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Design and Fabrication of Mobile Stirrer for Improved Performance of Diesel-Fired Crucible Furnace

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Abstract – In most automotive, aerospace and industrial applications, a homogeneous distribution of the particles is required in order to maximize the mechanical, thermal and tribological properties of a metal matrix. Such homogenous distribution is difficult most especially in a stationary oil-fired crucible furnace where manual stirring is the practice. This manual stirring is ineffective, laborious and difficult to control. In this study, mobile stirrer was designed, fabricated and improvised to work with a crucible furnace to ensure proper stirring and homogenous mixing of reinforcements with molten metal. The stirrer consists of features that enables stirring speed to be varied in order to handle molten metal of different volume and varying viscosity. Such features include, electric motor with variable speed reducer gear, impeller shaft with blades, pulleys and belt, and frames supported by caster wheels with adjustable lock roller for controlled mobility. The stirrer is designed to work with crucible furnace up to 100 kg sized crucible pot to deliver a maximum toque of 5 Nm and stirring speed ranging from 120 to 220 rpm. Performance evaluation of the stirrer was carried out using discarded aluminium can reinforced with rice husk ash (RHA). Optical micrographs revealed homogenous casting with isotropic grain structure when the stirrer was improvised with the furnace. When properly developed, the stirrer will help to transfer particles into the liquid metal and maintain the particles in suspension and thus ensure uniformity of particle dispersion in a melt before solidification. Therefore, this will contribute in no small measure to sustainable economic development of materials for automotive and many other industrial applications.

Keywords: crucible furnace, crucible pot, molten metal, rice husk ash, stirrer, viscosity

1. Introduction

The primary industrial manufacturing routes can be classified into liquid and solid phase processes. Liquid phase processes of the routes include, squeeze casting and squeeze infiltration, spray deposition, slurry casting (compocasting), and reactive processing (insitu composites) while solid state processes include powder blending with subsequent consolidation, diffusion bonding and vapour deposition. Kalaphathy (2000), reiterated that these above techniques have some drawbacks such as, uniform distribution/dispersion of reinforcement, problem of interfacial reaction between reinforcement and metal matrix, formation of detrimental second phase compounds, limitation of particle size in each process, delicate control of processing parameters to obtain solidified microstructure in surface layer.

Hashim (1998); Bonollo *et al* (1991); Sozhamannan *et al.*, (2012) stressed that among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting or liquid metallurgy is generally accepted, and popularly being used for commercial practice. Its simplicity, flexibility, low cost and applicability to large scale/volume production of complex shaped components and high productivity rates are its advantages. According to Skibo *et al.* (1988); Han Jian–min *et al.*, (2006); Shashi *et al.,* (2013) the cost of preparing composites materials using a stir casting method is about one-third to one-half that of a competitive method, and for high volume production, which has been projected to reduce to one-tenth in the long run.

Generally, stir casting of metal matrix composites involves production of liquid melt of the selected matrix material, followed by the addition of a reinforcing material into the melt and stirring through to obtaining a suitable dispersion of reinforcement in the liquid melt. The addition of particles to the melt drastically brings about a change in the viscosity of the melt, and this has consequences for casting processes. It is however desirable that solidification occur before appreciable settling is allowed to take place (Hashim 1998).

Stir casting furnaces include, crucible furnace, rotary furnace, induction furnace etc. Out of all these, crucible furnace is the cheapest and most commonly used by local foundry men in Nigeria. However, manual stirring is usually applied during melt preparation in such furnaces. This manual stirring is laborious, ineffective and difficult to control and therefore, produces casting with inhomogeneous distribution of reinforcement. Stirring has been identified as one of the major problems in using crucible furnaces.

Jaswinder and Amit (2016), stressed that obtaining the uniform distribution of reinforcing particles in the matrix alloy is the first challenge during fabrication of composites. Prevention of different forms of segregation and agglomeration of particles during the process of solidification is also important. Introduction of reinforcement particles to the stirred molten matrix like aluminium sometimes leads to the entrapment of not only the particles but also other impurities such as oxide of aluminum and slag, which is formed on the surface of the liquid melt. During pouring of such melt, air envelopes may form between particles, which can lead to change in the interface properties between particles and the melt and also retards the wettability between them. Factors to consider during mechanical stirring of aluminium melt include, the stirring condition, melt temperature, and the type, quantity and nature of the particles (Lloyd 1994; Mortensen and Jin 1992).

