 peaks and a "notch" or a point of inflection in the downslope (Laucevičius et al., 2004). The notch, also referred to as the dicrotic notch, corresponds to the closure of the aortic valve at the end of systole which causes momentary increase in blood volume of the arteries (Elgendi, 2012). The systolic peak corresponds to the heart muscle contracting and pushing blood through the arteries, whereas the diastolic peak corresponds to the heart muscle resting between beats and refilling with blood (American Heart Association, 2014).

3. Indices derived from PPG waveform

For cardiovascular diagnosis, the critical points of the PPG waveform are found by determining the second derivative of the photoplethysmogram (SDPTG) with respect to time (Elgendi, 2012). This allows for easier and more accurate interpretation of the inflection points (AHA, 2014). Figure 2 illustrates an example of a PPG waveform and the derived SDPTG. Features used from the first derivative of the PPG waveform (middle sub-figure) are not used in this work. The SDPTG is made up of four systolic waves, which are the 'a' to 'd' waves and one diastolic wave, which is the 'e' wave (Elgendi, 2012). The ratios which have been calculated from the critical points of the SDPTG are:

- the b/a ratio - an indicator of arterial stiffness which increases with age and increasing arterial stiffness (Baek et al., 2012);
- the c/a ratio - an indicator of arterial stiffness which decreases with age (Baek et al., 2012);
- the d/a ratio - an indicator of arterial stiffness and vascular tone which both decrease with age (Chowienczyk et al., 1999; University of Maryland Medical Center, 2014);
- the e/a ratio - an indicator of arterial stiffness which decreases with age (Elgendi, 2012);
- the aging index, expressed as ((b - c - d - e)/a or (b - e)/a) – an indicator of vascular aging and arteriosclerotic disease (Elgendi, 2012).

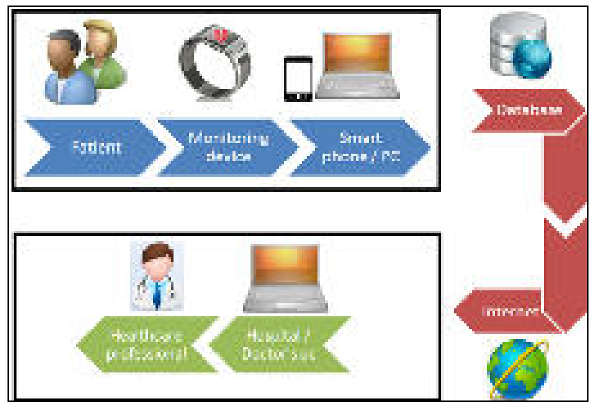

Figure 2. System data flow overview

Although these indices have been the primary focus of the investigation into characterising arterial health, they can be used to investigate other pathologies indicative of CVD, such as the diseases listed in Table 1. However, a full understanding of the diagnostic value of the different features, with respect to the application of the indices to the diseases, is still being researched (Elgendi, 2012).

4. Cardiovascular Monitor Design

The implemented interface allows for data transferred over the internet to be viewed and analysed remotely by a healthcare official, provided the relevant ICT access is available. The implemented measurement system contains a monitoring module, a data collection module, a data analysis module and a user interface. Figure 3 shows the hardware components used in the modules. The monitoring module comprises of the optoelectronic sensor and pre-processing circuitry for amplification and filtration of the received PPG waveform. A microcontroller was used for the data collection module and to communicate to the data analysis module and the user interface. In the data analysis module, the data is further filtered and processed to extract features of the waveform which are analysed. The user interface displays the resultant information, processed in the data analysis module, to the user.

