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Design and Development of a Mobile Stirrer for Enhanced Efficiency of Diesel-Fired Crucible Furnace

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Abstract – Current stirring solution for crucible furnaces are often fixed or manually operated, leading to limitations in manoeuvrability, control, and uniformity of melt. This research presents the development of a mobile stirrer designed to enhance the efficiency of diesel-fired crucible furnaces used in metal melting operations. The primary goal was to improve melt homogeneity, reduce fuel consumption, and minimize operator fatigue and safety risks associated with manual stirring. The mobile stirrer features a robust design equipped with a 1 hp electric motor capable of delivering a maximum speed of 1450 rpm, coupled with a variable speed reducer gear to allow precise control of stirring intensity. A 1520 mm-long stirring impeller shaft with blades was fabricated to effectively reach and agitate the molten metal within the crucible. Power transmission is achieved through a system of pulleys and belts, ensuring smooth operation and ease of maintenance. The entire assembly is mounted on a mobile frame fitted with caster wheels and adjustable lock rollers, enabling flexibility and positional stability during operation. Stirring is ensured through an impeller shaft with blades, pulleys and belt. 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 100 to 400 rpm. Experimental evaluations of the stirrer were carried out using discarded aluminium can reinforced with rice husk ash (RHA). The Optical Micrographs of the composites revealed homogenous casting with isotropic grain structure when the stirrer was improvised with the furnace. Temperature uniformity was greatly improved, melting time reduced with enhanced overall combustion efficiency of the furnace. The study concludes that integrating this stirring system can greatly enhance foundry productivity, energy efficiency, and operational safety.

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

1. Introduction

In many small to medium-scale foundries, diesel-fired crucible furnaces ate still widely used due to their low initial cost and ease of operation. However, these systems often suffer from poor metal homogeneity, uneven heating, and energy inefficiency due to the lack of effective stirring mechanism. 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.

However, the absence of a mobile stirrer in crucible furnaces leads to increased fuel consumption, longer melting times, and inconsistent melt quality. Therefore, there is a need to develop a mobile stirrer system that can enhance the thermal and mixing efficiency of the crucible furnace.

Ashok *et al.,* (2019a) addressed the stirring challenges in a bottom pouring type stir casting furnace with carrier gas by designing different shapes of mechanical stirrers. The influence of each stirrer on vortex formation and better distribution along with the use of carrier gas like Argon was studied. Ashok *et al.,* (2019b) extended the study by designing and fabricating a motorized stirrer mechanism for stir casting furnace to further improve the melting process parameters. Rahul *et al.,* (2022) designed and fabricated a portable and an adjustable stirring system for a coal furnace by incorporating rotor, shaft, frame, the motor with a driver, control panel, and a sliding mechanism.

Observations from previous studies revealed that there are limited number of fabricated mobile stirrer specifically designed for furnaces and the performance of the existing ones improvised for different furnaces suffer inadequate stirring performances, lack of adaptive control mechanisms and precise manoeuvrability, experience early mechanical failure and rapid wear when exposed to the high-temperature and corrosive environment of molten metal. Also, most mobile stirrers are not ergonomically designed for operator safety and also lack efficient energy utilization. Therefore, there is a pressing need for an improved design of portable mobile stirring device that ensures consistent melt quality, thereby improving the reliability of final cast products.

2. Materials and Methods

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

i. Variable speed reducer gear (100-400 rpm)
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
viii. 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

