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TIN MINE TAILING SAND FOR MAKING GREENSAND CASTING MOULD IN COPPER BASED MARINE APPLICATIONS

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ABSTRACT

Tin tailing sand is the mineral that is left behind after tin extraction. The silica content is high, ranging from 94%-99.5%. Tailing sand for sampling was taken in Batu Gajah, found to contain 95.9 – 98.9 % silica. A high content of silica purity is best for mould making especially for the ferrous metals. Greensand casting is a process of making mould using sand mixed with appropriate amount of clay and water and other additives and is widely used in casting of copper base marine components such as propellers, pumps impellers, pump casings, couplings, valves, and sub-surface platforms. Copper-base alloys such as aluminium bronze, nickel aluminum bronze, silicon bronze and copper nickel are the materials generally used in marine applications due to excellent corrosion resistance. The objectives of this research are to identify the effect of clay contents (addition of 4 wt% and 8wt%) on the mechanical properties of tailing sand and to determine the optimum mechanical properties of tailing sand as a moulding sand for copper based casting. American Foundry Society (AFS) standard of procedures were used as guidelines in conducting the experiments. For mechanical properties, cylindrical test pieces dimensioning of Ø50 mm×50 mm in height from various ratio of clay-sand water were prepared by applying three ramming blows of 6666 g each using Ridsdale-Dietert metric standard rammer. The results were then compared to the typical standard AFS tests for non-ferrous copper based casting. The findings have shown that the tin mine tailing sand with addition of 8 wt% is, applicable for use as moulding sand for making small copper based marine casting mould.

Keywords: tailing sand, clay content, permeability number, green compression strength.

INTRODUCTION

At the end of the 19th century, Malaysian economy had relied on tin mining industry, as the country was once a main provider in supplying about 55% of the world's tin. Tin tailing sand is the mineral that stays behind after tin extraction and later dumped beside of the alluvial mining operations and the silica content ranging from 94% to 99.5% [1]. Silica content is high due to the process of extraction of tin by using water jet and gravel pump during the process of the sand being washed. Batu Gajah is located in the Kinta valley of Perak was at one time the largest area that has been extensively mined for alluvial tin deposits over 100 years in Malaysia. It has approximately 27.55 million tons of tailing sand [2] and its silica content is between 95.9 to 98.9% [3]. Its average grain size for sieved sample (passed 425 µm) after clay wash is217 µm [4] where acceptable compared to commonly size as a foundry sand which is 220-250 µm [18].Due to these facts, this research was conducted to identify the characteristic of tailing sand as moulding sand for copper based casting in marine application in terms of its mechanical properties and to determine the effect of moisture and clay content on the mechanical properties.

Casting is one of the main and adaptable processes for manufacturing engineering components where sand casting is one of the processes. It's a common process for manufacturing marine components such as propeller, pumps impellers, pump casings, couplings, valves, and sub-surface platforms. Sand casting is a manufacturing process by which a liquid metal at high temperature is poured into a cavity of a mould (which made by mixture of sand, binder and other additives) of the required shape solely depend on the design of the pattern, and then allowed to solidify. The mould is broken out to complete the process. One of the processes in sand casting called greensand casting which is composed of high quality silica sand (85-95%) blended together with bentonite clay (4-10%) as a binder and water (2-5%) [7]. For aluminium bronze sand casted propeller mould, the sand with clay content of 12-17%, having a permeability of 70 AFS is most desirable for casting. In the case of greensand, the moisture content should not exceed 4% and should preferably be well below this figure [12]. Typical standard AFS tests on clay bonded moulding sand mixtures for non-ferrous copper based as shown in Table-1 stated that for small casting, the moisture content is 6% with permeability number of 25 and green compressive strength of 48 kN/m^2 while for large casting the permeability number is 60, green compression strength is 69 kN/m^2 at moisture content of 5.5%.

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Table-1. Typical standard AFS tests on clay bonded moulding sand mixtures [17].