Table 1. Types of Heart Disease (Source: Extracted from WHF (2014)

Type of Heart Disease	Cause	Effect
rheumatic	several attacks of rheumatic fever	damages the heart valves
hypertensive	high blood pressure (BP)	overburdens the heart and blood vessels
ischemic	the narrowing of the coronary arteries	reduces the blood flow to the heart
cerebrovascular	obstructed blood supply to the brain	leads to strokes
inflammatory	toxic or infectious agents	inflammation of the heart muscle

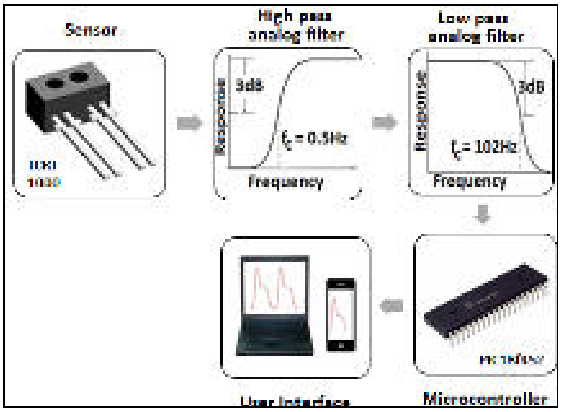

Figure 3. Hardware components utilised for each module

The implemented cardiovascular diagnostic system was intended to be more compact and portable than the PPG diagnostic system developed by Elgendi (2012). And the system discussed in this paper automates the evaluation of the indices discussed in the previous section. The end goal was to enable automatic evaluation of the presence and extent of different heart diseases, as opposed to the typical functionality of current PPG-based devices which primarily focus on blood pressure, heart rate monitoring, and blood oxygen saturation.

The diagnostic system comprises several signal processing stages, as shown in Figure 4. The first stage is the retrieval of the cardiovascular signal using an optoelectronic sensor. The next stage is pre-processing of the PPG signal using analog signal processing to isolate the desired PPG waveforms. The DC component is filtered out of the signal, using a high pass filter with cut-off frequency 0.5Hz, since the AC signal contains the necessary information. Low pass filters are used to aid in identifying key points of the waveform and minimise power line interference without compromising the integrity of the signal. An active analog filter was used to amplify the output of the sensor, and to prevent aliasing during analog-to-digital conversion. Following analog signal processing and analog-to-digital conversion the digitised signal was sent to the microprocessor. The third stage (implemented in the microprocessor) included data transmission and feature extraction.

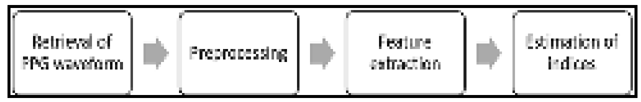

Figure 4. Signal processing stages of implemented cardiovascular diagnostic system

For this study, feature extraction involved the determination of the ‘a’, ‘b’ and ‘e’ waves, since most of the indices can be calculated by using only these waves. To identify these features a period of the PPG waveform is first extracted and then the systolic peak, the diastolic peak and the dicrotic notch of the PPG waveform are identified. The indices that are subsequently calculated are the b/a, e/a, and (b-e)/a, (i.e., the aging index).

4.1 Feature extraction algorithm

To determine the ‘a’, ‘b’ and ‘e’ waves, the systolic peak, the diastolic peak and the dicrotic notch were extracted. To identify the systolic peak, the diastolic peak and the dicrotic notch it was necessary to extract a period of the waveform. Strictly speaking the waveform is quasiperiodic, but for the measurement interval, the captured sequence of waveforms is assumed to be approximately periodic, which is reasonably assumed in practice (Elgendi, 2012). Following this assumption, each period of the PPG waveform has a:

- prominent positive-going zero-crossing corresponding to the start of the waveform; and
- less pronounced positive-going zero-crossing, corresponding to the dicrotic notch.

Smoothing was used to determine the more prominent positive-going zero-crossing points to find the period between zero-crossings. Upon extraction of the period, the systolic peak and the diastolic peak were identified. Figure 5 illustrates the algorithm for this. The first derivative of the period of the PPG waveform was then used to determine the positive-going zero that corresponded to the dicrotic notch of the PPG signal. To reduce the fluctuations in the amplitude of the first derivative, to clearly identify the positive-going zero-crossing points, smoothing was used. These false zero-crossings were as a result of random fluctuations in the amplitude of the first derivative.

