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Analysing the Strength Parameters of Concrete Manufactured Using Natural and Recycled Guanapo Aggregates

Abrahams Mwasha [aΨ] and Jason R.F. Lalla [b]

[a] Department of Civil and Environmental Engineering, The University of the West Indies, St Augustine Campus, Trinidad and Tobago, West Indies; E-mail: Abrahams.Mwasha@sta.uwi.edu

[b]The Trinidad and Tobago Housing Development Corporation, #44-46 South Quay, Port of Spain, Trinidad and Tobago, West Indies; E-mail: jrflalla@hotmail.com

[Ψ] *Corresponding Author*

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Abstract: *The purpose of this paper is to investigate the strength parameters of concrete manufactured using natural and recycled Guanapo coarse and fine aggregates and to determine by analysis any correlations between their compressive strength and splitting tensile strength testing as conducted according to ASTM C39 and ASTM C496 respectively. The results of this investigation were intended to highlight the viability of using recycled Guanapo aggregates as a suitable substitute for natural aggregates in order to alleviate the acute shortage and demand for concrete aggregates in Trinidad and Tobago.*

Keywords: *Concrete, Cement, Recycled Aggregates, Strength Parameters*

1. Introduction

Portland Cement Concrete (PCC) remains one of the major construction materials being utilized worldwide. Natural aggregates as the major component for the manufacturing of PCC are known to occupy 55-80% of concrete volume. The consumption of aggregates for the concrete industry has been forecasted to expand by 2.9 percent annually through 2013 to 28.7 billion metric tons (World Construction Aggregates, 2009).

The majority of aggregates used for construction in Trinidad and Tobago are natural aggregates derived from either limestone or Quartzite rock. The availability and destructive process of obtaining these rocks in small islands of the Caribbean has contributed colossal negative environmental consequences. The need for reducing the environmental impact of concrete should be pursued by each one involved in this industry, especially concrete technologists who are currently challenged to lead and develop concrete technology in a way that protects environmental quality whilst projecting concrete as a construction material of choice. Sustainability should be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases caused by the extraction and manufacturing process of concrete components (Mehta 2001).

Given the current decrease in availability of relatively cheap and high quality aggregate and the increase in the demand for such materials for the production of concrete in Trinidad and Tobago, it is certain that new sources of aggregate will have to be identified. This research paper presents the results of such tests which includes compressive strength and splitting tensile strength of concrete and it seeks to give a comparison of both naturally made concrete and recycled Guanapo Quartzite aggregate concrete, as well as comparisons involving recycled aggregate concrete and the original refuse concrete the recycled aggregates were manufactured from.

2. Progress on the Use of Recycled Aggregates

The use of recycled aggregate concrete (RAC) started mainly about 60-65 years ago, when large quantities of concrete debris became available from World War II damaged structures, and suddenly a great need for aggregate rose up when these structures were to be re-constructed or repaired (Kheder and Al-Windawi, 2005). It is expected that the use of recycled/secondary aggregates globally, will increase by 2.4% to 3.1% for the period 2008-2013 as a result of more stringent environmental especially for small islands such as Trinidad and Tobago where the price for the land for the land fill is extremely high and land use regulations are stringent. It is expected that the world demand for construction aggregates is forecasted to expand 2.9% annually though to 2013 to 28.7 billion tonnes (World Construction Aggregate, 2009).

Among the conclusions by Frondistou-Yannas

(1977) was that recycled concrete suggests itself as a useful substitute for aggregate in regions where concrete disposal is a problem or where natural aggregates are not accessible. Properties such as workability, compressive strength and elastic modulus were found to be very similar and even match in some cases to that of conventional concrete. Buck (1977) also showed that it is possible to produce new concrete from crushed concrete coarse aggregate. However, Buck (1977) studied concrete mixes that contained recycled concrete as coarse aggregate as well as mixes that contained recycled concrete both as fine and coarse aggregate. His findings are that recycled concrete can best be used as a substitute for coarse aggregate only.

Utilisation of recycled concrete has been taking place and steadily growing every year. In 2001, 42 million tonnes of construction and demolition waste including concrete was recycled in the United Kingdom (UK). That represents an increase of 382% since the early 1990s whereby the use of primary aggregates for construction has decreased by 28% between the years 1989 to 2002.