A popular method for consideration when using a liquid melt technique is continuous stirring of the melt with a motor driven agitator to prevent settling down of particles. If the particles or reinforcements are heavier than the matrix, they will definitely settle at the bottom of the melt (Ray, 1996). Therefore, careful method of stirring the melt must be properly designed and adopted before casting to ensure that the particles are evenly distributed by agitation throughout the casting.

Dispersion by stirring with the aid of a motorized mechanical stirrer has being in use since the method was introduced by Ray (1969). This external force helps to properly mix a non-wettable reinforcing particle into a liquid melt, and also create a uniform and homogeneous suspension in the liquid melt. The uniformity of particle dispersion in a melt before solidification is further assisted by the dynamics of the particle movement in agitated crucible pot. Surappa and Rohatgi (1978) suggested development of other mechanical stirrer for agitation of the composite slurry. Yilmaz and Altintas (1994) used graphite stirrer and by steel stirrer coated with ceramic as suggested by McCoy *et al.,* (1988), and four bladed alumina spray-coated stirrer by Wang and Ajersch (1994) or alumina stirrer. Since stirring of a melt naturally results in a formation of a vortex. The vortex method is the most frequently used according to Yilmaz and Altintas (1994); Milliere and Suery (1988); Gupta and Surappa (1995); Ghosh and Ray (1987); McCoy *et al.* (1988); Yamada *et al.* (1989); Surappa and Rohatgi (1978),

Ceramic reinforcement particles are introduced through sideway of a vortex which is created in the melt with a mechanical impeller at different agitation speeds demonstrated at 100 rpm (Yilmaz and Altintas 1994), 580 rpm (Yilmaz and Altintas 1994), 600 rpm (Wang and Ajersch 1994; Yamada *et al*. 1989), 1000 rpm (Milliere and Suery 1988), or 400-1500 rpm (Gosh and Ray 1987). Particles have, for examples be continuously stirred after being incorporated into the melt, for 45 minutes (McCoy *et al*. 1988), or for 15 minutes (Miwa *et al.* 1993). In some foundries, a slowly rotating propeller are used for continuous stirring. Gibson *et al.* (1982) designed a special rotor to dispersed graphite powder in agitated slurry of Al-Si alloys to avoid surface agitation of the melt and resulting air entrapment. Therefore, it becomes necessary to improvise stationary furnace like crucible furnace with mobile stirrer for the purpose of studying the influence of stirring on microstructure of the casting.

2. Materials and Methods

The following materials/components were locally sourced for fabrication of the stirrer:

i. Variable speed reducer gear
ii. 1 HP electric motor with maximum speed of 1450 rpm.
iii. Stirring shaft of 1520 mm length.
iv. Mild steel angle plate of 5 mm thickness.
v. Stainless steel plate of 6 mm thickness.
vi. Screws, bolts and nuts.
vii. Pulleys and belts
viii. Base metal table and stands
ix. 4 No. Caster wheels with adjustable lock roller

2.1 Assembly Procedure

A variable speed electric motor of 1 HP with maximum speed of 1450 rpm was selected. The motor shaft is connected to the driver pulley of diameter 95 mm. Driven pulley of diameter 65 mm at a center to center distance of 734.5 mm was linked with the driver pulley with a belt. The driven pulley is linked with the speed reduction gear via a shaft. The motion is transferred at right angle through bevel gear to rotate the impeller shaft with pillow bearing. The assembly is coupled on a support base which is placed on the frame supported by four caster wheels for mobility. The mobile stirrer has been designed to require less effort to operate when correct stirring speed is selected and also reduce the time spent during melting and to ensure proper mixture of reinforcement in molten metal. At stirring speed of 140 rpm selected in this work, the stirrer ensured homogenous mixture of molten aluminium and reinforcements.

Development of this mobile stirrer has eliminated the major deficiency of crucible furnace and if adopted, will in the long run reduce preference for rotary furnace, most especially for melting where homogenous mixture of molten metal is a necessity. The detailed drawings are shown in Figs 1a and b while Plate 1 shows the picture of the developed stirrer.