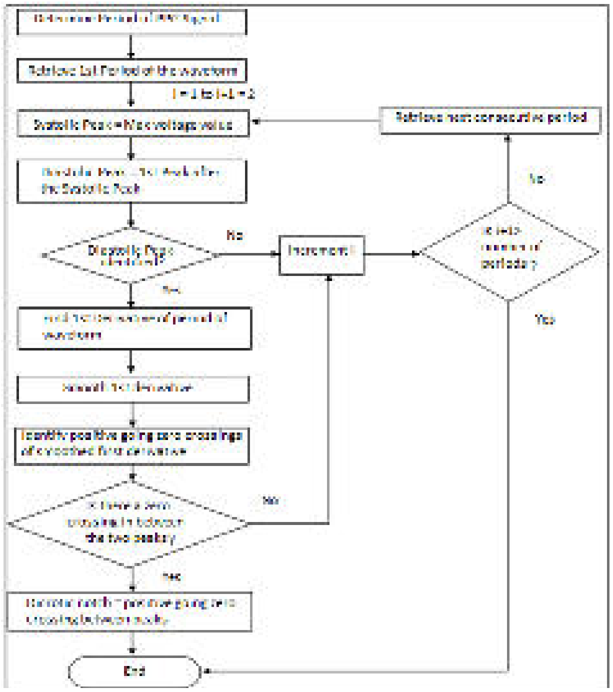

Figure 5. Algorithm to identify systolic peak, diastolic peak and dicrotic notch

If these features could not be identified from the extracted period, which may be as a result of distortion due to motion artefacts, another period from the recorded dataset was used. Once the systolic peak, diastolic peak and dicrotic notch were identified the second derivative was calculated from the unsmoothed first derivative, which was then used in conjunction with the PPG signal to determine the 'a', 'b' and 'e' waves. Figure 6 illustrates the algorithm for this.

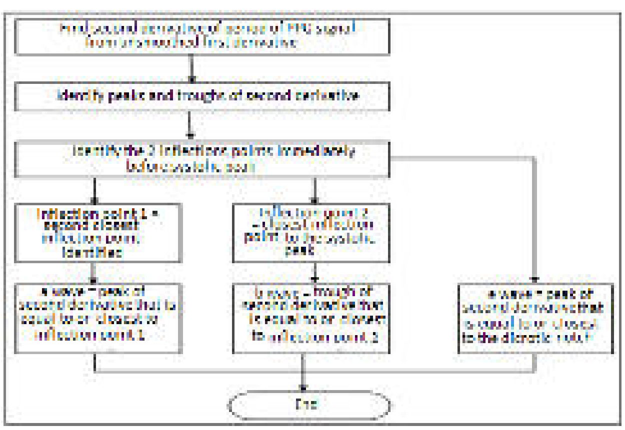

Figure 6. Wave identifying algorithm

5. System Testing

The system's functional requirements were verified in two stages:

- unit testing – testing of each individual module e.g. testing the sensor to ensure a PPG waveform was being retrieved; the microcontroller to ensure that it was accurately retrieving and transmitting the PPG voltages; and the algorithms used for signal processing
- system testing – testing of interconnected modules

For system testing, each test subject was required to remain as motionless as possible, to reduce motion artefact, and the sensor was placed on the measurement site. The PPG waveform was captured, and processed using the automatic feature extraction approach described and displayed using the user interface which was implemented as a MATLAB executable. Figure 7 shows an example screenshot of the implemented user interface for visualisation of the signal points of interest, as well as to display the automatically-extracted indices.

Following system testing, the system was further evaluated using 10 test subjects. Appropriate permissions were obtained prior to collecting data from test subjects. The medical state/history of each test subject was unknown. The heart rate, gender, age and weight and height for each of the 10 test subjects were recorded before testing. The sensor from the monitoring module was placed on each test subject to observe the PPG waveforms being retrieved. To retrieve the best suited waveform, the sensor was positioned on the left wrist. Each subject was required to remain as motionless as possible to reduce disturbances due to motion artefacts of captured waveforms. Captured data was used to extract the features and determine indices demonstrating the required functionality of the system.