In addition, it was proposed by Poon et al. (2004) that the replacement level of recycled course aggregate at air-dried state should not exceed 50% to produce concrete having less workability loss and higher compressive strengths. On the other hand, it was observed from tests carried out by Khatib (2005) that the 91-day compressive strength of concrete having recycled fine aggregate with a replacement level below 50% was similar to that of concrete with only natural aggregates and only 10% reduction was recorded for concrete with a replacement level of 100%.

Tu et al. (2006) tested high performance concrete having recycled aggregates with high water absorption and concluded that recycled aggregates have a minor effect on the initial slump of concrete but an adverse effect on the workability with time. Thus, this research paper investigates the influence of type and percentage of recycled aggregate in three recycled aggregate concrete mixes and these were compared to the natural aggregate concrete control mix. Compressive and splitting tensile tests were measured for both types of concrete and compared against each other. Additionally, the ability to reproduce concrete of compressive strengths comparable to that of the refuse/original concrete (using recycled aggregates produced from the refuse concrete) was also investigated.

On the other hand, Tam and Tam (2006) in a study to alleviate the growing concrete waste problem experienced by the Hong Kong government, investigated the use of recycled aggregate concrete using a two stage mixing process and determined that recycled aggregate (RA) should be restricted to being used in low grade applications.

According to Etxeberria et al. (2007), in a study to determine the investigation recycled aggregate concrete as a structural material, concrete made with up to 25% recycled concrete aggregate is suitable for structural use, provided that all measures related to dosage; compressive strength and durability aspects have been adopted.

Rahal (2007) showed that the compressive strength of concrete using recycled coarse aggregate having water absorption of 3.47% was 90% of that of natural aggregate concrete. Therefore, it is noted that workability and compressive strength development of recycled aggregate concrete are significantly dependent of type, quality and replacement level of recycled aggregates (Yang et al. 2008).

Yang et al. (2008) investigated the influence of type and replacement level of recycled aggregate on concrete properties and they concluded that both compressive strength and splitting tensile strength of recycled aggregate concrete specimens decreased generally with an increase in water absorption. However, compressive strength of concrete containing either higher absorption fine or coarse aggregates was 60% to 80% of that of the control specimen at the early ages of 1 and 3 days and slightly improved with the increase of age.

Despite the economic and environmental benefits of concrete produced with recycled concrete aggregates (RCA) dubbed RCA-concrete and steadily increased usage of the material, the construction industry has not totally embraced it, especially for structural applications, partly due to previous findings that have concluded that RCA-concrete is inherently inferior to conventional concrete made with natural aggregate (Fathifazl, 2007). Others have shown this to be false as studies on the use of recycled aggregates have been ongoing for the past 50 years and in fact, none of the results have shown recycled aggregates to be unsuitable for structural use. Instead, hypothetical problems related to durability aspects resulted in recycled aggregates being employed practically only as base filler for road construction (Etxeberria et al., 2006, 2007). This however is changing as more research is done to investigate the how recycled aggregates can be put to practical use safely, whilst adhering to international quality standards.

3. Availability of Recycled and Natural Aggregates in Trinidad and Tobago

In Trinidad and Tobago, the local quarrying industry comprises of fifty-six (56) active quarries of which thirty-eight (38) produce mainly sand and gravel. The total output of the quarrying sector for 2002 was approximately seven (7) million cubic yards (5.3 million cubic meters) of which 4.5 million cubic yards (3.4 million cubic meters) were sand and gravel (T&T, 2005)

The majority of quarrying operations in Trinidad occur within the Northern Range of mountains, which are an extension of the Andean Mountains in the South America. This area has primeval tropical rainforests, renowned for their diversity of flora and fauna. Typically, the rainforest includes over 2,300 plant species with 700 species of orchids, and provides a habitat for over 430 species of birds, 620 species of butterflies, 100 species of mammals, 70 species of amphibians and freshwater fish, and 70 species of reptiles. Unfortunately, it should be noted that the regions with the greatest biodiversity are also often the same locations, where conservation measures are the most difficult to implement because of the limited natural resources, difficult access, and poor enforcement of laws for controlling poaching and habitat destruction due to illegal mining.