2.2 Design Analysis

Calculation of torque transmitted and length of belt is shown in section 3.2.1 and 3.2.2

2.2.1 Determination of Stirrer Torque

Torque transmitted can be determined by using equation 2 (Khurmi and Gupta, 2012).

$$T = \frac{P \; X \; 60}{2 \; \pi \; N} \qquad (1)$$

P = 1 HP = 760 Watt,

N = 1450 rpm

$$T = \frac{760 \; X \; 60}{2 \; X \; 3.142 \; X \; 1450} = 5 \text{ Nm}$$

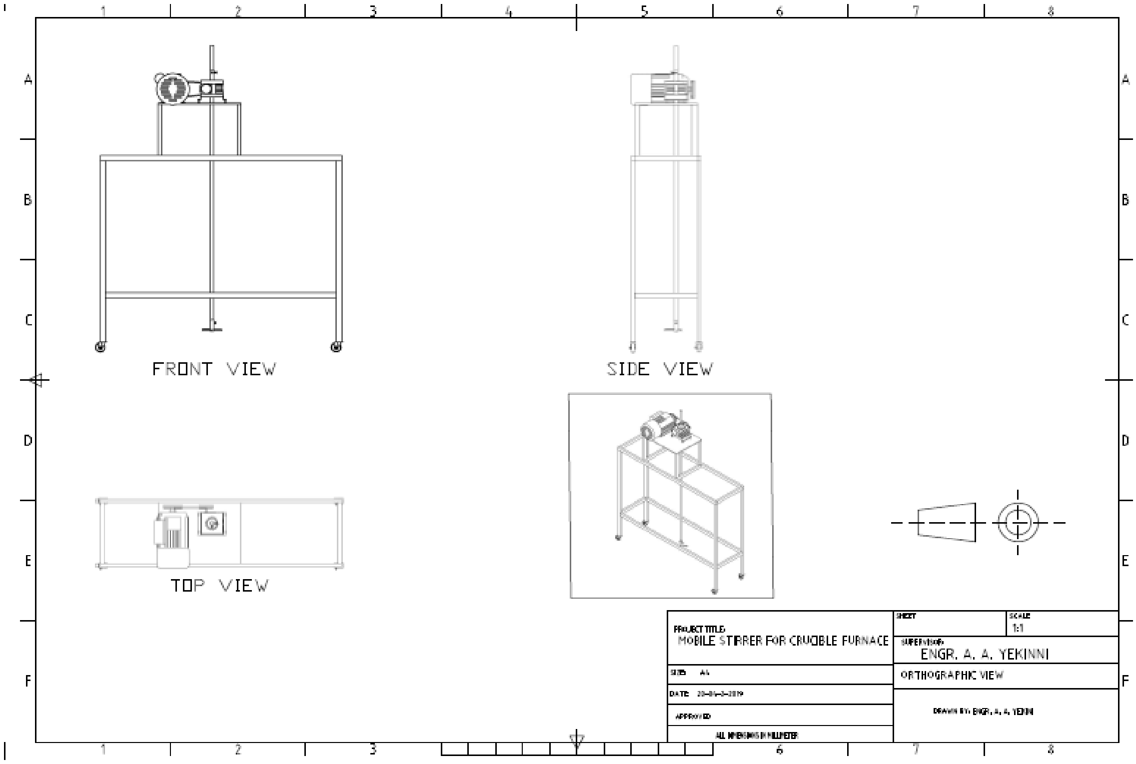
2.3 Determination of length of belt

