ISSN 0511-5728
The West Indian Journal of Engineering
Vol.41, No.1, July 2018, pp.4-12

Potential of Green Sand Rice Husk Ash Mould as Carbide Deactivator in Thin Wall Ductile Iron

Ezenwanyi F. Ochulor [a,Ψ] Mohammed O. H. Amuda[b] , Samson O. Adeosun[c] and Sanmbo A. Balogun[d]

[a, b, c] Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria; E-mails: fochulor@yahoo.com; samsonoluropo@yahoo.com; mamuda@unilag.edu.ng

[d] Department of Mechanical and Biomedical Engineering, Bells University of Technology, Ota, Nigeria. Email:sanmbo2003@yahoo.co.uk

[Ψ] *Corresponding Author*

(Received 10 March 2017; Revised 16 July 2017; Accepted 07 November 2017)

Abstract: *Thin wall ductile iron (TWDI) components are prone to massive carbide precipitates and non-nodular graphite in the as-cast microstructure. Precipitated carbide phase is brittle and damaging to mechanical properties of the iron matrix. The non-nodular graphite reduces nodularity ratings, ductility, tensile and fatigue strength. The use of cast 2 mm TWDIs for automotive parts' applications is limited owing to the above short comings. Moulding sand thermal characteristics is vital in defining the solidification kinetics of a cast part, which in turn determines the evolving microstructure and mechanical properties. Modification of the thermal properties of moulding sand mix for the production of sound 2 mm TWDI castings in automotive applications is expected to suppress these microstructural features that limit this profile application. Efficient monitoring of cooling rate of solidifying cast parts will be a useful step towards controlling and tailoring cast TWDIs properties to desired application. This study presents the effects of 1-6 wt.% rice husk ash (RHA) additions to moulding sand on microstructure (Optical and SEM) and mechanical properties of cast 2 mm TWDIs. RHA significantly reduced carbide precipitates in microstructure of cast 2 mm TWDI parts, also castings with nodularity ratings ~ 90%, high nodule count > 1,000 nodules / mm^2 and high strength of 564 MPa were obtained at 4 wt. % RHA addition. High ductility of 4.7 occurred at 6 wt. % RHA addition.*

Keywords: *Cooling rate, mould sand mix, microstructure, nodularity, mechanical properties, thermal properties*

1. Introduction

The mechanical properties of ductile iron (DI) depend primarily on developed microstructures during solidification (Sheikh, 2008). In most foundries, certain methods or techniques to modify the thermal properties of mould and cores are utilized. Iron or steel chills can be placed in moulds to increase heat extraction and local solidification rates. Special sands like zircon, chromite or carbon can be used singly or mixed with silica sand to change moulding sand thermal and physical characteristics (Showmann and Aufderheide, 2003). The cooling rate is largely dependent on the cast size, as the section thickness affects solidification and cooling rates through the austenite transformation range (Gorny and Tyrala, 2013). Solidification and cooling rates influence nodule count, carbides precipitation and the amount of ferrite and pearlite formed. Variation in cooling rates and solidification times can produce significant changes in the evolving structure and properties. For instance, die casting, which uses metal moulds, has faster cooling rate and produces higher-strength casts than those from sand mould with more insulating constituents (Abed, 2011).

The manufacturing of thin-wall sand casts presents unique problems traced to phenomenon arising from its high surface area to volume ratio. This results in very high solidification rates and can lead to mis-runs or other defects, undesirable microstructures and poor mechanical properties. Showmann and Aufderheide, (2003) reported the reduction of thermal conductivity in moulding sand using low density alumina silicate ceramic (LDASC) as an additive in thin wall sand casting technology. This concept was adopted by Labrecque et al. (2005) to reduce heat extraction capacity of the moulding material, thereby reducing the undercooling level and the cooling rate of the TWDI castings under investigation. In the study by Gorny and Tyrala (2013) on the effects of cooling rate on microstructure and mechanical properties of TWDI, varying proportions of LDASC were blended with silica sand to stimulate different cooling rates for casting TWDI samples. Their study established that by blending silica sand with varying proportions of LDASC, similar cooling rate, number of graphite nodules, ferrite fraction and mechanical properties as 13 mm thick reference casting in silica sand mould is achievable in TWDIs. To date, most methods used to produce thin wall castings focus on metal chemistry, inoculation and gating practice. Few practical methods have been available to reduce cooling and solidification rates in convectional sand moulds. This could be achieved 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 (Showmann and Aufderheide, 2003).

Modification of the thermal properties of the moulding sand mix is considered vital in ensuring sound 2 mm TWDI castings. Ochulor et al. (2017) investigated the effects of using rice husk ash (RHA) as an additive in silica sand on its moulding and thermal properties. The researchers observed a progressive reduction in thermal conductivity with increased weight percent of RHA additive, 30% reduction in thermal conductivity occurred at 6 wt. % RHA. During casting, heat transfer occurs between the hot liquid metal and the mould (i.e. the heat transfer medium) and the temperature decreases from that of the cast to the surrounding. The process involves three (3) successive stages namely; initial cooling of the melt, the solidification of the liquid metal and the cooling of the solid metal (Abed, 2011). The thermal properties of the sand mould have an influence on the solidification process and behaviour of the liquid metal in it. 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 cast (Rihan, 2010).