From a geological perspective, the Northern Range region comprises primarily low grade metamorphic rocks of the Caribbean Group belonging to the Maraval formation. Limestones and recrystallised limestones are the most common rocks of the region, inter-laid by thinly bedded phyllitic limestones at some locations together with inter-bedded phyllites which are often calcareous. These are the oldest rocks in the Northern Range.

4. Development on the Use of Recycled Aggregates in Trinidad and Tobago and Abroad

Although there has been significant increases in the use of recycled concrete in T&T, recycled aggregate are still only used in the most basic of forms as road filler in road construction and in low-level applications due to impurities and defect associated with recycled aggregates (Mwasha and Mark, 2008; Mwasha, 2009). Recent renovations and reconstruction of the administration building, chemical engineering department and senior common room at The University of the West Indies (UWI), St Augustine campus is one example of a huge source of recycled aggregates locally. Recently with the creation of the campus recycling committee, greater volumes of construction and demolish wastes will be turned to useful aggregates which would serve to supplement the demand for natural aggregates for construction projects at UWI, St. Augustine in addition to minimising the demolition wastes that are deposited in the Beetham Land Fill. Presently, the Beetham Land Fill is used to deposit 65% of solid waste produced in Trinidad (SWMCOL, 2010).

The UWI St Augustine campus' recycling committee has come up with many ways to minimise solid waste reaching the Beetham landfill whilst at the same time the People's Partnership Government manifesto of 2010 has emphasised the need for sustainable development with environmental preservation and management being the cornerstone of such a drive. This paper aims to present the results of testing the recycled aggregate concrete materials thereby showing that the recycled aggregate materials can be used to manufacture concrete that meets with local and international standards. In order to do this, the recycled aggregate material was tested and compared with conventional concrete products of the same mix design. This information would be vital in ensuring customer confidence in recycled aggregate concrete products and to gain and maintain a stable foothold in the local construction industry.

5. Experiment and Testing

5.1 Materials

5.1.1 Portland cement

The composition of typical cement used in this experiment is given in European Standards ENV 1974 (Johnson and Corcelle, 2010).

5.1.2 Water

Natural (ordinary tap water) pipe borne water was used. Natural pipe borne water in Trinidad is slightly acidic. The content of humic and organic acids was at minimum.

5.1.3 Natural Aggregate

Quartzite aggregates used in this work were extracted from a number of quarry sites in Valencia, Trinidad. Guanapo Quartzite is classified as a non-foliated metamorphic rock. This is probably because these rocks were once exposed to high temperature conditions, but not to high directional pressure conditions. The parent rock for the Guanapo quartzite was probably a quartz-rich sandstone deeply buried and rising temperature fused the grains together forming highly strong aggregates with low porosity. These aggregates are highly weather-resistant making them excellent construction material. The Valencia quartzite tends to have a sugary appearance, and when broken, the fractures cut through the sand grains and not around them as with sandstone (Mwasha, 2009). The specific gravity of these aggregate was 2.65 and the moisture contents of approximately 2.25%. The variations of moisture content in the mixes were adjusted accordingly, taking into account this increase in moisture so as to maintain specified water/cement ratios.

5.1.4 Recycled aggregates

All coarse and fine recycled aggregates used to produce the recycled aggregate concrete were manufactured at The University of the West Indies, Civil Structural Laboratory, using refuse 150mm concrete cylinders tested in compression, obtained from the Geotechnical Laboratory of Trintoplan Consultants Limited. All natural aggregates used to produce natural aggregate concrete were obtained from the laboratory storage depots and the natural aggregates were sourced from the National Quarries Limited's Guanapo quarry.

6. Methodology

6.1. Manufacturing and Testing of Samples

6.1.1 Mix design

The concrete mix used in this study was designed to achieve a 28-day concrete compressive strength of 30MPa as the design strength of the original/refuse concrete was the same.

The mix design was carried out in accordance with the Absolute Volume Method from Section 6.2 ACI 211.1-91 using metric units of measure (ACI, 2009). Table 1 shows the proportions of materials and mix ratios that constitute this study's mix design.