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

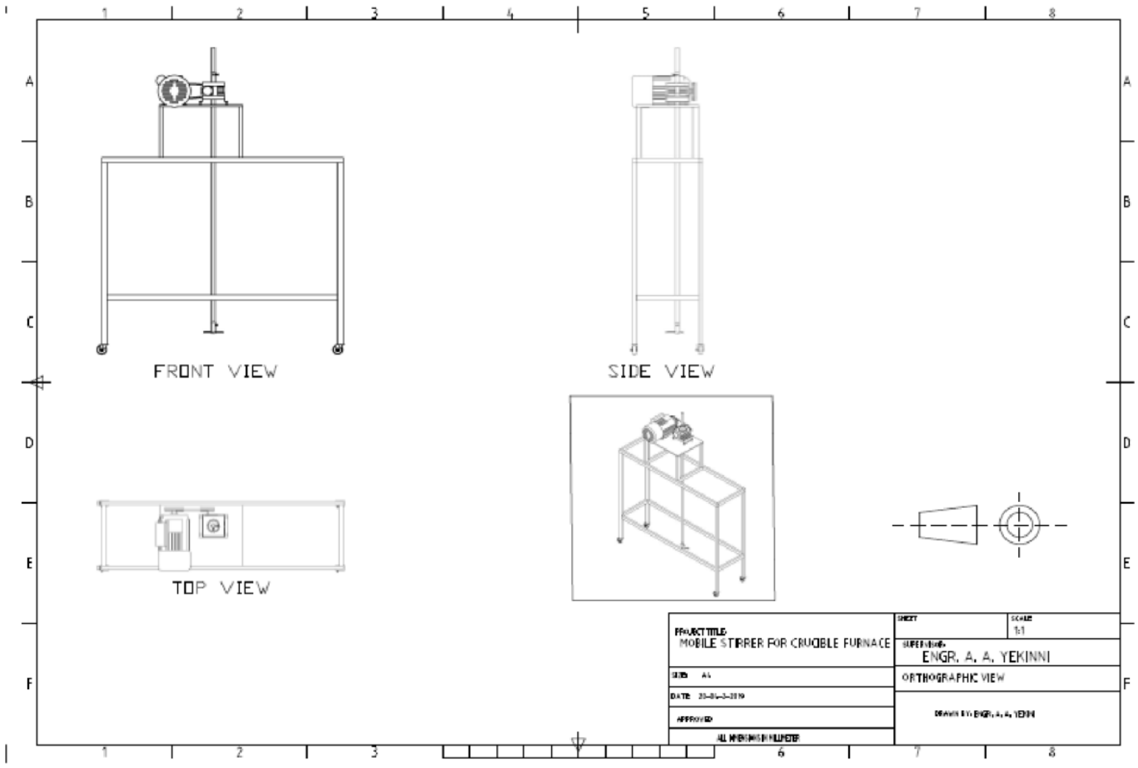
2.3 Determination of length of belt

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

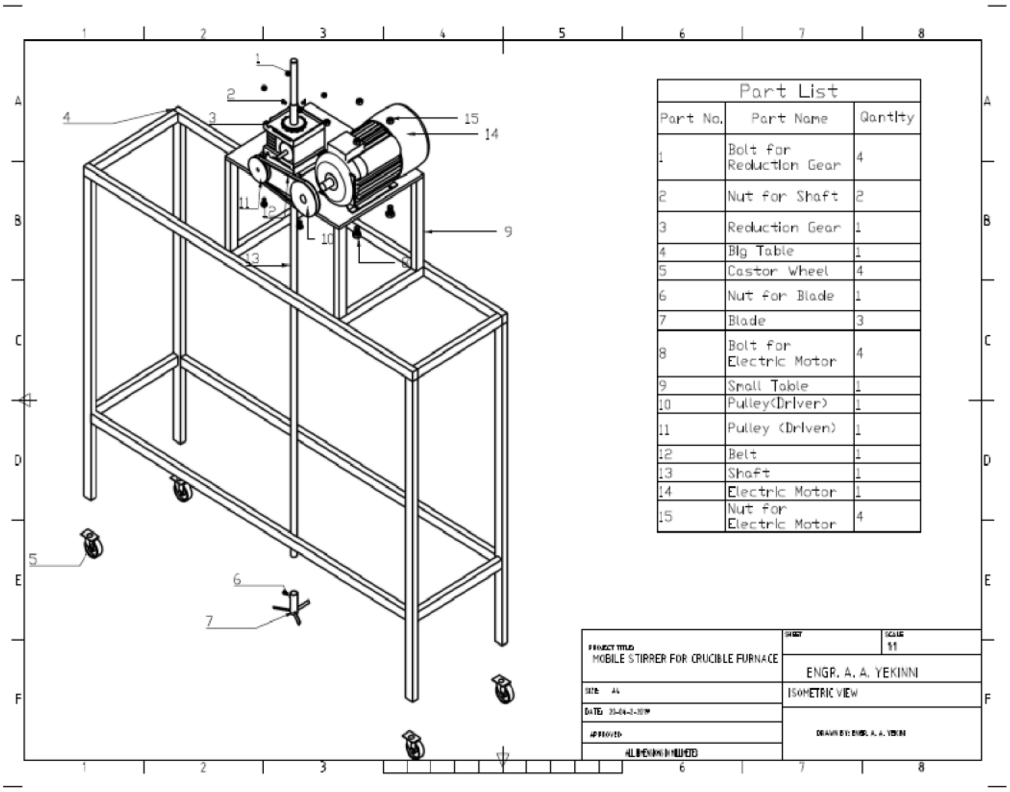
$$L = 2C + 1.57\,(D - d) + \frac{(D-d)^2}{4C} \qquad (2)$$

