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Effect of Vibration on Mechanical Properties in Sand Casting Process using Organic Binder

Shah Alam Bhuiyan[1,*], Anayet U Patwari[1], Wasib U Navid[1], Rahman M Morshed[1], Sakib A Showkhin[1]

[1] Department of Mechanical & Production Engineering, Islamic University of Technology, Gazipur, Dhaka, Bangladesh

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ABSTRACT

Casting setups must create the components with a short lead time in today's highly competitive world market. This essential industry now demands defect-free castings with low production costs. Rejection of casted products is caused due to defective components which are influenced by various factors which includes process parameters, all of which can be optimized to improve the quality of the casted products. In this study, an experimental approach was made using vibrated assisted techniques to assess the applicability of the method and improvement of the quality of the casted parts using organic binders in terms of mechanical properties especially the tensile strength, hardness and micro-structure of the products. After investigations, it has been observed that with the influence of vibration frequency at 40 Hz with amplitude 2 V the tensile strength has been improved from 176.60 MPa to 180.81 MPa, hardness improvement from HB33 to HB36 and uniformity in the micro-structure has been observed.

1. Introduction

Sand Casting process is one of the simple and versatile process adopted for the fabrication of the casted products. It is mostly used for making compound shapes that are both difficult and costly. There is always a chance of the stated casting process going wrong which will also affect the desired product quality. If there are any minor defects, they can be fixed but in case of any major defects, it could result in significant changes in the final product which will not only consume time but also cost a lot of money. Different research works still now are conducted to improve the sand-casting process technology to solve different qualities faced while casting. Liu *et al.,* [1] tested with 7050 aluminium alloys and compared Ultrasonic cast ingot (UI) with the conventional cast ingot (CI) and found that for hot rolled plates, UI alloy aged faster and aging strength also increased compared to CI alloy. It was concluded that with the application of Ultrasonic wave in casting, the grain size decreases. UI alloy shows better age hardening effect than CI alloy but it lacks in plasticity. Wagmare *et al.,* [2]

* *Corresponding author.*
E-mail address: alomdcc@gmail.com

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studied the effects of varying ultrasonic frequencies on treated LM25 alloy. High frequency ultrasonic vibrations were induced to the molten metal during solidifying. The frequencies were varied from 10 to 50 kHz in the step of 10 kHz keeping the amplitude at 15 V. From their studies, it was found that the grains reduced by 40% from coarse to fine equiaxed grains. Hardness improved by 57.7% as well as the wear properties. Zhao *et al.,* [3] studied the effect of ultrasonic vibration and pressure on the micro structure and mechanical properties of Al-5.0Cu-0.6Mn-0.6Fe alloy. It was found that compared to non-treated alloy, the properties obtained by inducing ultrasonic vibration and pressure resulted in tensile strength, yield strength and elongation of 268 MPa, 192 MPa and 17,1% respectively and also reduced the porosity while solidification. Shi *et al.,* [4] investigated the effects of ultrasonic flexural vibration guided into 35CrMoV steel through an L-shaped guide during solidification on the microstructures, microstructures and mechanical properties of 35CrMoV cast ingot. It was found that the size of grains was smaller compared to the conventional one. Tensile strength increased by 3.14% to 17.12% and elongation increased by 39.13%-287.5% compared to the conventional one at different places of the casted product. Ultrasonic-assisted squeeze casting has been found to have a positive impact on the properties of 2024 Aluminium alloy (Al). The microstructure of the alloy was seen to be restructured into fine grains with an increase in ultrasonic power up to 1.8 kW, which improved the mechanical and morphological properties of the alloy. According to the study, the ultimate tensile strength and young's modulus have improved by 20% to 22%. One of the key qualities of the alloy that determines its mechanical capabilities is the refining of the grains, which has been made possible by ultrasonic vibrations studied by Chen G *et al.,* [5]. Additionally, few studies have been conducted on the introduction of ultrasonic vibration into the solidification process, while many studies to date have concentrated on the impacts of ultrasonic vibration in melt preparation. The tendency of small melt particles to group together and reduce the system's overall free energy is constant. Particulate reinforced metal matrix composites are easily susceptible to the formation of tiny particle clusters [6]. Also, it is simple for oxide inclusions to form on the surface of the molten aluminium, and these inclusions can mix vigorously into the melt [7]. Additionally, as the oxide inclusions solidify and create the porosity in the metal, gases are inexorably entrapped inside of them [8].