6.1.2 Manufacturing of concrete samples

Two types of concrete were manufactured; firstly natural aggregate concrete (NAC) and secondly, recycled aggregate concrete (RAC). Different proportions of RA and NA were used to manufacture four variations of concrete. For each of the four variations of concrete, two batches of each concrete variety were manufactured. Table 2 shows the four variations of concrete manufactured.

6.1.3 Testing of the samples

Two types of tests were performed on the 150mm concrete cylinders samples produced. These two tests were compressive strength and splitting tensile strength testing and they were carried out according to ASTM C39 and C496 (ASTM, 2009a, b), respectively. Table 3 summarizes the configuration of concrete cylinder testing according to batch and number of samples tested.

Table 1. Mix Design Quantities and Ratios (based on 1m^3 batch)

Concrete Design Strength/MPa	Water Content, kg	Cement Content, kg	Course Agg. Content, kg	Fine Agg. Content, kg	Water/Cement Ratio	Course/ Fine Ratio
30	205	380	930	830	0.54	0.62

Table 2. Concrete Mix, Batch and Sample ID's and Corresponding Aggregate Proportions

Concrete Variety	Concrete Mix	Batch and Sample ID's	Proportions of Aggregate, %				Comments
			Natural Aggregate		Recycled Aggregate		
			Coarse	Fine	Coarse	Fine	
1	Natural Aggregate Mix 1	NA 1-30	100	100	0	0	No RAgg
	Natural Aggregate Mix 1A	NA 1A-30A	100	100	0	0	No RAgg
2	Recycled Aggregate Mix 2	RA_{25}1-30	75	75	25	25	25% RAgg
	Recycled Aggregate Mix 2A	RA_{25}1A-30A	75	75	25	25	25% RAgg
3	Recycled Aggregate Mix 3	RA_{50}1-30	50	50	50	50	50% RAgg
	Recycled Aggregate Mix 3A	RA_{50}1A-30A	50	50	50	50	50% RAgg
4	Recycled Aggregate Mix 4	RA_{100}1-30	0	0	100	100	No NAgg
	Recycled Aggregate Mix 4A	RA_{100}1A-30A	0	0	100	100	No NAgg

Table 3. Concrete Mix, Batch and Sample ID's and Corresponding Number of Samples Tested

Concrete Variety	Concrete Mix	Batch and Sample ID's	Number of Samples Per Test Performed	
			Compressive Strength	Splitting Tensile Strength
			Number of Samples Tested	Number of Samples Tested
1	Natural Aggregate Mix 1	NA 1-30	30	-----
	Natural Aggregate Mix 1A	NA 1A-30A	-----	30
2	Recycled Aggregate Mix 2	RA_{25}1-30	30	-----
	Recycled Aggregate Mix 2A	RA_{25}1A-30A	-----	30
3	Recycled Aggregate Mix 3	RA_{50}1-30	30	-----
	Recycled Aggregate Mix 3A	RA_{50}1A-30A	-----	30
4	Recycled Aggregate Mix 4	RA_{100}1-30	30	-----
	Recycled Aggregate Mix 4A	RA_{100}1A-30A	-----	30

Various tests were performed on both the NA and RA to provide supportive data for the tests performed on the concrete cylinders produced from the concrete batches mixed. Aggregate tests performed include moisture content, specific gravity and absorption and particle size analysis. Table 4 shows the summary of the aggregate tests performed.

6.2 Analyses

Statistical analysis of data obtained from the concrete testing phases of this investigation was carried out using one-way ANOVA method (Wikipedia, 2010). Microsoft Excel 2007 software was used to perform this analysis. Analyses to determine significant differences that were carried out in three sections below:

Table 4. Aggregate Type and Tests Performed

Aggregate Test	Test Performed (Yes / No)				
	Aggregate Type / Gradations				
	Natural		Recycled		
	Coarse	Fine	Coarse		Fine
	<20mm & >5mm	<5mm	>20mm	<20mm & >5mm	<5mm
Moisture Content	Yes	Yes	Yes	Yes	Yes
Specific Gravity	Yes	Yes	Yes	Yes	Yes
Water Absorption	Yes	Yes	Yes	Yes	Yes
Particle Size Distribution (Gradations)	Yes	Yes	Yes (Combined)		Yes

1) Analysis of Splitting Tensile Strength Results (i.e., NAC versus RAC),
2) Analysis of Compressive Strength Results (i.e., NAC versus RAC), and
3) Analysis of Original/Refuse Compressive Strength versus RAC Compressive Strength Results.