The time involved in this transition may be as short as seconds or as long as hours depending upon the casting process, the size of the cast, the chemical composition of the metal being cast, the manner of solidification and the subsequent solid state treatment, which determines the ultimate microstructure and properties (mechanical and physical) of the cast (Schmidt, 2010). In the study of Ochulor et al. (2016), aluminium dross was incorporated into silica moulding sand mix, a reduction in thermal conductivity and diffusivity of the sand mix was observed. Cast TWDI samples using this mix showed undesirable graphite characteristics, decline in hardness and tensile strength. However, samples showed good percent elongation values.

The heat exchange in the metal-mould system is essential to the kinetics of cooling and solidification of a cast, especially in TWDI castings, which start to solidify during mould filling and determines the cooling rate (Gorny, 2009). The goal here is to control the solidification event, so that the desired microstructure (nodularity and nodule count, matrix type) for enhanced mechanical properties in the final product is obtained. The ultimate physical and mechanical properties of the cast metal depend on one hand on intrinsic factors such as chemical composition, cooling rate, heat and mechanical treatments after solidification. On the other hand, it depends on extrinsic factors namely; metal cleanliness, additives for microstructure control, cast design, riser and gating design, solidification rate control, and temperature control subsequent to solidification, which are present in each casting event and in the processing events subsequent to casting (Kalpakjian, 2008; Cantor, 2003). In the study of Ruxanda et al. (2002) on microstructural characterisation of TWDI castings, it is observed that high solidification / cooling rates, presence of carbide forming elements in the charge materials, low carbon equivalent and/or silicon content and poor inoculation are some parameters responsible for carbide formation.

The main constituents of the matrix of TDWI castings are ferrite, pearlite and carbides. Their actual ratio is highly dependent on the processing parameters that include cooling rate, liquid treatment, chemical composition, and pouring temperature. The mould thermo-physical property 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 early and stop flowing. Moulds with high heat diffusivity transfer heat faster from the molten metal and this causes it to freeze earlier than desired.

In this study, rice husk ash (RHA) - silica sand mix mould is used to cast 2 mm TWDIs to improve nodularity ratings, nodule count and strength and reduce carbide precipitation. RHA is used as a moulding sand additive to reduce its thermal conductivity and investigate impact on cast 2mm TWDI microstructure and mechanical properties. Hitherto, RHA has been used as a moulding sand additive to achieve moulding properties such as improved dry strength or decrease in moisture content requirement (Aribo, 2011; Aigbodion et al., 2008).

2. Materials and Methods

2.1 Materials Preparation

Fifty (50) kg of rice husk, a by-product of rice production in rice mills is obtained from Ifo in Ogun State, Nigeria. Combustion of this agro-waste was carried out in a Gemco CFR 90337 electric furnace at 700^0C in a controlled atmosphere for 10 hours at Federal Institute of Industrial Research Oshodi, Lagos. After combustion and cooling, sieve analysis is conducted and only RHA particles between 250-300 µm were used for the moulding sand preparation. This was done to ensure the use of similar particle size to that of silica moulding sand, as good surface finish is required in TWDI casts. A control composition of the green moulding sand is used to cast the 2 mm plates for comparism with that of the sand-RHA mixes. The sand constituents are mixed for 5 minutes using a Rhino model IRM-500 sand mixer located at Nigerian Foundries Ilupeju Lagos. Using this standard composition of moulding sand, six different compositions of the moulds are prepared by adding varying weight percentages of RHA to the moulding sand. Chemical analysis of RHA used and the control composition of green moulding sand are shown in Tables 1 and 2, respectively. Table 3 shows six different mould compositions as prepared by adding varying weight percentages of RHA to control moulding sand.

The choice of weight percentages of RHA used is based on a preliminary trial test conducted on 600 g of moulding sand. The test determined the upper limit (6 wt. %) of RHA to be used as higher weight percent of decline in the moulding sand properties. Moulding sand property test is conducted on moulding sand-RHA mixes to ensure that these properties are adequate and conform to established standard foundry practice.

Table 1. Chemical Composition of Rice husk ash

Const.	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO
Wt. % in RHA	93.15	0.21	0	0.21	0.41

Const.	MgO	K_2O	Na_2O	LOI
Wt. % in RHA	0.45	3.21	0	2.36

Table 2. Control Composition of the green moulding sand

S/No	Materials	Wt. Comp (%)
1	Silica Sand	96.4
2	Bentonite	2.2
3	Starch	0.8
4	Water	0.4
5	Coal Dust	0.2

Table 3. Sand Specimen with wt. % of RHA

S/No	1	2	3	4	5	6	7
Specimen	RH	RH1	RH2	RH3	RH4	RH5	RH6
Wt% of RHA	0	1	2	3	4	5	6

2.2 Thermal Property Test

The thermal conductivity and thermal diffusivity properties of the sand mixes were determined using the KD 2 Pro Thermal Conductivity Meter (see Figure 1a), during moulding after the pattern is removed, i.e. before coupling. The read temperature is 28.83^0C, the TR-1 (see Figure 1b) and SH-1 (see Figure 1c) sensors are used to measure thermal conductivity and thermal diffusivity, respectively.

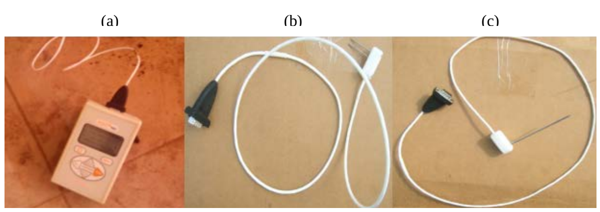

Figure 1. (a) KD 2 Pro Thermal Conductivity Meter, (b) TR-1 sensor (c) SH-1 sensor

The samples are cast using standard casting procedure after melting charge materials. Charge material composition is shown in Table 4.