It has been found that grain refining can be accomplished either by using external forces to cause fluid movement during solidification, such as rotating the mold, mechanical, electromagnetic, ultrasonic stirring of the melt, etc. The mechanical characteristics of the alloy are gradually improved by vibrations [9-12]. When rolling a 1060 aluminium alloy in twin rolls continuously while adding various doses of Al-Ti-B refiner, a new L-shaped ultrasonic rod was used to create an ultrasonic vibration. It was discovered that the ultrasonic cast rolling strip with 0.18/.12 wt% Al-Ti-B refiner outperformed the conventional cast rolling strip in terms of grain refinement, precipitates that were more uniform, the reduction of slag flaws, and microstructure and characteristics [13]. A T shaped wave guide was used for providing the ultrasonic vibration into a 35CrMo steel die casting melt. Though the microstructure was coarse dendritic grains, after giving ultrasonic vibration they transform to equiaxed grains and the dendrites also become more refined [14]. Molten A356 alloy was given a frequency of 18 kHz and the melt was poured into a mold comprised of ASTM B108-02. It showed better microstructure with low porosity [15].

Investigation was done on the casting fault rectification methods resources, energy and environmental impacts and the cast defects were classified into more component, less component and unqualified component. It was found that impact for less component was the largest, considering 50% of total scrap and 60% resource consumption. The cost for unqualified component defects is 1.8 times higher than average and their energy regeneration was 41% [16]. In continuous casting, it was found that the solidifying slabs undergo creep deformation which might cause flaws in it. To clarify it an as-cast low alloy steel was put under continuous casting process. Creep performances were evaluated with respect to temperature and stress. It was found that under high temperatures the deteriorated creep resistance and enhanced susceptibility to micro crack initiation and propagation [17]. Light metals and innovative casting process provide cost effective technologies to provide light weight components for industrial applications. Here investigation was done for development of light alloy using different components. Innovations regarding gravity casting, high pressure die casting and low pressure casting to overcome issues found while casting [18].

It is necessary to reduce the casting defects that mostly appear during the metallurgical process. It is also crucial to shed light on certain issues, such as the gradient in temperature, the delay in alloy solidification, the surface area of the casting material, the effects of varying volumes of molten metal, and the conclusion that the shape of the mold opening should be squared rather than tapered in order to improve the efficiency of the casting process [19]. It was also discovered that by blending and combining economically and environmentally non-hazardous ingredients, an investment casting sprue wax may be transformed into a low-cost pattern wax with superior qualities to a high-cost commercial one [20]. To prevent the reaction between the ceramic mold and metal that occurs during metal casting processes, an efficient binder system made of aluminium tri-sec-butoxide [Al(OCH(CH3)C2H5)3] and ethyl silicate [C8H20O4Si] can also be created [21]. A novel method has also been devised for creating molds that can withstand heat treatment at 1000 °C, producing cast products with thin walls and intricate shapes. A tetraethyl orthosilicate and sodium methoxide-based inorganic binder and bead powder with strong heat resistance and minimal thermal expansion to molten metal were employed in the novel mold technique [22]. Alternative approaches have been conducted by studying the different types of gating systems and different binder effects assessment on casting process and optimization [23,24]. Investigation was done to find the feasibility to produce magnesium metal matrix nano composite using stir casting process where AZ31B used as matrix and nano alumina (Al2O3) and nano hydroxyapatite (nHA) as a reinforcement. It was found that addition of nHA reinforcement in AZ31B has affects in the microstructure and mechanical characteristics of a nanocomposite made of magnesium metal matrix, including compressive strength, hardness, corrosion resistance and biocompatibility [25]. J. Idris *et al.,* [26] assessed casting quality of AA5083 alloy of four different casting techniques using non-destructive testing (NDT) using liquid penetration test, 3D optical microscope, ultrasonic test. Mardy Suhandani *et al.,* [27] examined to improve the mechanical properties of Al-Si through the addition of Cobalt Oxide (CoO) nanoparticles using stir casting process and observed that the melting temperature during the stir-casting process of Al-Si has played a significant role in influencing the resulted properties of Al-Si filled CoO nanoparticles metal matrix composites for the quality improvement of the casted products. As a part of the quality improvement approaches, an attempt was made to investigate the effects of mechanical vibration applied directly on the middle of the base plate used in the casting process using organic binders located at the bottom of the drag using an electrodynamic shaker and to investigate its effect as initial findings assessment in this study.