7. Results and Analyses

The following sections give the results of testing according to concrete batch. Figure 1 gives a summary of the average splitting tensile strengths obtained from testing of the four concrete mixes/batches. Figure 2 gives a summary of the average compressive strengths obtained from testing of the four concrete mixes/batches.

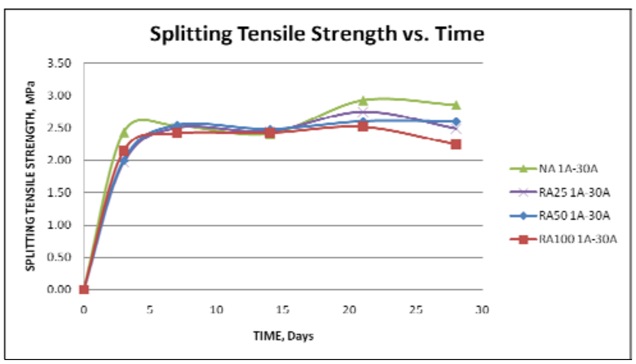

Figure 1. Results of Splitting Tensile Strength Testing For Concrete Mixes/Batches

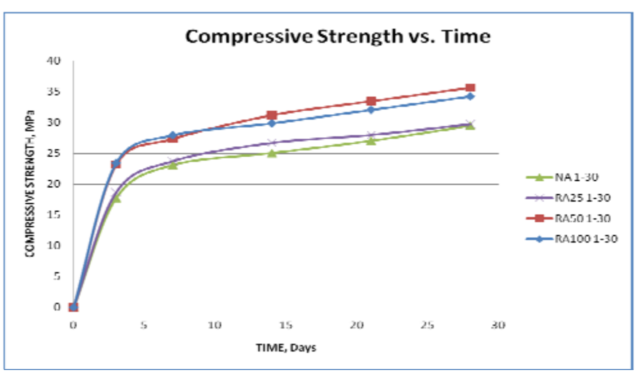

Figure 2. Results of Compressive Strength Testing For Concrete Mixes / Batches

Analysis of results obtained from the splitting tensile testing of concrete cylinder samples was carried out for each of the age breaks (i.e. 3 days, 7 days, 14 days, 21 days and 28 days) to determine significant difference between the NAC and the RAC strengths. A summary of the statistical analyses performed is given in Tables 5 and 6.

Analysis of results obtained from the compressive strength testing of concrete cylinder samples were carried out for each of the age breaks (i.e. 3 days, 7 days, 14 days, 21 days and 28 days) to determine significant differences between the NAC and the RAC strengths. The findings of statistical analyses are given in Tables 7 and 8. It should be noted that there are differences in the concrete batch ID's (i.e. compressive strength batches are labeled 1-30 whereas splitting tensile strength batches are labeled 1A-30A).

The results of the aggregate testing phase of this research have shown that the recycled aggregates exhibit much higher absorptive capacities than that of its natural counterparts. Therefore this signifies that the coarse and fine aggregate can be substituted as a granular fill material in applications that require free draining materials. The recycled aggregates can be utilized for use as fill material to be compacted behind retaining walls, for road sub-base fillers and as foundation fill materials.

From the results of the concrete testing phases of this research have shown that the recycled aggregate concrete mix (of the same mix design as the natural aggregate concrete mix) which contains 25 % recycled aggregate, produces average splitting tensile strengths of 2.50MPa at twenty-eight days and this is comparable (with only a 12% decrease) to the average splitting tensile strength of 2.85MPa produced by the natural aggregate control mix at twenty-eight days. Therefore as reported in other research papers, an increase in the cement content of the recycled aggregate mix should compensate for this slight decrease in split tensile strength observed.

The results of the compressive strength testing performed in this study indicate that the recycled aggregate concrete mixes (which are of the same mix design as the natural aggregate control mix) outperform the natural aggregate mix in terms of average twenty-eight day compressive strengths and rates of hydration.