Non- ferrous copper base casting	Moisture, %	AFS green permeability number	Green compressive strength, 10^3 Pa
Small	6.0	25	48
large	5.5	60	69

In greensand casting mould, the pattern which is the full-sized of the product is made first. The technique of making pattern such as propeller is challenging due to the shape of propeller. Mainly wood is used in making pattern. The advantage of greensand casting is many components for marine application can be molded in different sizes, shapes and cheaper in cost [5]. Sand casting remains the most popular method of casting despite it has poor finish and tolerance, accounting for more than 90% of cast metal production [7]. Incorrect sand condition result in the production of scrap therefore due to this reason, majority of foundries today require costly laboratories for controlling existing foundry sands and for testing new sands to discover their foundry suitability. Foundry sand control can only by testing of all the raw materials; sands, binders, and additives prior to the preparation of the sand mix. Sands found in different locations can have wide variations in surface, physical, and chemical characteristics due to environmental, ecological, climatic and geological factors. Different sands have different foundry properties thus standard necessary laboratory tests are properly carried out on it [8].

Copper-base alloys such as aluminium bronze, nickel aluminum bronze, silicon bronze and copper nickel are the material generally used in marine applications due to excellent corrosion resistance. Copper and its alloys of aluminum, silicon, tin, beryllium, and nickel had significantly lower long-term corrosion rates after 18 months compared to those specimens measured after only 6 months of exposure to seawater [9].Castings of aluminium-bronze are generally employed as components of propellers, pumps, valves for water and steam, gear wheels, helical gearings of certain type, chemical and marine fitting [12].The materials from which propellers are made today can predominantly be classed as members of the bronzes or stainless steels, by the mid to late 1980s nickel aluminum bronze (NAB), a copper based alloy had gained an almost complete dominance over the other materials, accounting for some 82% of the propellers [10]. This alloy is generally used in as cast condition [11]. Other material is stainless steel where stainless steel propeller is manufactured by CO_2 process where the mould consist of powdered chromo magnesite (tailing from grinding of chromomagnesitic brick) is mixed with sodium silicate (water glass) as binder and water and hardened by CO_2 then the mould is coated by titanium oxide paint which keeps it from metal penetration in the pores of the mould thus produced cleaner surface. It was found that 5-6.5% water is required in this casting process to get permeability of 25 and green compression strength of 0.18-0.3 kg/cm^2 [13].

The permeability is the mechanical property of the moulded mass of a sand mixture, which allows gas to pass through it. It is determined by measuring the rate of flow of air (2000 cm^3) under standard pressure (10 g/cm^2) through the standard cylindrical sand test piece (Ø50 mm × 50 mm in height) [14].A sand mixture of high permeability has good venting quality because of its porosity. The grain size, shape and distribution of the grains of foundry sand, the type and quality of bonding material, the density to which the sand is packed and the percentage of moisture used for tempering are important factors in regulating the degree of permeability [15]. A permeability figure of 150 to 200 is normal practice, with moisture content of between 3 and 4% [16]. The permeability number for bronze is 35 and aluminium is 20-40 [17]. Permeability number for mixture of synthetic sand and 8% of Ogharaki clay from Delta state, Nigeria is 55.5 [19]. The permeability number for moulding sand from Mansfield Sand Company mixed with 6% water is 21 [22]. Sand no 95 from King's Lynn, Norfork mixed with 5% Montmorillonite clay and 3.5% moisture has green permeability of 61, Redhill No. 65 sand is 120 and Chelford 50 is 220 [6].

The green compression strength of foundry sand is the maximum compressive strength a mixture is capable of developing when moist and for routine purposes, green strength is always measured in compression. The green compression strength of foundry sand is the maximum compression strength where AFS standard cylindrical specimen (size Ø50 mm×50 mm in height) mixture of sand, water and clay is capable of sustaining when prepared and rammed by applying three ramming blows of 6666 g each using a metric standard rammer. This standard size of test piece was designed by the American Committee (1921-1924) [20]. The specimen then is tested using a universal sand strength-testing machine. The standard practical value of green compression strength is 20-80 kN/m^2 [21] for instance; the green compression strength of Niger River sand with addition of 3% bentonite clay is 28 kN/m^2[22].

Clay and water have a significant role in improving the strength and permeability of greensand mould. Clay and water act as control addition to influence mechanical properties of moulding sand. This controlled addition can thus be made in the order of 5-7% clay and 3-3.5% water to produce moulds with better strength and higher permeability [23]. For making greensand mould, clay acts as binder. Bentonite clay has been used for this research. Bentonite is the clay predominantly used by the foundry industry. Since bonding materials are not highly refractory, the required strength must be obtained with the minimum possible addition, of the order 5-7% [24].