2. Methodology

The experiment was carried out with vibration assisted sand casting process using cotton seed oil as binders. Cotton seed has been collected and extraction were made accordingly using special type of locally made grinding machine. Extraction procedure of the cotton seed grinding process are shown in Figure 1. The fundamentals of the molds' compositions and the percentages of the binding materials in the mold are shown in Table 1. The molds have a circular cross-section at the gate. A wood pattern for the cast product was made and mold was created accordingly. The bottom gating system was used to ensure that inside the mold cavity, the molten metal flows without turbulence.

Table 1
Compositions of the mold materials

Compositions	Percentage (%)
Silica Sand	80%
Cotton Seed Oil	6%
Bentonite	7%
Coal powder	2%
Water	5%

The riser, basin, and gate were all installed and standard formulae were used to ensure the best results in casting for excellent quality with no flaws. The casting metal chosen was aluminium. The aluminium was melted at a temperature of over 700-750 °C in a crucible furnace.

Fig. 1. Extraction steps for collecting the cotton seed oil used as binders in this study

The molten metal was formed after the metal was melted and a ladle was used to pour metal into the mold's basin. The experiments were carried out using an electrodynamic shaker [model 2007E] as an excitation model unit within the bottom of the drag keeping the vibration frequency at 40 Hz with amplitude 2V. Different equipment used in this study are shown in Figure 2.

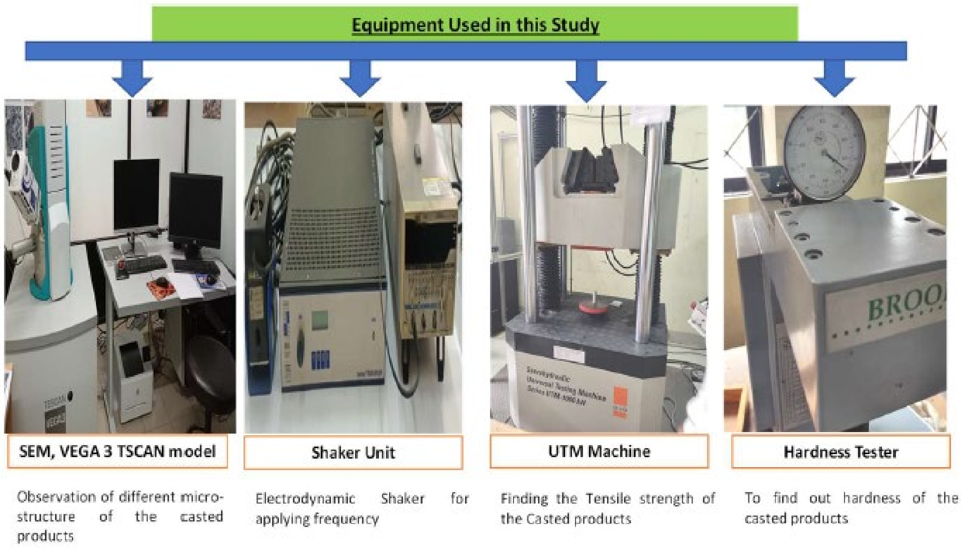

Fig. 2. Different Equipment used in this study

In this study, several experiments have been conducted considering two different conditions without vibration and with vibration. In vibration assisted techniques 40 Hz frequency has been considered to assess the effectiveness of the study. Mold preparation and experimental procedure are shown in Figure 3.