Table 5. Statistical Analysis Performed for Splitting Tensile Strength Data

Natural Aggregate Concrete Batch / Age Breaks, Days	Splitting Tensile Strength Data Statistical Analysis Performed (Yes/No)															
	Recycled Aggregate Concrete Batch / Age Breaks, Days															
NA 1A-30A		RA_{25} 1A-30A					RA_{50} 1A-30A					RA_{100} 1A-30A				
		3	7	14	21	28	3	7	14	21	28	3	7	14	21	28
	Versus															
3	Versus	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N	N	N	N
7		N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N	N	N
14		N	N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N	N
21		N	N	N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N
28		N	N	N	N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**

Table 6. Results of Statistical Analysis Performed for Splitting Tensile Strength Data

Concrete Mix	Variance of Splitting Tensile Strength					P-Value				
	3 Days	7 Days	14 Days	21 Days	28 Days	3 Days	7 Days	14 Days	21 Days	28 Days
NA 1A-30A	0.062667	0.062667	0.037667	0.065667	0.311	0.054222	0.906123	0.982059	0.297721	0.171469
RA_{25} 1A-30A	0.062667	0.032	0.058667	0.159	0.132					
RA_{50} 1A-30A	0.12	0.231	0.189667	0.248	0.316					
RA_{100} 1A-30A	0.114667	0.133667	0.110667	0.093667	0.043					

Table 7. Statistical Analysis Performed for Compressive Strength Data

Natural Aggregate Concrete Batch / Age Breaks, Days	Compressive Strength Data Statistical Analysis Performed (Yes/No)															
	Recycled Aggregate Concrete Batch / Age Breaks, Days															
NA 1-30		RA_{25} 1-30					RA_{50} 1-30					RA_{100} 1-30				
		3	7	14	21	28	3	7	14	21	28	3	7	14	21	28
	Versus															
3	Versus	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N	N	N	N
7		N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N	N	N
14		N	N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N	N
21		N	N	N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**	N
28		N	N	N	N	**Y**	N	N	N	N	**Y**	N	N	N	N	**Y**

Table 8. Results of Statistical Analysis Performed for Compressive Strength Data

Concrete Mix	Variance of Compressive Strength					P-Value				
	3 Days	7 Days	14 Days	21 Days	28 Days	3 Days	7 Days	14 Days	21 Days	28 Days
NA 1-30	0.51867	1.408	0.579	3.546667	1.710667	1.8E-07	0.001162	2.57E-05	9.01E-06	4.08E-08
RA_{25} 1-30	0.40267	0.046667	0.449667	2.350667	1.134667					
RA_{50} 1-30	0.86267	9.817667	5.459	4.682547	2.52					

The three recycled aggregate mixes contained 25%, 50% and 100% recycled aggregate, respectively. All attained the design strength of 30MPa at twenty-eight days whilst the recycled aggregate mixes that contained 50% and 100% recycled aggregates both achieved the design strength at fourteen days and surpassed the 30MPa mark at twenty-eight days. In addition, from the compressive strength results obtained and the statistical data calculated, it has been shown that it is very possible to reproduce with very little variance, the design strength of the refuse/original using the recycled aggregates produced from the very same refuse/original concrete.

Micro-structural analyses

The scanning electron microscope (SEM) was used to analyze the micro-structural nature of recycled aggregate.

A sample surface was scanned with a high-energy beam of electrons in a raster scan pattern. The electrons interacted with the atoms that make up the sample producing signals that contain information about the sample's surface topography. Magnification in a SEM could be controlled over a range of about 5 orders of magnitude from x25 or less to x250,000 or more (Wikipedia, 2011)

The samples were examined for definitive observation points, i.e. areas on the sample that were of interest. The samples were placed on a testing platform, and then coated with a gold mist for better absorption of the electrons in a vacuum sealed chamber as well as to prevent the accumulation of static electric charge on the specimen during electron irradiation. The sample was placed in the electron microscope chamber and a highly focused electron beam was directed towards the sample under observation. The interaction between the sample and electron beam produced signal that was detected and projected by the display. The bonding between the mortar associated with the recycled aggregate and that of the new mortar mixed with the recycled aggregate.

Using electron beam microscope showed the separation between old mortar and new mortar. Examined was a layer approximately 200μm in depth of a different mortar than that of the rest of the sample. This displayed the approximate bond depth of the two samples. A line of weakness had formed a certain distance away from the bond area, similar to the failure experienced by glued surfaces, adhesion/cohesion failure.