According to Khurmi and Gupta, 2012, equation 2 shows the length of belt

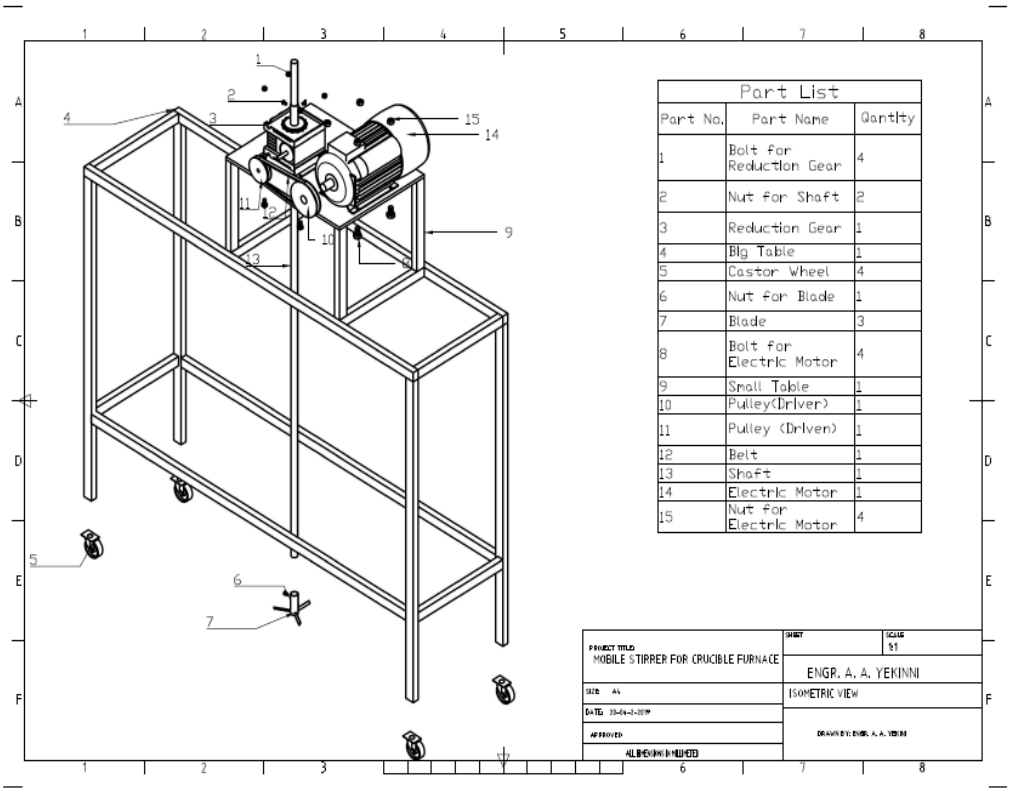
$$L = 2C + 1.57 \,(D - d) + \frac{(D-d)^2}{4C} \qquad (2)$$

Where, D = Diameter of larger pulley = 95 mm, d = Diameter of smaller pulley = 65 mm, C = Center distance between pulleys = 240 mm

$$L = 2(240) + 1.57\,(95 - 65) + \frac{(95-65)^2}{4(240)} = 528.04 \text{ mm}$$



(a)



(b)

Fig. 1: Improvised Mobile Stirrer for Crucible Furnace (a) Orthographic Projection (b) Isometric Drawing