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Figure-1 explains the effect of moisture on the permeability for various size of grain sand. Permeability is lower at low moisture content regardless the size of grain and increased with the increased of water but further addition of water after achieved the maximum value, the permeability will be decreased.

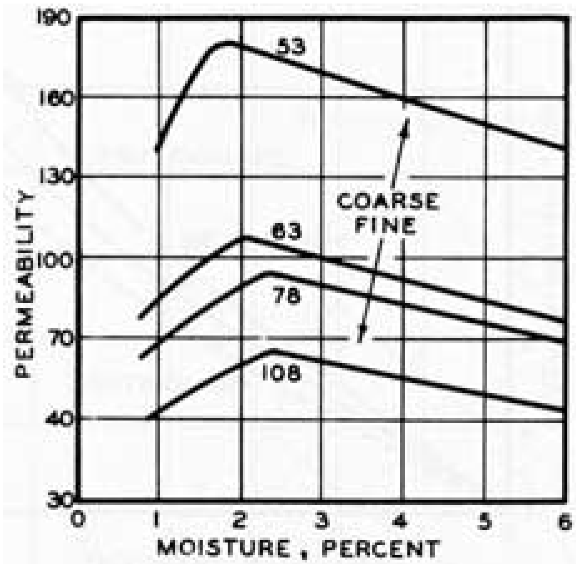

Figure-1. Permeability as affected by moisture with various sizes of sand according to foundry manual published by bureau of ships, Navy Department U.S. [25].

Figure-2 and Figure-3 explain the effect of moisture on the green compression strength and permeability number with addition of various clay contents. At lower moisture content, no strength and permeability would be achieved as the sand and clay would be just two dry materials. The clay adsorbs the water up to a limiting amount. Only that water rigidly held (adsorb) by the clay appears to be effective in developing good permeability and strength. Too little water fails to develop adequate strength and permeability. The development of bond strength between grains depends upon hydration of the clay, the green strength and permeability of a moulding mixture increases with water content up to an optimum value determined by the proportion of clay. Above this value, additional free water causes permeability to diminish due to the increasing on thickness of the water films, so that the clay becomes soft, lose its bonding power and less stiff and the sand grains are held further apart thus decrease the strength [24]. Therefore excessive moisture must be avoided since it lowers the permeability and increases the chances of a defect such as blown casting. At the same time plasticity and deformation of the mould will occur. Low permeability and low green compression strength encourage entrapment of gas and the washing away of sand by molten metal [23].

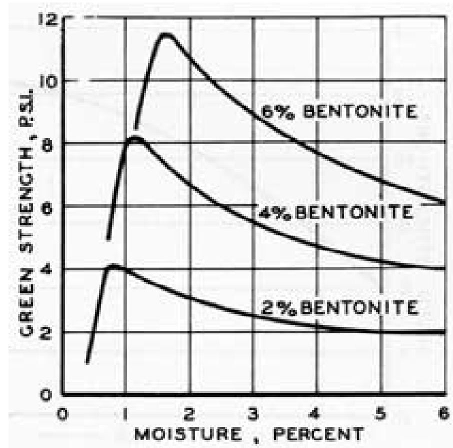

Figure-2. Green strength as affected by moisture with various clay contents according to foundry manual published by bureau of ships, Navy Department U.S. [25].

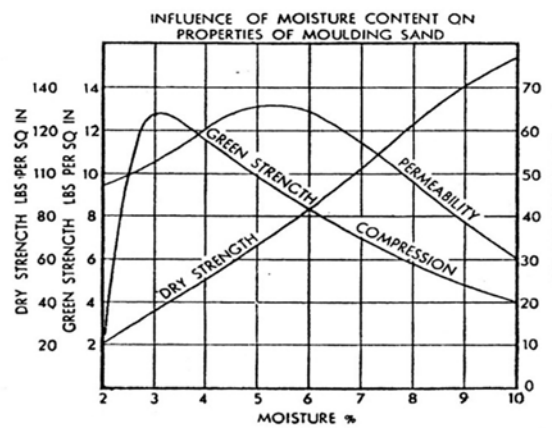

Figure-3. Influence of moisture content on properties of moulding sand (silica sand bonded with Wyoming bentonite) [26].