2.3 Microstructural analysis

Samples for microstructural characterisation were cut, grounded and polished according to the standard procedure outlined in ASTM Standard E3 for metallographic analysis. The prepared samples were viewed in their unetched and etched (using 2% nital solution) conditions using both a CETI Optical Metallurgical Microscope Model No. 0703552 at magnification of X100 located at the Metallurgical laboratory at the University of Lagos, Akoka, Lagos and a Scanning Electron Microscope at magnification of X2000 located at the Mechanical Engineering Laboratory of the Covenant University, Otta Ogun State. Microstructural analysis (nodularity as in Equation 1, nodule count and matrix type) was carried out using manual procedure as outlined in ASTM A247 and E407 standard procedures. The latter technique (SEM) was used to enable a detailed observation of the matrix microstructure resulting from subsequent eutectoid reaction.

$$\text{Nodularity } \% = \frac{\text{area (number) of acceptable particles}}{\text{area (number) of all particles}} \text{ X } 100 \quad (1)$$

Nodule Count (graphite nodules / mm^2) is the quantity of nodules per square millimeter on a polished surface examined at X 100 magnification.

2.4 Hardness Test

Brinell hardness test is carried out using a 10/3000 kg indenter ball on tester model Foundrax/B.H.D/1003402 at the Nigerian Foundries Limited Ilupeju, Lagos in accordance with ASTM E10 standard.

2.5 Tensile Test

Tensile property test was carried out in accordance with ASTM E8 standard using a Universal Instron 3369 Tensometer, system identification number: 3369K1781, located at the Energy Centre of Obafemi Awolowo University, Ile-Ife, Osun State. Regression analysis of plots is done to correlate if significance relationships exist among the variables under investigation, equations and regression coefficients were also predicted.

3. Results and Discussions

3.1 Effect of RHA addition on Moulding Sand Thermal Characteristics

Spectrometric analysis of TWDI samples is shown in Table 5. Figures 2 and 3 show variation of thermal conductivity and thermal diffusivity of the sand mixes with wt. % RHA additive. These thermal properties reduced with increases in wt. % of RHA and this indicated that some level of thermal insulation of the sand mix was achieved. The thermal conductivity of control sample without RHA addition is 1.631 W/m.K and that with 6 wt. % RHA is 1.141 W/m.K. Using RHA

Table 4. 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	0.0	70	0.0
Graphite	23	4.6	70	0.0	0.0

as moulding additive declined the thermal conductivity by 30% (Ochulor et al., 2017). Showmann and Aufderheide (2003) had obtained similar results when low density alumino-silicate sand (LDASC) was used as sand additive/replacement in thin wall casting study.

Regression analysis shows that the relationship follows a downward exponential trend as in Equation 2.

$$Thermal\ Conductivity = 1.6866e^{-0.0626(Wt.\%\ RHA)}$$
$$R^2 = 0.9971 \quad (2)$$

From the Regression analysis, the mould thermal diffusivity varied with wt. % RHA in a decline exponential manner as in Equation 3. Thermal diffusivity reduced by 42% ie0.954 mm^2/s and 0.549 mm^2/s for 0 and 6 wt. % RHA, respectively (Ochulor et al., 2017). These sand properties allow molten metal additional time to maintain its fluidity, hence solidification of melt is delayed in the mould, through reduction in cooling /heat transfer rate. This is expected to hinder metastable transformation that could favour carbide precipitation and other defects, which may occur during high cooling rates, rapid undercooling and high solidification rates.

$$Thermal\ Diffusivity = 0.7757e^{-0.0585(Wt.\%\ RHA)}$$
$$R^2 = 0.9464 \quad (3)$$

Table 5. Spectrometric analysis of TWDI samples

Element	C	Si	Mn	S
Comp. (Wt. %)	3.550	2.390	0.230	0.008
Element	P	Mg	Fe	CE
Comp. (Wt. %)	0.017	0.048	93.757	4.350

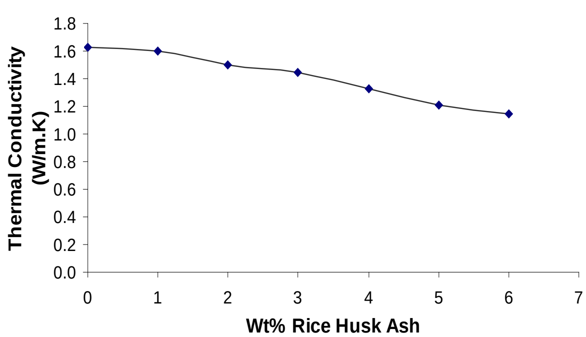

Figure 2. Thermal Conductivity of RHA-sand moulding mix
Source: Ochulor et al. (2017)

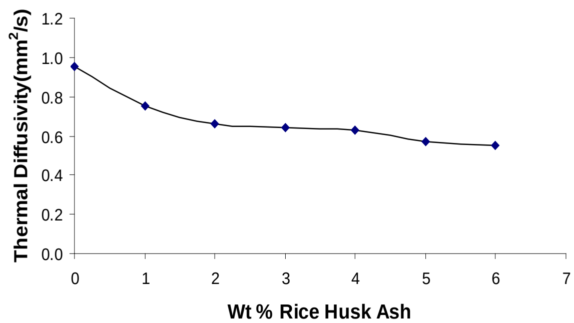

Figure 3. Thermal Diffusivity of RHA-sand moulding mix
Source: Ochulor et al. (2017)