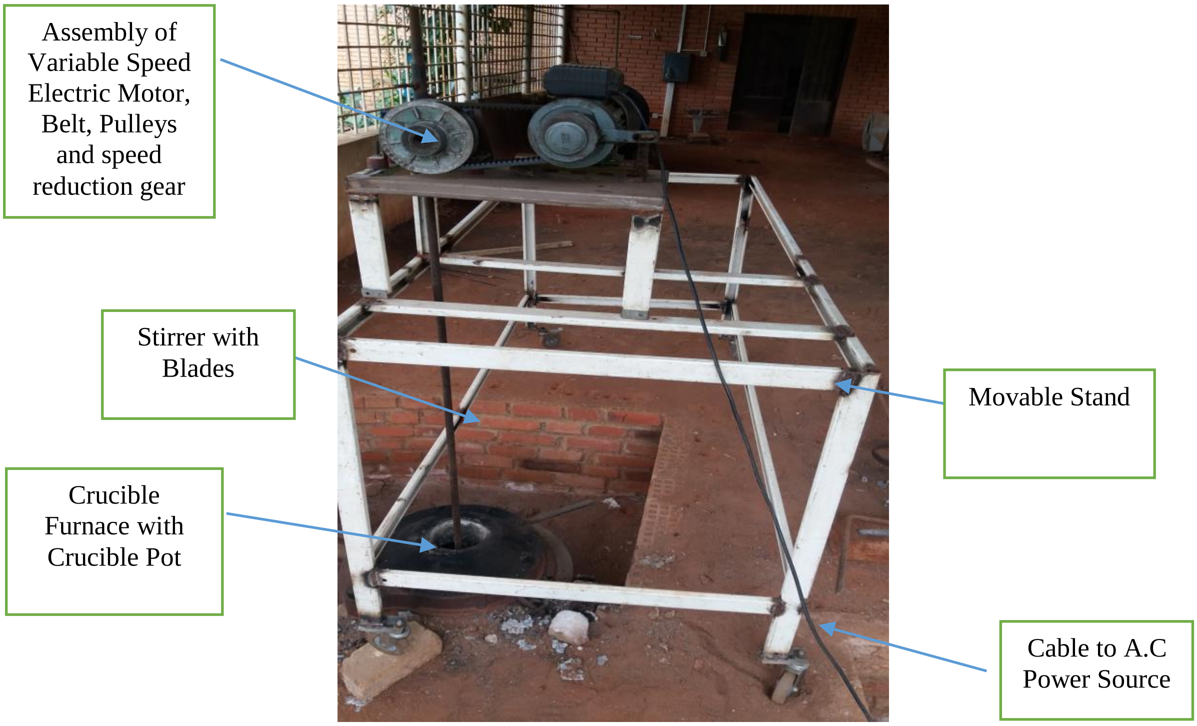


Plate 1: Fabricated and Improvised Stirrer Set up for Stir Casting

2.3 Production of Rice Husk Ash

This is carbonization of rice husk, which requires burning of rice husk in the absence of air. The variety of indigenous rice grown in Nigeria include, Fadama rice, Upland rice and Lowland rice. Fadama rice, a variety of red grain specie (oryza glaberrina) was used in this study. The rice husk comes with some rice grains, adhering sand particles and other contaminants mixed together both in particles and powder form was separated before use.

The mixture was first blown manually to separate the husk from rice grains and other contaminants and then washed with tap water twice by stirring in a container to allow the sand impurity and rice particles to settle at the bottom while the powdered grains and sand mixed with the water became muddy. This muddy water was then poured away and the rice husk was manually removed from the container leaving behind the settled sand. The blown and washed rice husk was then dried under sun rays for three days (Plate 2a). The rice husk was placed inside a crucible pot, well-lagged with cotton wool (Plate 2b) and then burnt at 700 ^{o}C for two hours inside the muffle furnace to ensure proper carbonization (Plate 2c). It was sieved and 150 µm was collected (Plates 2d).

(a) (b) (c) (d)

Plate 2: (a) Rice Husk (b) Rice husk lagged with cotton wool (c) Furnace for Carbonating the rice husk (d) 150 µm Rice Husk Ash

2.4 Production of Aluminium Alloy Casting

Disposed aluminium cans (Plate 3a) of about 18 kg was charged into the crucible pot of the diesel-fired crucible furnace (Plate 3b) situated at Foundry Workshop, Mechanical Engineering Department, Lagos State Polytechnic, Ikorodu. The compressed aluminium cans were heated at about 850 ^{o}C in a continuous process, as the furnace was left open while the scrap is being charged into the pot, and was coked (mixed together) by the use of a long metal rod. After subsequent charging, the crucible pot became filled-up with molten Al metal. The pot was carried out of the furnace by the use of tong. The molten metal in the pot was thoroughly turned to remove the slag. After which it was degassed to prevent blow holes in the cast billet by dropping some piece of aluminium cans into the molten metal.

The molten metal was then poured in an open metal cavity mould (Plate 3c) and allowed to air cool. This was later removed from the metal mould as aluminium billet. The sequence of operation was repeated until the scrap was exhausted. Billets were produced, weighed and the percentage mass loss due to slag formation was calculated using equation 3.

$$\% \text{ mass loss} = \frac{\text{Mass of Al cans charged into the furnace} - \text{Mass of all Al billets cast}}{\text{Mass of Al cans charged into the furnace}} \; x \; 100 \quad (3)$$

Each aluminium billet gotten from the scrap was re-charged into the furnace and re-melted for homogenization since the waste aluminium cans were obtained from different sources. Billets of average weight of 1000 g were produced. One of the billets was used as control sample while other were used to produce Al composites reinforced with rice husk ash. shown in plate 3d.