MATERIAL AND METHOD

Clay bonded moulding sand mixture for testing consists of tailing sand from Batu Gajah with average grain size of 217 µm, bentonite clay and water. The tailing sandwas mixed with 4wt% and then 8 wt% of bentonite clay, and subjected to milling for 5 minutes. Then, water was added to the mixture which started with 10 ml addition (approximately 1% moisture). Below than 10 ml the test piece was unable to produce. The mixture was milled appropriately for 3 minutes. A test piece of Ø50 mm × 50 mm in height was prepared by weighing out specimens ranging from 138 grams to 150 grams depending on the sand/clay/water ratio [27] and produced using Ridsdale-Dietert Metric Standard Rammer where compacted by applying three ramming blows of 6666 g each. A test piece was tested using Ridsdale-Dietert universal sand strength machine and Ridsdale-Dietert permeability meter. After three readings were obtained where average reading will be taken, addition of 10 ml water was added and the green compression strength and permeability were tested again.

RESULT AND DISCUSSIONS

Figure-4 shows the results for green compression strength for tailing sand from Batu Gajah bonded with 4wt% and 8wt% bentonite clay having the moisture content being increased. At low moisture content (2% moisture), the green compression strength for both mixtures (4 wt% and 8 wt%) is poor due to the dry state of the mixtures and without the addition of appropriate water, no strength would be achieved. The strength is developed when the moisture content in increased. The maximum strength for 4 wt% is at 32 kN/m^2 (5.48 % moisture) while for 8 wt% is at 34 kN/m^2 (6.11% moisture). At this percentage of moisture, clay has absorbed the water up to a limiting amount to produce effective strength. Further increased the moisture content, the strength is decreased because of the mixture becomes too wet. Thicker water films act as a lubricant thus the clay becomes so soft and unable to hold the grains together and lose its bonding power hence decreases the strength. The figure also shows that for mixture bonded with 8 wt% has higher green compression strength than 4 wt%. This is because it has more clay content resulting more bonding power, therefore needs higher moisture content to develop its maximum strength.

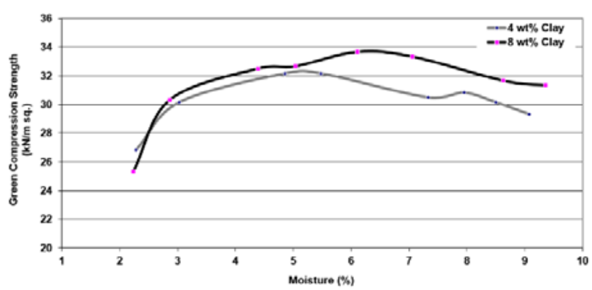

Figure-4. Green compression strength for clay bonded moulding sand mixtures.

Figure-5 shows the results for permeability number for tailing sand from Batu Gajah bonded with 4wt% and 8 wt% bentonite clay when the moisture content is increased. Permeability number is low at low moisture content. At this state, the mixture is too dry where the gap between grains sand filled with the fine particles of clay as the sand and clay would be just two dry materials. The permeability number is increased for both mixture when the moisture content is increased. For 4 wt% mixture, the maximum permeability is 94 at moisture content of 4.1% while for 8 wt% mixture is 80.7 at 5.87% moisture. The increased of permeability revealed that only water rigidly held by the clay appears to be effective in developing permeability where the air is easily penetrates the gap between grains. Further increased in the moisture content, the permeability started to diminish due to the increased on thickness of the water films and the sand grains are held further apart. The figure also shown that mixture bonded with 8 wt% has lower permeability number than 4 wt% due to the higher clay content in the mixture consequently more fine particles of clay are existed.

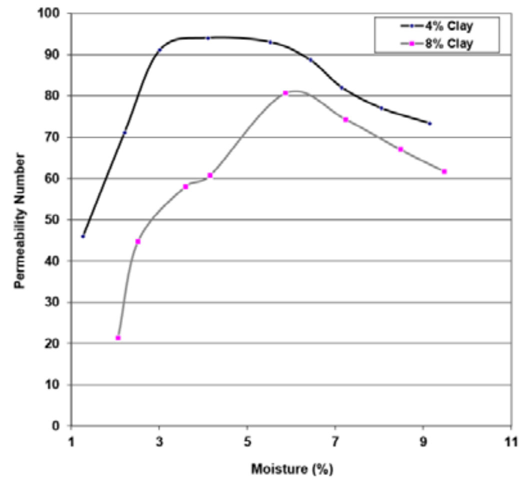

Figure-5. Permeability number for clay bonded moulding sand mixtures.