Figure 3 shows a line of failure/fracture, approximately 5 μm in thickness, the failure crack can be seen extending from the natural aggregate (represented by the darker color) through the mortar (represented by the grey color).

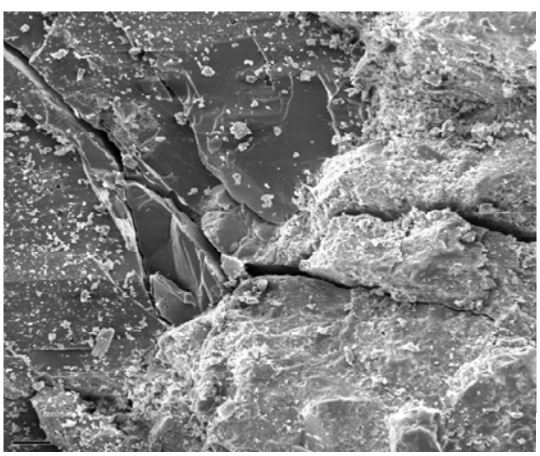

Figure 3. Image of recycled aggregate
(The magnified in the order of 1000X)

This can cause premature failure in a concrete mix containing these recycled aggregates. While not being a general characteristic of recycled aggregate, it does not deny the fact that for a sample amount, certain individual aggregates may be faulty. This creates a somewhat random fault factor.

8. Conclusion

From the results of this research, it has also been concluded that producing recycled aggregate concrete comparable to natural aggregate concrete can be done without much difficulty in terms of splitting tensile and compressive strength properties.

Based on the unique properties of the recycled aggregate concrete, it is possible to use them in specialised applications that require fast hydrating concrete. Such applications may include coastal structures such as jetties, revetments and breakwaters to name a few. Recycled aggregate concrete may be particularly useful in war zones and areas devastated by natural disasters where concrete debris is plentiful and accessing natural aggregates may be expensive and difficult. Such areas exist presently is conflict ridden countries such as Iraq and Afghanistan in addition to Japan, New Zealand, Chile, Haiti and Pakistan where earthquakes have destroyed large portions of concrete infrastructure.

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Authors' Biographical Notes:

Abrahams Mwasha *is presently a lecturer in structural engineering of the Department of Civil and Environmental Engineering at The University of West Indies, St Augustine Campus, Trinidad and Tobago, West Indies. He obtained his PhD in Wolverhampton, England England, Kandydata Nauk (min) equivalent to PhD in Kharkov Academy of Municipal management, Ukraine (KAMM). Previously, Dr. Mwasha was a Resident Engineer at The Ministry of Education Tanzania where he was involved in the Construction of Vocational training centre, Morogoro, Tanzania (World Bank project), Extension of Sokoine University, Morogoro, Tanzania, Extension and maintenance of several educational infrastructures in Tanzania, and in the Construction of Mbeya Technical College. He also served as a Lecturer at Stourbridge College and Wolverhampton University in England. Dr. Mwasha was the first prize winner of the BIZCOM social enterprise award, organised by the MERCIA Institute of Enterprise for the idea of "Novel and Sustainable Technology". His research interests include Problematic soils (expansive, collapsible, soft soils), Ground reinforcement, Vegetable fibres, Slope stability, and Wastes management.*

Jason R.F. Lalla *is a Civil Engineer presently employed with the Trinidad and Tobago Housing Development Corporation (HDC) in the position of Project Manager: Geotechnical. He earned both his B.Sc. Civil Engineering (2007) and M.Sc. Civil with Environmental Engineering (2010) degrees from The University of the West Indies, St. Augustine campus. With approximately five (5) years professional experience Mr. Lalla has gained significant experience in the design and construction of infrastructure related to Civil, Geotechnical and Structural applications. He has also recently become a registered Project Management Professional and is currently engaged in providing geotechnically related project management expertise to the HDC. Apart from his professional work, Mr. Lalla is actively involved in pursuing research opportunities pertaining to sustainable construction technologies as suggested in his undergraduate and postgraduate research on the use of recycled concrete aggregate and sustainable development as a whole.*

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