The tensile specimen has been prepared using ASTME8 for Tensile specimen standard. In hardness test, 1/16-inch indenter with 100 kg applied load has been used to find out the hardness foe both the specimen using vibration and without vibration conditions. The tensile strength of the specimens has been determined by using universal testing machine (w+b) of servo-hydraulic type of series UTM-1000KN.

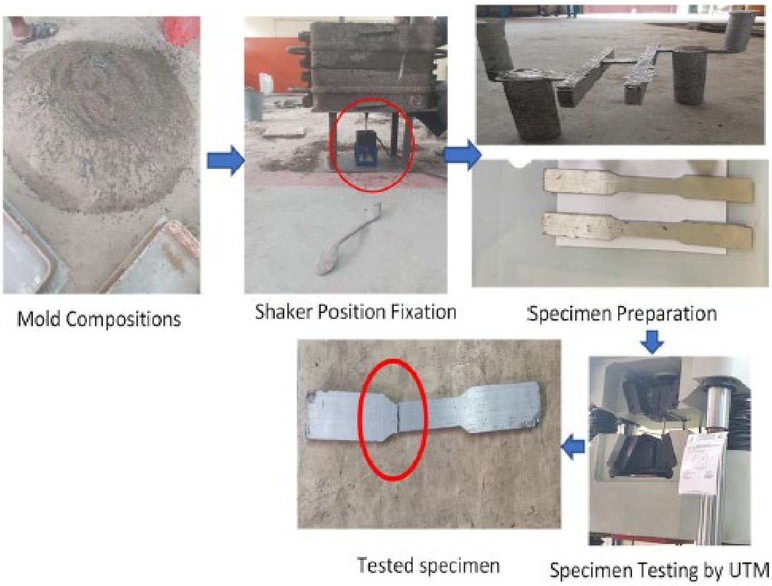

Fig. 3. Different steps involved for the experimentation and Testing

3. Results

3.1 Effect of Vibration on Mechanical Properties

This section discusses the different results obtained from experiment with and without vibration effect on tensile strength variation, hardness variation and SEM analysis are discussed for a particular set of experiment considering the vibration frequency at 40 Hz with amplitude 2 V positioned on the base plate of the casting platform keeping all other parameters same. The detailed discussion is made in the following sub-sections.

3.1.1 Tensile test comparison

A universal testing machine Series UTM 1000 KN has been used to find out the tensile strength of the aluminium casted products using the ASTM E8 standard with and without vibration. Different samples specimen was casted and tested accordingly to assess the tensile strength of the products. Figure 4 expresses the deformation (%) versus tensile stress of the casted specimen having the similar dimensions.

It has been observed from the Figure 4 that with vibration specimen has high strength compared to without vibration specimen and ductility is also better in vibration assisted casted products. Figure 4 reveals the tensile strength of without vibration casted products 176.60 MPa whereas 180.81 MPa strength was found for vibration assisted casted products. In case of elongation in terms of deformation percentage without vibration specimen elongated 0.56 % whereas vibration assisted specimen elongation capacity improved up-to 0.62%.