3.2 Effect on Microstructure of Sand – RHA TWDI Cast Samples

Microstructural analysis was carried out using the Optical Microscope and Scanning Electron Microscope (SEM). Microstructure of TWDI cast samples is greatly enhanced through RHA addition to silica moulding sand (Plates 1-7). Excellent nodule characteristics namely; shape, size and number were observed with 4 wt. % RHA. These resulted in good nodularity rating and high nodule counts (Plates 5 –7). The nodule count continues to increase as the wt. % of added RHA increases and this enhances better TWDI properties.

Nodularity rating reached ninety percent (90%) for RH4, RH5 and RH6 samples while the nodule counts for RH5 and RH6 samples were high exceeding 1,000nodules/mm^2. Table 5 shows nodularity and nodule counts for 2 mm TWDI samples.

Table 5. Nodularity and nodule count results for RHA samples

No	Sample	Nodularity (%)	Nodule Count (nodules/mm^2)
1	RH-2	84	341
2	RH1-2	86	678
3	RH2-2	87	547
4	RH3-2	89	721
5	RH4-2	97	1376
6	RH5-2	97	1693
7	RH6-2	98	1974

These occurrences promote structure homogeneity as observed by Labrecque et al., (2005). The matrix consists of varying proportions of carbide, ferrite and pearlite for RH (control), RH1, RH2 samples while carbide free structure and mostly ferrite and pearlite of the bull-eye structure-type dominated the remaining cast samples using higher weight percent of RHA. Pearlite structure is the highest in RH4 samples, but reduces in RH5 and RH6 samples due to increased carbon diffusion giving way to larger ferrite matrix proportion.

3.3 Nodularity, Nodule Count and Matrix type

Nodularity and nodule count is established during solidification and can only be modified by remelting. RHA additions to moulding sand result in thermal conductivity reduction owing to reduction in cooling rate and this enhances the nodule count and nodularity ratings. This occurrence is comparable with that obtained in the study by Showmann and Aufderheide, (2003) when low density alumino-silicate sand (LDASC) was used as sand additive/replacement. Nodularity ratings of ≥ 80% was observed for all samples cast using sand-RHA mix with peak value of 98% at 6 wt. % RHA addition. Nodule count also followed the same trend reaching its maximum of 1974 nodules/mm^2 at 6 wt % RHA addition.

The final microstructures consist of graphite nodules formed during eutectic solidification with the matrix phases of ferrite, pearlite or carbides formed from subsequent eutectoid decomposition. These transformations depend on rate of carbon diffusion.

Annex-1 contains Plates 1-7 that are the optical and SEM micrographs of 2 mm TWDI samples. The control sample produced from sand mould without RHA addition showed the presence of carbide precipitates as evident in Plate 1c. This carbide precipitates obtained from metastable transformation lowers ductility and tensile strength. During solidification of RH-2 sample in the sand mould of thermal conductivity of 1.631 W/m.K, there was rapid heat transfer from the melt, which inhibited the formation of significant number of graphite nodules before melt solidification. Matrix in RH-2 sample consists of ferrite, pearlite and carbides as in Plates 1a, 1b and 1c with nodule size of ~10µm.

Sand mould with 1 wt. % RHA addition has lower thermal conductivity (1.601 W/m.K) slightly less than 1.631 W/m.K which is that of the control sand mould ie 0 wt. % RHA (Ochulor et al., 2017). Thus, there was no significant change in microstructure as evident in Plates 2a, 2b and 2c, which do not differ much from those of Plates 1a, 1b and 1c. This trend is also observed in Plates 3a, 3b, 3c, 4a, 4b and 4c, though to a much lower degree in terms of volume of carbide precipitated as the thermal conductivity decline with increase in wt. % RHA. Matrix of the cast consists of ferrite, pearlite and carbides.

Plates 5a, 5b and 5c show improved nodularity and nodule counts with carbide free matrix containing large pearlite volume. Nodule size ranges from 5-10 µm, however for Plates 6a, 6b, 6c. 7a, 7b and 7c, large volume of ferrite phase was observed due to decreased carbon content in melt available for eutectoid reaction as most of this carbon formed nuclei for graphite nucleation during eutectic solidification, nodule size also ranges between 5-10 µm.

3.4 Hardness Analysis of Sand – RHA TWDI Cast Samples

The variation of hardness of TWDI cast produced from moulding sand-RHA mix is shown in Figure 4. The hardness values displayed a linear relationship with wt. % RHA, which decreases as wt. % RHA increases in the sand mix. Regression plots conform to this relationship as given in Equation 4. This pattern agrees with Gorny and Tyrala (2013) position, that cooling rate affects the maximum degree of undercooling at the beginning of graphite eutectic solidification and consequently, the structure of the iron in terms of the number of graphite nodules and metal matrix.

The BHN values for the samples that showed carbide free matrix namely; RH4, RH5 and RH6 are attributed to the large volume fraction of pearlite phase in the matrix for RH4 (Labrecque et al., 2005; Sangame and Shinde, 2013), which dropped at 5 and 6 wt. % RHA where increased ferrite volume was observed. The increased ferrite volume occurred as a result of more graphite segregation with cooling rate decline, leading to higher nodule counts (>1,000 nodules/mm^2). The control sample - RH corresponds to the highest BHN (207), which is attributed to the large volume of carbide precipitates as in Plate 1 followed by 195 as in Plate 2 for RH1 samples.