6. Results and Analysis

Table 2 is a compilation of the information recorded from the test subjects. In addition to functional testing, the system performance has to be assessed to provide a baseline for future work on enhancements to the system.

Of prime importance at this stage was the error performance of the implemented system. Currently, there are no available gold standard devices which extract the features and indices which can be used for comparison. Therefore visual inspection and waveform annotation by an expert provided a reliable method for comparison to the automatically-extracted features for error analysis. This is the currently accepted approach in the literature (see Elgendi 2012).

Table 2. Summary of characteristics parameters of test subjects

Number of Subjects	10
Male/ Female	5/5
Age range (years)	20-53
Heart rate range (bpm)	70 –111
Weight range (kg)	54.4-90.7
Height range (m)	1.6- 1.8
Body mass index range (kg/ m^2)	19.0 - 27.9

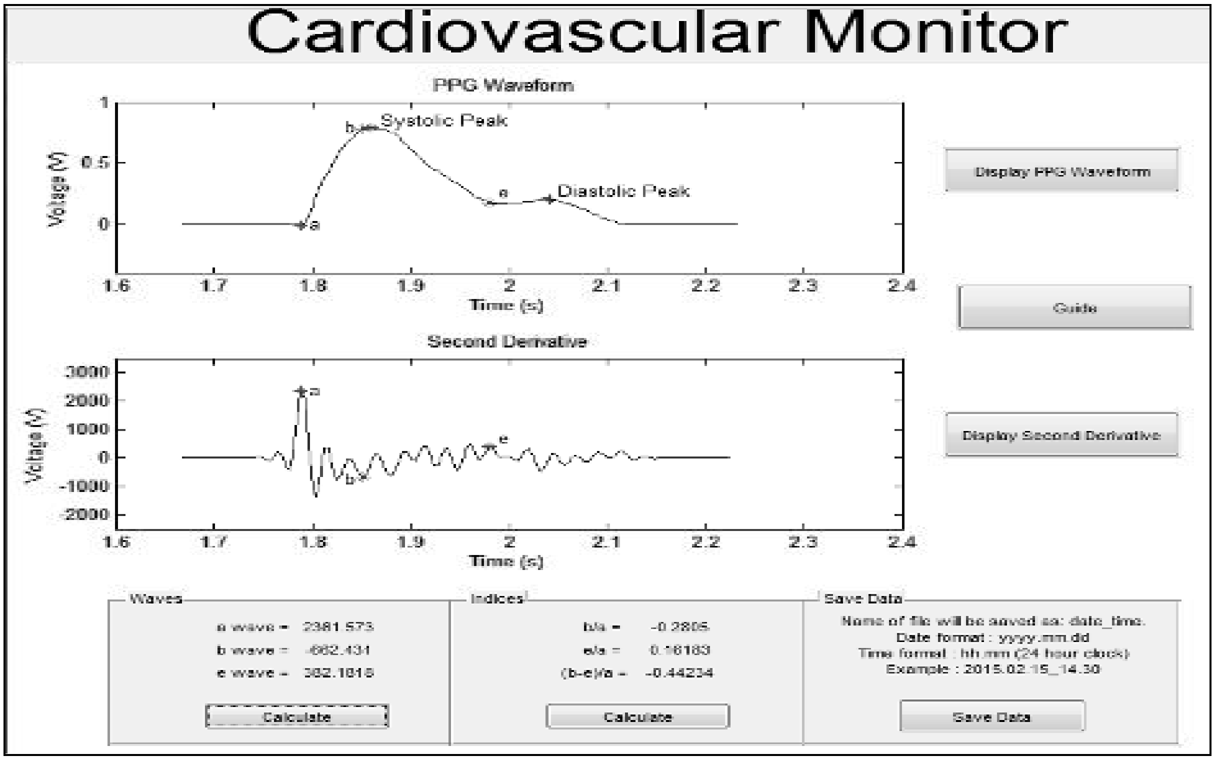

Figure 7. Example screenshot of user interface for cardiovascular monitor

Figures 8, 9 and 10 present the error graphs for each index, comparing the indices derived from automatically-extracted waves to the indices derived from expert visual inspection of the waves for all test subjects. While in general, as seen from the plots, there was a small deviation of the automatically-derived values from the values identified by visual inspection for the ‘a’ and ‘b’ waves for both genders, the ‘e’ wave sometimes deviated significantly.