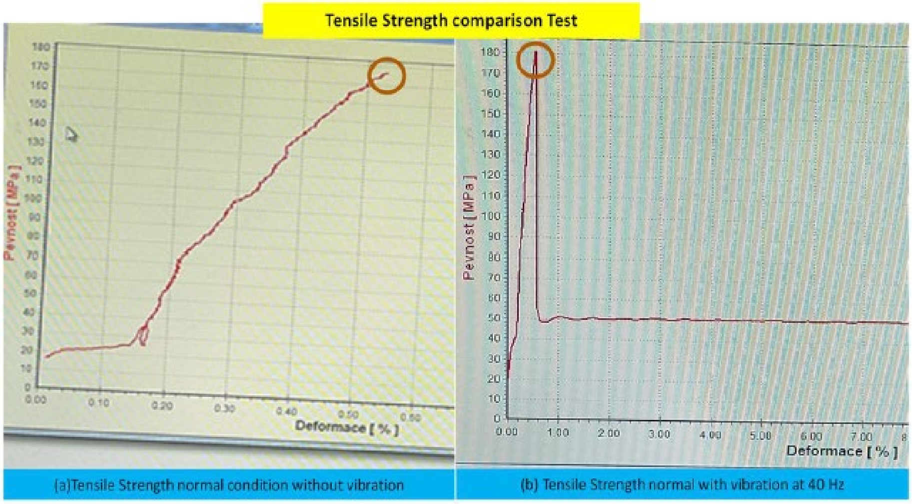

Fig. 4. Tensile strength (a) Without Vibration (b) With Vibration

3.1.2 Hardness variation and micro-structure analysis

A Brooks hardness testing machine has been used with 1/16-inch indentation keeping 100 kg load to measure hardness value of the specimen of without vibration and with vibration. It has been observed that in vibration assisted specimen the hardness measured in Brinell scale was 33 HB whereas in vibration assisted specimen hardness was slightly improved as 36 HB. Measurement was made in different locations of the specimen and average value were taken into consideration to measure the hardness values.

Further analysis has been made to investigate the grain structure of two different conditions to map the possible reasons of the improvements. A Scan Electron Microscope (VEGA 3 TESCAN) was used to capture the microscope image of with and without vibration. Figure 5 indicates the scan image evidence of the micro-structure assessment for both the sample specimen. It has been observed that in vibration assisted casted products has more uniform grain structure compared to without vibration specimen.

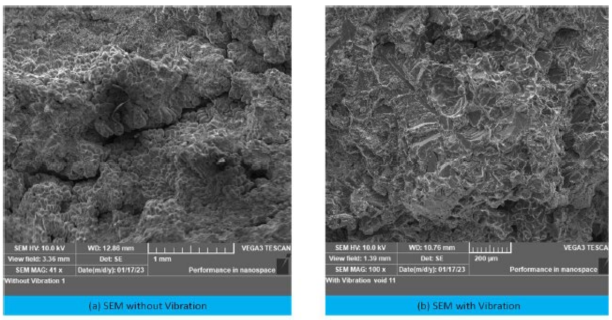

Fig. 5. Micro-structure analysis (a) Without Vibration (b) With Vibration

4. Conclusions

A vibration assisted approach using an electro-dynamic shaker has been applied on a base plate has been adopted to investigate the quality of casted products and relevant analysis were made to find out the quality of the products in terms of mechanical properties improvement. In the process of preparing the mold materials organic binder extracted from cotton seed oil has also been used to find out the combined effects and the following initial observations has been made.

i. The measured tensile strength of the vibration assisted casting process has been improved from the scale of 176.6 MPa to 180.81 MPa for 40 Hz frequency with amplitude 2V of mechanical vibration. The elongation of the vibration assisted casted products has been improved from 0.56% to 0.62%. Further analysis will be made with different vibration frequency and vibration amplitude.
ii. It has also been observed that the measured hardness value has been improved slightly from HB33 to HB36 and also improvement of grain structure featured observed from SEM view showed the grain structure uniformity in case of vibration assisted casting process compared to traditional approach.

From the discussion stated above, it has been observed that with the application of vibration the mechanical properties of the casted products have been improved and showed the initial effectiveness of the proposed method. This method may be used to get the better quality and defect free casted products.

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