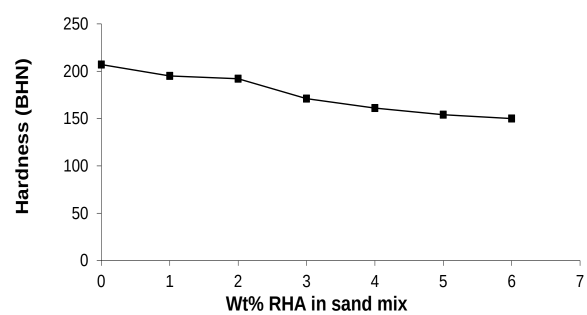

Figure 4. Variation of BHN of TWDI samples with Weight % RHA

Regression analysis shows that the relationship of wt. % RHA in sand mould on BHN follows a linear relationship governed by Equations 4.

$$BHN\ (_{2mm}) = -10.143(RHA_{\ Wt.\ \%}) + 206.14$$
$$R^2 = 0.9642 \qquad (4)$$

3.5 Tensile Test of Sand – RHA TWDI Cast Samples

The UTS of the TWDI sample improves as RHA addition (Figure 5). The control samples cast in silica sand moulds gave UTS of 248 MPa, which corresponds to lowest tensile strength in the plot. The highest UTS values of 564 MPa is observed for sample cast in 4 wt. % RHA silica sand mould at which the matrix is free from carbide precipitates. This is attributed to large volume fraction of pearlite phase in matrix as in Plates 5-7 (Labrecque et al., 2005; Sangame and Shinde, 2013). The percent elongation at fracture is highest for samples cast with 4-6 wt. % RHA in moulding sand. The highest value of 4.7 is observed for the samples at 6 wt. % RHA as in Figure 6. This is attributed to the increased ferrite volume, as cooling rate reduced in mould blend with 4-6 wt. % RHA. This finding agrees with that of Sangame and Shinde (2013) where pearlitic content of as-cast DI influences its nodule count. Increasing the nodule count decreases both the pearlite content and tensile strength while improving percent elongation.

The Regression analysis for the data shows a quadratic relationship of wt. % RHA in sand mould and UTS as in Equation 5.

$$UTS\ (_{2mm}) = -3.9155(RHA\ _{Wt.\%})^2+53.432(RHA\ _{Wt.\%})+229.22$$
$$R^2 = 0.8601 \qquad (5)$$

As for the elongation, regression analysis shows linear relationship of wt. % RHA in sand mould with percent elongation as in Equations 6.

$$\%\ _{Elong.}\ (_{2mm}) = 0.4107(RHA\ _{Wt.\ \%}) + 2.025$$
$$R^2 = 0.9684 \qquad (6)$$

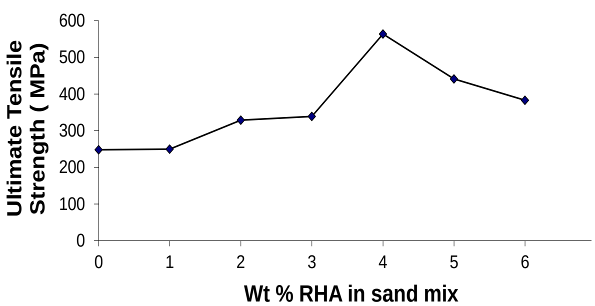

Figure 5. Variation of UTS of TWDI samples with Weight % RHA

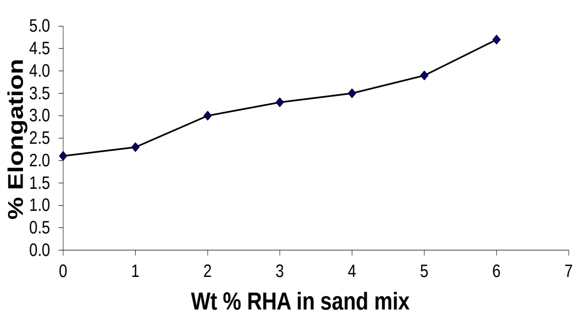

Figure 6. Variation of Percent elongation of TWDI samples with Weight % RHA

Samples cast using sand-RHA mix showed improved microstructures and mechanical properties over the control samples (0 wt.% RHA). This is mainly attributed to ability of mix to lower thermal conductivity (see Figure 4) as the quantity of RHA increased. The controlled heat transfer with reduction in undercooling during the eutectic solidification process favoured formation of stable transformation products namely; graphite structures instead of metastable product of carbide precipitates.

The matrix microstructure in DI is the result of austenite decomposition, which is further influenced by chemical composition and cooling rate, as-cast microstructure is known to be directly influenced by alloy content and cooling rate (Sangame and Shinde, 2013). The cooling rate is affected by the section thickness and rate of heat removal. This in turn depends on mould geometry, mould material, treatment and pouring temperature. Thus, the mechanical properties of TWDI are influenced by graphite shape characteristics and matrix type.