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

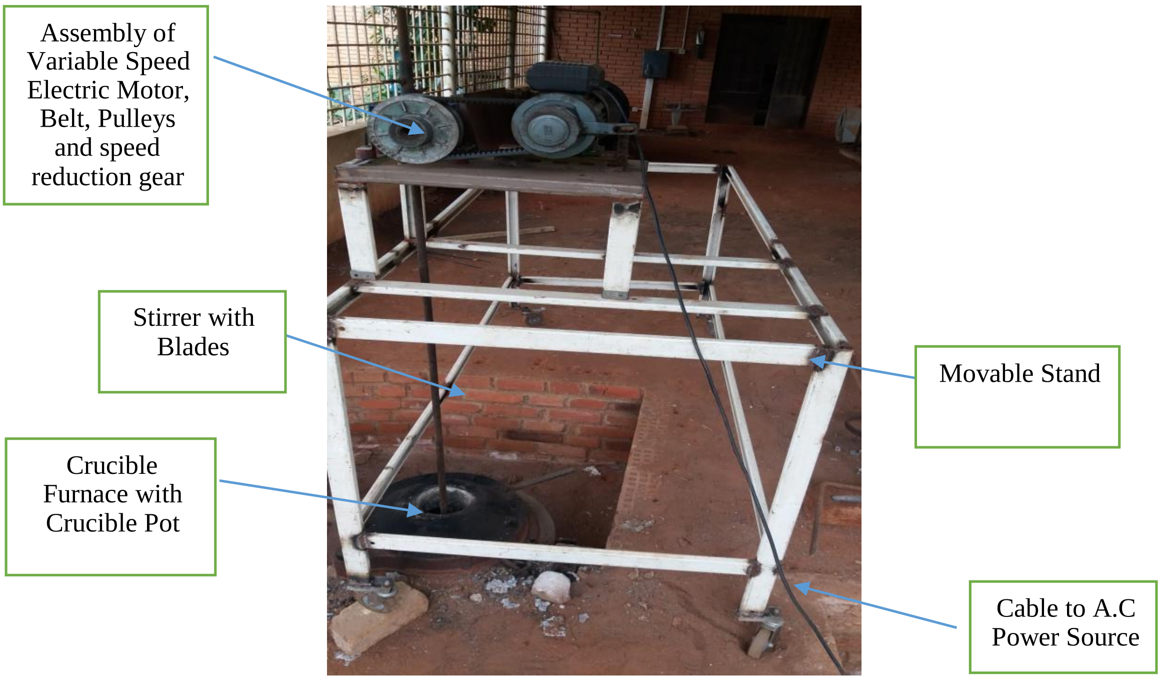


Plate 1: Fabricated and Improvised Stirrer Set up for Stir Casting

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 °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 °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.

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

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 °C before melting at 750 °C and 6, 8 and 10 % wt. rice husk ash was measured and preheated to about 100 °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.

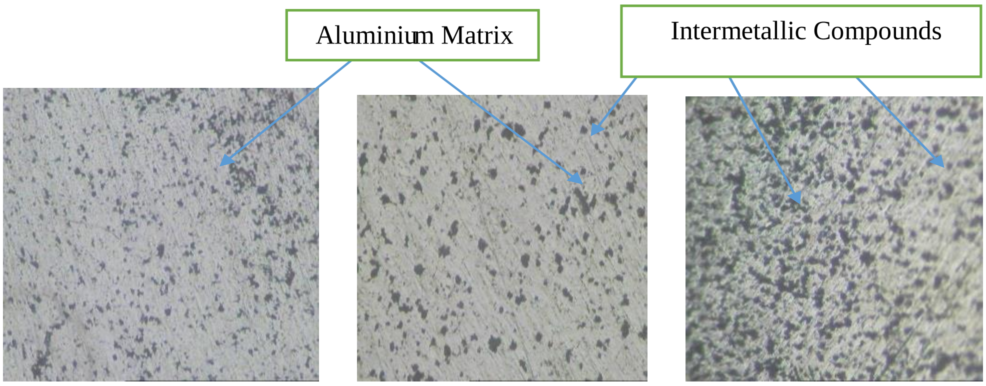
A designed and developed stirring set-up (Plate 1) was improvised for proper stirring through which a steel rod stirrer is lowered into the molten melt slowly up to 2/3 of the height of the molten metal from the bottom of the crucible pot. The molten metal was stirred by the improvised stirrer at a speed 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. Experimental evaluations demonstrated that the mobile stirrer significantly improved temperature uniformity, reduced melting time, and enhanced the overall combustion efficiency of the furnace. The optical micrograph of Al/RHA composites produced confirmed homogenous casting with isotropic grain structure.

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