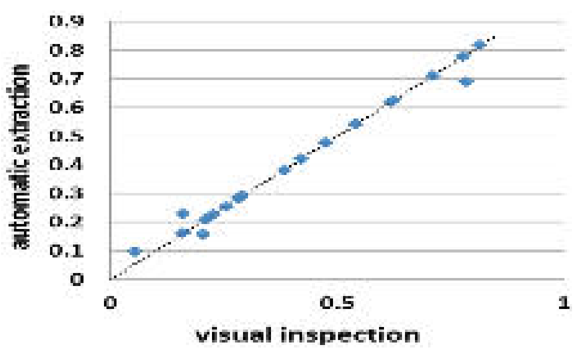

Figure 9. Comparison of automatically extracted e/a index to expertly visually extracted e/a index

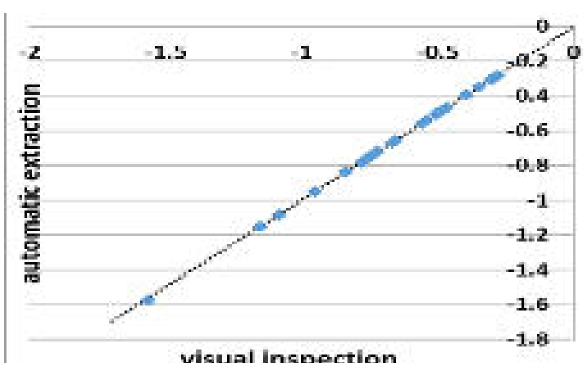

Figure 8. Comparison of automatically extracted b/a index to expertly visually extracted b/a index

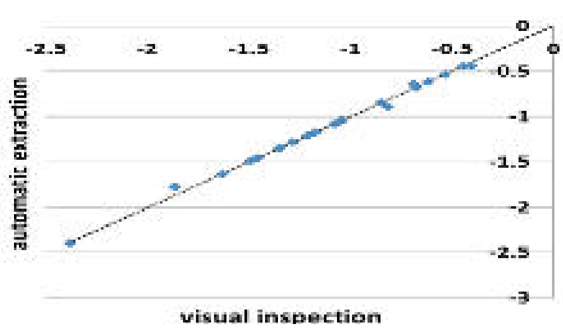

Figure 10. Comparison of automatically extracted (b-e)/a index to expertly visually extracted (b-e)/a index

This heavily impacted the e/a index and the aging index as seen in Table 3 since the mean square errors (MSE) for both were higher than that of the b/a index. However the MSE for all were small which suggests that the implemented algorithms were fairly accurate. Despite measurement precautions, errors in identifying the waves could have been due to motion artefacts.

Table 3. Mean Square Error for each index

Index	MSE
b/a	0.000008
e/a	0.000680
(b-e)/a	0.000698

The system was further validated through comparison of the relationships between the variables BMI, weight, height and age with each index. This was done by measuring the correlation of each index with the listed parameters using the Spearman's Rank Correlation (SRC). The results in Table 4, where correlated to both the automatically-derived indices as well as to the expert-derived values are given. The following is the ranges for the types of correlation that were used to analyse the data (Laerd Statistics, 2016):

- high correlation: 0.5 to 1.0 or - 0.5 to -1.0
- medium correlation: 0.3 to 0.5 or -0.3 to -0.5
- low correlation: 0.1 to 0.3 or -0.1 to -0.3

Further validation involved comparing results to that in related work. The obtained results were similar to those reported in the literature. For instance, it was observed that BMI and age have medium to high correlation with these indices, while weight had a medium correlation and height had a low correlation. The BMI is an index that is calculated using height and weight and is used as a measure of obesity. Since obesity is a risk factor for heart diseases (British Heart Foundation, 2014) then it should be expected that as the BMI increases, the risk of heart disease should generally increase (Pilt et al., 2014).