Tensile strength and BHN values showed similar trend for all samples cast using the different sand mixes with improvement in these properties observed up to 4 wt. % RHA in sand mould before dropping slightly at 5 and 6 wt. % RHA mould additive. These values are due to increased graphite segregation. Increased graphite segregation results from increased solidification time, which favours more active nuclei for graphite nodule formation vis-a-vis the case of reduction of solidification time for moulds with higher thermal conductivity and diffusivity. This leads to increased nodule count, better structure homogeneity (Labrecque et al., 2005), increased volume of ferrite phase and percent elongation (better ductility) but at expense of a decline in UTS and BHN at 5 and 6 wt. % RHA samples. At 6 wt. % RHA addition, the mechanical properties meet ASTM property standard specification (Spec. No. A536-80 (80-50-06)) for automotive application.

3.6 Conclusion

This study has shown that the addition of RHA to silica moulding sand led to the achievement of desired microstructure in cast 2 mm TWDIs. . As the weight percent of RHA increased in the sand mould, sufficient time is allowed for formation of potent nuclei for graphite nodule formation, thereby impeding carbide precipitation. Besides, it is possible to obtain carbide free, good nodules and nodule counts in TWDI castings through modification of the thermal properties of moulding sand. This is targeted at reduction in cooling rate with increased solidification time.

The results show that samples cast in 4, 5 and 6 wt. % RHA - moulding sand mix, show good nodularity ratings > 90%, high nodule counts >1,000 nodules/mm^2 with high tensile strengths of 564 MPa and ductility of

4.7 for 2 mm thick samples from 4 and 6 wt. % RHA additions, respectively.

This study is targeted at improving the mechanical properties of Thin Wall Ductile iron (TWDI) used for automotive part manufacture by control cooling to avoid excessive carbide precipitation with improved nodularity and nodule count. This has been achieved using the sand-RHA mix which shows lower thermal conductivity than the silica moulding sand.

Acknowledgements:

The authors gratefully thank the Management and Staff of Nigerian Foundries Ltd, Lagos and those of the Foundry shop of Federal Institute of Industrial Research (FIIRO), Oshodi, Lagos, Nigeria for their assistance in the use of their facilities. The contributions of Staff of Metallurgical Laboratory of the Department of Metallurgical and Materials Engineering, University of Lagos are also recognised.

References:

Abed, E.J. (2011), "The influence of different casting method on solidification time and mechanical properties of Al-Sn castings", *International Journal of Engineering and Technology* (IJET-IJENS), Vol.11, No.6, pp.26-33

Aigbodion, V.S., Hassan, S.B., Olajide, S.O., Agunsoye, O.J., Abdulrahaman, A.S. and Okafor, G.E. (2009), "The use of rice husk ash as an aggregate for foundry sand mould production", *Journal of Metallurgy and Materials Engineering*. Vol 4, No. 2, pp 11-17

Aribo, S. (2011), "Effect of varying corn cob and rice husk ash on properties of moulding sand", *Journal of Minerals and Materials Characterisation and Engineering*, Vol.10, No.15, pp.1449-1455.

Cantor, B. (2003), *Solidification and Casting*, Series in Materials Science and Engineering, CRC Press. United Kingdom

Gorny, M. (2009), "Temperature drop in liquid iron in thin wall channels during mould filling", *Archives of Foundry Engineering*, Vol.9, No.1, pp.137-142

Gorny, M. and Tyrala, E. (2013), "Effect of cooling rate on microstructure and mechanical properties of thin wall ductile iron castings", *Journal of Materials Engineering and Performance*, Vol.22, No.1, pp.300-305

Ochulor E. F, Amuda M.O. H, Adeosun S. O, Balogun S. A (2017) "Effect of aluminum dross and rice husk ash on thermal and moulding properties of silica sand", *Nigerian Journal of Technology*, Vol.36, No.3, pp 794-800

Kalpakjian, S. (2008), *Manufacturing Processes for Engineering Materials*, Fifth Edition, Pearson, USA

Labrecque, C., Gagné, M. and Javaid, A. (2005), "Optimising the mechanical properties of thin-wall ductile iron castings", *AFS Transactions* (Schaumburg, IL USA), Vol.05-116, No.5, pp.1-10

Ochulor, E.F., Amuda, M.O.H., Adeosun, S.O. and Balogun, S.A. (2016), "Mechanical properties of thin wall ductile iron cast in moulding sand aluminium dross mix", *The West Indian Journal of Engineering*, Vol.39, No.1, pp.17-24

Rihan, Y. (2010), "Numerical study on the effect of solidification parameters during the continuous casting of Al-Si alloys", *The Online Journal on Mathematics and Statistics* (OJMS), Vol.1, No.1, www.infomesr.org.

Ruxanda, R.E., Stefanescu, D.M. and Piwonka, T.S. (2002), "Microstructure characterisation of ductile thin wall iron castings", *AFS Transactions*, Vol. 110, pp.1131-1147.

Sangame, B.B. and Shinde V.D. (2013), "The effect of inoculation on microstructure and mechanical properties of ductile iron", *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE), Vol.5, No.6, pp.17-23.

Schmidt, D. (2010), Solid Cast, Effective Casting Simulation, Solidification Time. Finite Solutions Incorporated. Version 8.0.93.

Sheikh, M.A. (2008), "Production of carbide-free thin ductile iron castings", *Journal of University of Science and Technology Beijing*, Vol.15, pp.552-555

Showman, R. and Afderheide, R. (2003), "A process for thin wall castings", *AFS Transactions*, Vol.111, pp.567-578

Stefanescu, D.M., Dix, L.P., Ruxanda, R.E., Corbitt-Coburn, C. and Piwonka, T.S. (2002), "Tensile properties of thin wall ductile iron", *AFS Transactions*, Vol.110, pp.1149-1162.