Figure-6 shows the mechanical properties of mixture bonded with 4 wt% clay. According to typical standard AFS tests, for large casting, the permeability number is 60 and the green compression strength is 69 kN/m^2 at moisture content of 5.5%, while for small casting components, the moisture content at 6%, the permeability is 25 and green compression strength is 48 kN/m^2.The result exposed that mixture bonded with 4 wt% clay is not suitable for small or large copper based casting where at 5.5% or 6% moisture, the green compression strength is lower approximately 32 kN/m^{2}but it has better permeability which is 94.The reason of this because the mixture was added with low clay content thus it is not appropriate enough to develop strength but with less finer particle of clay in the mixture the permeability is increased.

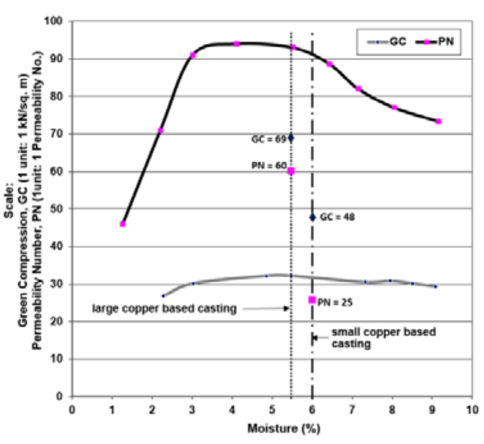

Figure-6. Mechanical properties of mixture bonded with 4 wt% clay compared to small and large copper based casting.

Result for mechanical properties of mixture bonded with 8 wt% clay is shown in Figure-7. The result explains that tailing sand bonded with 8% mixture is appropriate for small copper based casting. At 6% moisture, the green compression is 34 kN/m^2 while for the typical standard AFS is 48 kN/m^2. The permeability is found superior which 92 as compared to typical standard AFS is 25. It would suggest that to achieve the typical standard of AFS, more clay should be added where will increase the bonding power and at the same time will decrease the permeability due to finer particle of clay. This result verified that high clay content is required for moulding aluminium bronze sand casted propeller, where the clay content of 12-17% and having a permeability of 70 AFS is most desirable for casting [12].

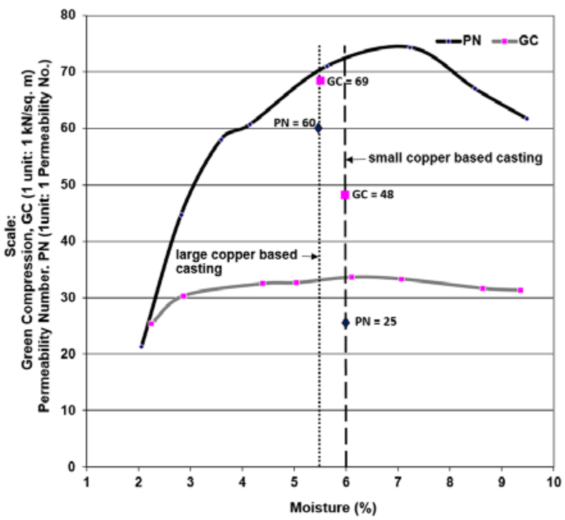

Figure-7. Mechanical properties of mixture bonded with 8 wt% clay compared to small and large copper based casting.

SUMMARY

This research discovered that clay contents has significant effect on the mechanical properties of tailing sand from Batu Gajah for making greensand casting mould. Tailing sand tested with addition of 4 wt% bentonite clay is found not sufficient enough for making sand casting mould for copper based components. This is due to the clay content added in the mixture is too low and not sufficient to develop the appropriate mechanical properties. The mechanical property is improved when more clay which is 8 wt% clay is added and it's found suitable for small copper based casting. Addition of more clay will increase the bonding power thus increase the strength and due to finer particle of clay will decrease the permeability. Further study on the addition of clay from 12-17 wt% is suggested to be conducted to verify that higher clay content is required for making greensand casting mould for copper based marine components.

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REFERENCES

[1] Mackay and Schnellmann. 2000. Mineral processing consultancy silica sand. Mines Research Institute. Kuala Lumpur.

[2] Ali A. 2002. The silica-based industry in Malaysia. Paper presented at the Sesi Dialog Mineral.