In a study conducted by Chen et al., (2013) a high BMI (> 25) was associated with CHD especially for individuals below the age of 53. From this small scale study, it was observed that test subjects with higher BMIs (looking at BMI independent of other factors) generally had higher b/a and aging indices (more positive) and a decreased e/a index is associated with heart diseases such as atherosclerosis. According to the Texas Heart Institute (2014) as age increases the risk of developing CHD increases as the heart's walls may thicken and arteries may stiffen and harden. This was borne out by the data as age had a medium to high correlation which the indices.

Although height and weight are both contributing factors to BMI, which had a high correlation to the indices, they have medium to low correlation with the indices. Since weight is a large contributing factor to obesity, the correlation of the indices with weight was expected to be similar to that for BMI. This trend was observed, as seen in Table 4.

Using similar reasoning, since height contributes less to obesity a lower correlation was expected between height and the indices. Table 4 also highlights this. The results are further supported by the main trends observed in the literature (Chowienczyk et al., 1999; Elgendi, 2012; Baek et al., 2012; University of Maryland Medical Center, 2014). Thus, although there were some observable measurement errors (refer to Figures 9-11), the indices followed trends discussed in past literature: the b/a and (b-e)/a indices generally increased with age, i.e. became more positive, since the values for these indices are negative; whereas the e/a index generally decreased with age.

Table 4. Spearman's Rank Correlation for the relationship between the indices and BMI, weight, height, age and each other

Degree of Correlation	Relationship	Spearman's rank correlation coefficient	
		Automatically Extracted Value	Value from Visual Inspection
High	b/a index vs aging index	0.92	0.92
	b/a index vs age	0.88	0.88
	aging index vs age	0.86	0.86
	e/a index vs aging index	-0.83	-0.83
	e/a index vs age	-0.77	-0.77
	aging index vs BMI	0.76	0.76
	b/a index vs BMI	0.71	0.71
	b/a index vs e/a index	-0.70	-0.70
	e/a index vs BMI	-0.62	-0.62
Medium	e/a index vs height	0.41	0.41
	aging index vs weight	0.41	0.41
	b/a index vs weight	0.34	0.34
Low	b/a index vs height	-0.25	-0.25
	aging index vs height	-0.24	-0.24
	e/a index vs weight	-0.21	-0.21

7. Conclusion and future work

An overview of the development of a continuous, non-invasive cardiovascular monitoring device for the real-time extraction of cardiovascular features was presented. The monitoring device automatically identified cardiovascular features which were used to calculate indices that would possibly provide information about the cardiovascular health of an individual. Initial results demonstrate the functionality of this system, and corroborate results presented in the literature. This system may therefore form the basis from which remote monitoring systems can be developed to increase self-monitoring.

The proposed system is in line with increasing research into the use of wireless sensors for monitoring individual medical data continuously, outside of traditional settings (e.g., clinic, doctor's office, hospital). Such technology would equip individual patients with better health monitoring capabilities, while also providing healthcare researchers and service providers with valuable data for enhancing diagnosis, treatment and prevention strategies.

Visual inspection was the reference for the derived values, since there was no commercially available solution that could be used to automatically extract 'a'-'e' waves or annotate PPG-waveforms with the 'a'-'e' waves for measurement and comparison to the implemented system. The accuracy of the system can only be gauged from a "gold standard" device. For further work the system will be enhanced to fill this gap.

Additionally, there are no standard measurement protocols currently available to account for measurement variability due to posture and positioning of test subjects. This is extremely important, given the impact of motion artefacts in PPG-based signal acquisition and processing and considering that PPG-based devices, especially wearable devices, are susceptible to motion artefacts (Lai, 2015; Kim and Yoo, 2006). Thus future work will include the implementation of low-computational cost motion artefact compensation algorithms to further improve the accuracy of the measurements.

Finally, while the general functionality and small-scale performance of the device was investigated, the device needs to be further tested in a wider scope of scenarios, using a wider range of test subjects.

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