Annex-1:

Optical and SEM micrographs of 2 mm TWDI samples

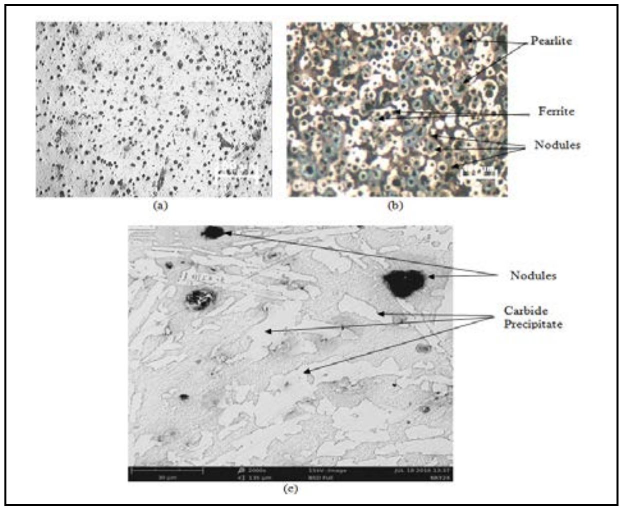

Plate 1: RH- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

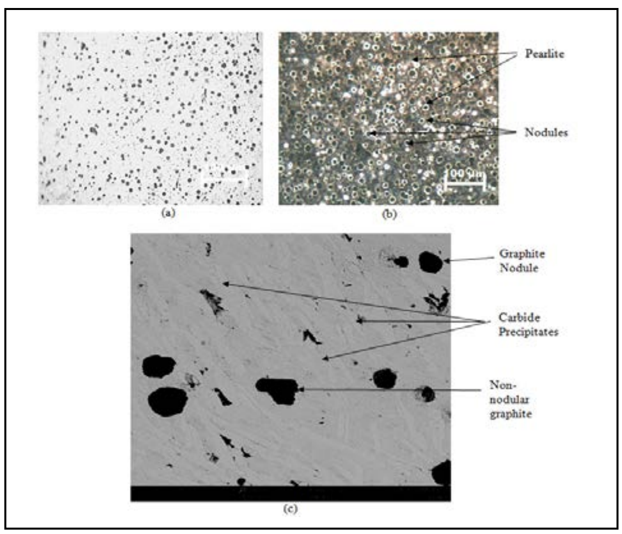

Plate 2: RH1- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

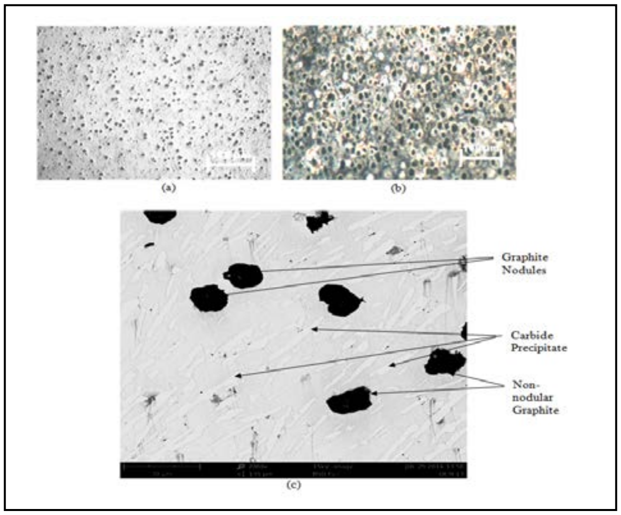

Plate 3: RH2- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

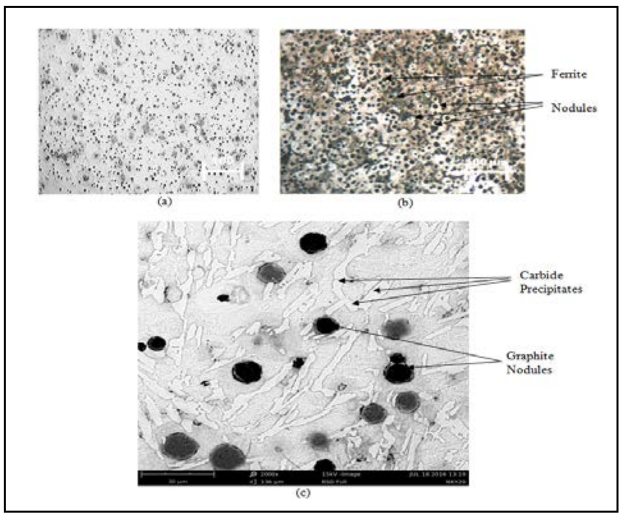

Plate 4: RH3- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

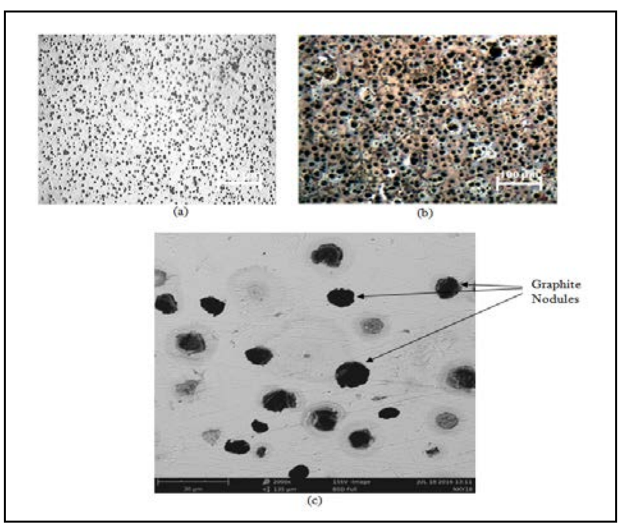

Plate 5: RH4- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

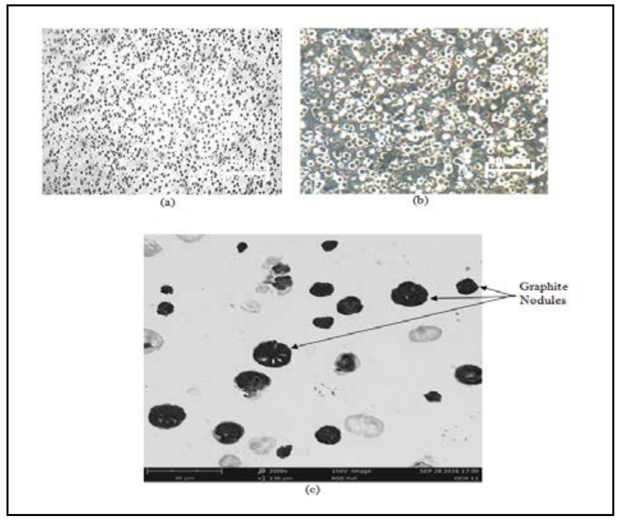

Plate 6: RH5- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

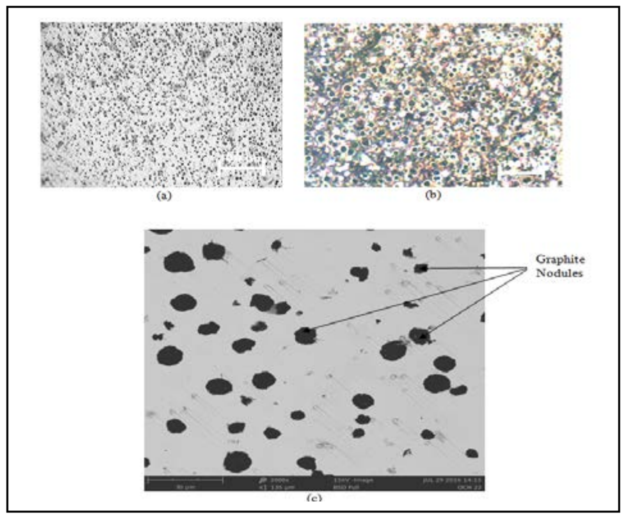

Plate 7: RH6- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

Authors' Biographical Notes:

Ezenwanyi Fidelia Ochulor *is a faculty member of the Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria. She holds a Master's of Science and Ph.D. degree from the same department, and Bachelor's degree in Engineering from the Federal University of Technology Owerri (FUTO), Nigeria. Her areas of research include materials processing, development and characterisation.*

Mohammed Olawale Hakeem Amuda *is an Associate Professor/Reader in the Department of Metallurgical and Materials Engineering, University of Lagos, Lagos, Nigeria. He holds a PhD in Materials Science and Engineering from the International Islamic University Malaysia, a Master's of Science in Mechanical Engineering, University of Lagos, Nigeria and Bachelor's degree in Metallurgical and Materials Engineering from the Obafemi Awolowo University, Ile-Ife, Nigeria. His research interests span materials development and processing for emerging technologies such as low energy fusion welding processes and surface modification of metallic materials for* *improved corrosion and thermal efficiency. Professor Amuda is