2.5 Production of Al/RHA Composites

To produce the composites, the melting was carried out in a crucible pot placed inside the crucible furnace. Each aluminium alloy billet melted was first preheated at 450 ^{o}C before melting at 750 ^{o}C and 6, 8 and 10 % wt. rice husk ash was measured and preheated to about 100 ^{o}C before incorporating into the melt which was then degassed to control the porosity. To enhance the wettability between the rice husk ash particles and aluminium alloy melt, 1 wt.% of magnesium was simultaneously added into the molten melt. Saravanan and Kumar (2013), stressed that particles of rice husk ash will be rejected without addition of magnesium.

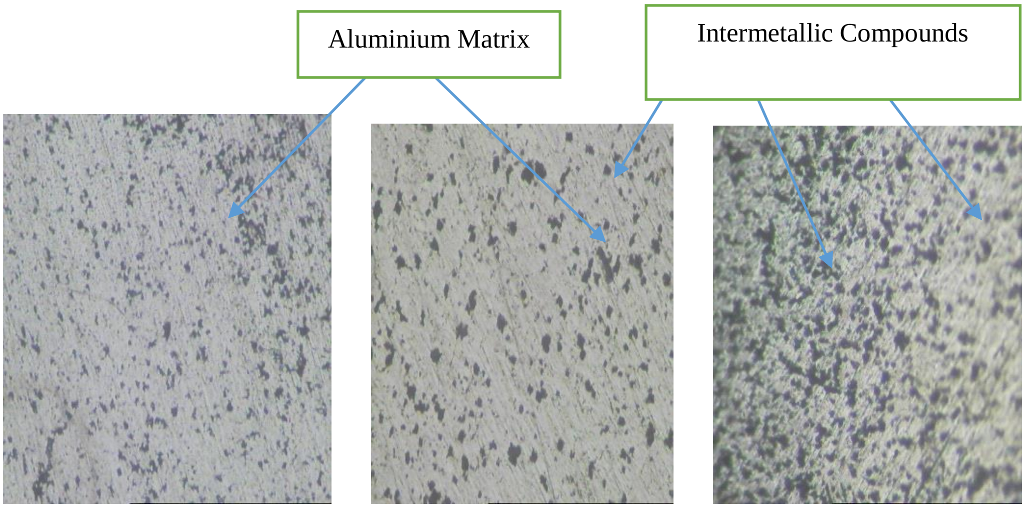
A designed and developed stirring set-up (Plate 1) was improvised for proper stirring through which a steel rod stirrer is lowered into the molten melt slowly up to 2/3 of the height of the molten metal from the bottom of the crucible pot. The molten metal was stirred by the improvised stirrer at a speed of 140 rpm for 2 minutes. This stirring speed and stirring time was carefully chosen, taking into consideration, the capacity and dimensions of the crucible pot.

(a) (b) (c) (d)

Plate 3: (a) Aluminium Scrap (Waste Aluminium Can (b) Aluminium scrap melting in crucible furnace (c) Pouring of molten metal and Aluminium alloy billet (d) Control Sample

2.6 Optical Microscopy

The optical micrograph showed reasonably uniform distribution of RHA particles in the matrix of aluminium alloy at 6, 8 and 10 wt.% as shown in plate 4a, b and c respectively. The homogeneous distribution of the particles throughout the matrix is as a result of effective stirring of mixture of RHA reinforcement and molten aluminium alloy. It can also be observed that the grain size increases with increase in concentration of RHA particles.



(a) (b) (c)

Plate 4: Optical Micrographs (100X) of Al/RHA Composites at (a) 6 wt.% RHA (b) 8 wt.% RHA (c) 10 wt.% RHA

Conclusion

A mobile stirrer has been successfully developed and improvised for use with diesel-fired crucible furnace. Easy to operate and comfortable to use. Its mobility makes it adaptable to work with small to medium sized crucible furnaces. The performance evaluation revealed that the machine worked effectively in ensuring uniform dispersion of rice husk ash in molten aluminium alloy. The optical micrographs of Al/RHA composites produced confirmed homogenous casting with isotropic grain structure.

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