[3] Hashim A.S.B.H and Sulaiman Z.A.B. 1999Research on resources of ex-tin tailing sand in Perak State. Mineral and Geoscience Department Malaysia, Kuala Lumpur.

[4] Azhar A. and Shamsuddin S. 2009. Preliminary study on tailing sand from ex-tin mine sites in Peninsular Malaysia for use as foundry sand: grain size distribution and average grain size. Proceeding of the International Conference on Advances in Materials and Processing Technologies (AMPT 2009).

[5] Degu1 Y.M., and Sridhar K.2014. Marine Propeller Manufacturing - A new approach. American Journal of Engineering Research (AJER). 03(05): 207-211.

[6] Beatle J.D. Castings. 1971. The Macmillan Press Ltd. Hampshire.

[7] Siddique R., Schutter G.d. and Noumowec A. 2008. Effect of used-foundry sand on the mechanical properties of concrete. Construction and Building Materials. 23: 976-980.

[8] Patel D, Deshpande V., Jha E., Patel V., Desai S. and Patel J. 2015. The proceeding of 4th International Conference on Progress in Production, Mechanical and Automobile Engineering (ICPMAE-2015)

[9] Tuthill, A.H. 1987. Copper Alloys: Guidelines for the use of copper alloys in seawater. National Association of Corrosion Engineers. 26(9): 12.

[10] Carlton J.S. 2012. Marine Propellers and Propulsion. 3rdEd. Elsevier Ltd. pp. 415-420.

[11] Sarkar A., Chakrabarti A.,Nagesha A., Saravanan T., Arunmuthu K., Sandhya R., Philip J., Mathew M.D., and Jaya Kumar T. 2014. Influence of casting defects on S-N fatigue behaviour of Ni-Al Bronze. The

Minerals, Metals & Materials Society and ASM International.

[12] Vaidyanath L. R.1969. The manufacture of aluminium-bronze castings. In: Symposium on Non-ferrous Metals Technology. Jamshedpur. pp. 72-85. Information onhttp://eprints.nmlindia.org/3803/1/72-85.pdf.

[13] Sokolov N.N. and Rosen M.L. 1965. Stainless steel screw propeller. State Union Publishing House of the Shipbuilding Industry. Leningrad. pp. 84. Information onhttp://www.dtic.mil/dtic/tr/fulltext/u2/627518.pdf.

[14] AFS, American Foundrymen's Society. 1963. Foundry Sand Handbook, Chicago.

[15] Bolger R. 1996. Foundry Minerals: Recycling the newname of the game, Industrial Mineral. p. 29.

[16] Howard, E.D. 1958.Modern Foundry Practice. Odhams Press Limited. London. pp. 229-245.

[17] Salmon W.H. and Simons E.N. 1966. Foundry Practice, Sir Isaac Pitman and Sons Ltd. London.

[18] Brown J.R. 2003. Sands and greensand. Foseco Ferrous Foundryman's Handbook. Butterworth-Heinemann. Oxford.

[19] Eze E.O., Alli A. and Thompson E.O. 1993. Foundry qualities and applications of local synthetic sand mixtures: submitted to Journal of Applied Clay Science.

[20] Parkes W.B. 1971. Clay-Bonded Foundry Sand Applied Science Publishers Ltd., London.

[21] Olasupo O.A. and Omotoyinbo J.A. 2009. Moulding properties of Nigeria silica-slay mixture for foundry use, Applied Clay Science. 45(4): 244-247.

[22] Ademoh N.A. 2008. Evaluation of the foundry properties of River Niger sand behind Ajaokuta Steel Company Limited, Ajaokota, Nigeria, American-Eurasia Journal of Scientific Research, (3)1: 75-83.

[23] Griffiths, J. 1990. Minerals in foundry casting: Investment in the future. Industrial Minerals Journal. pp. 39-51.

[24] Webster P.D. 1980. Fundamentals of Foundry Technology, Surrey, Portcullis Press, Redhill.

[25] Foundry Manual. 1958. Bureau of Ships, Navy Department Washington 25, D. C.

[26] Heine R.W., Loper C.R. Jr. & RosenthalP.C.1967. Principle of Metal Casting. New York: McGraw-Hill Book Company. pp. 86-89.

[27] Foundry Sand Testing Equipment Operating Instructions, Ridsdale & Co. Ltd., Newham, Hall, Newby, Middlesbrough, Cleveland, England.