currently working on laser cladding of aerospace grade titanium alloy with premix carbide+boride ceramics for extreme conditions. Other works include characterisation of flow behaviour in AA 7075 aluminum alloy during hot deformation, and optimisation of design parameters of flame torch melting for surface modification. He was a visiting scholar at the University of Johannesburg and the International Islamic University Malaysia.*

Samson Oluropo Adeosun *is a full Professor in the Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria. His works are in the area of materials development, processing and characterisation. He currently works on biodegradable polymer composites for orthopaedic applications and ferrous/non-ferrous alloy and its composites for high temperature and wears applications.*

Sanmbo Adewale Balogun *is currently a contract Professor in Bells University of Technology, Ota. Nigeria. He holds a Bachelor's, Master's and PhD degrees in Industrial Metallurgy and Management Techniques. He started his academic career in 1972, and was appointed Full Professor in the University of Lagos in 1983. Professor Balogun received training in Iron and Steel production in various steel plants in the old Soviet Unio,n and was a visiting research fellow to the Steel Casting Research & Trade Association (SCRATA), Drop Forging Research Association (DFRA) in England and the Central Metal-Forming Institute (CMFI) and the Hindustan Machine Tool Co. Limited Hyderabab, India. He serves as Chairman of Technical Committee on Iron and Steel of the Standard Organisation of Nigeria, Chairman of the Examination and Certification Board of the Nigerian Society of Engineers, and Chief Interviewer of the Council for the Regulation of Engineering in Nigeria for Mechanical, Production, Chemical and Materials Engineering fields. He is a Chartered Engineer, a fellow of the Nigerian Society of Engineers and the Nigerian Academy of Engineering.*

■