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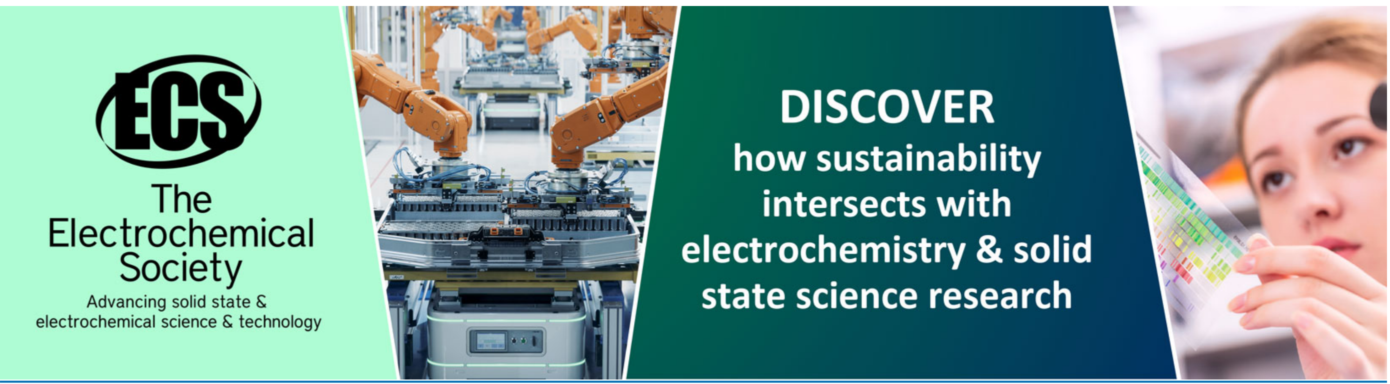

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Effect of vibration of moulding on the gravity casted specimen during pouring of molten aluminium in metallic mould

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Abstract. Effect of vibration moulding has been carried out for different advanced cast products, such as die cast aluminum cylinder head, etc. Vibration moulding generally decreases the solidification time of the casting which is very important for the microstructure of cast aluminum alloys. In the present investigation, the effect of applying vibration of mould (i.e., made of cast iron) during pouring of aluminium alloy was analyzed. The mould meant for making tensile test specimen was tightly clamped on the vibration table, which vibrated with suitable frequency and amplitude.

The characteristics including microstructure, hardness and tensile strength of the specimens made by with-vibration and without-vibration gravity casting processes were observed. The finer grain and denser microstructure were found in the material produced by vibration casting process compared to normal gravitation casting (with-out vibration) process. Ultimate tensile strength (UTS: 224 MPa) and elongation (3.23%) of the vibrated moulding specimens were significantly higher than the conventional gravity casting AlSi-10Mg alloy specimens (UTS: 129 MPa and elongation: 1.03%). The compared results showed significant improvements in the properties for the vibration gravity casting process.

The problems in the common gravitation casting (without-vibration) normally faced are porosity, blow holes and leakage. However, these casting defects could be easily avoided by using vibration moulding at suitable frequency. Interestingly, the dense microstructure obtained from the microscopic study in the vibration casting process showed that the above mentioned problems can be eliminated easily.

Keywords: Aluminium alloy, vibration, permanent mould, density, microstructure, tensile strength, hardness, casting quality.

1. Introduction

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Aluminium–silicon based alloys have been considered as one of the most commonly used foundry alloys. They are used due to several advantages, including excellent castability, good thermal conductivity, high strength-to-weight ratio, high wear and corrosion resistance, good weldability and pressure tightness. One of the main challenges faced in the foundries is controlling the microstructure obtained from the casting process [1]. Fine grained structure normally exhibits desired mechanical properties that included high strength and high ductility. The applying mechanical vibration, including mechanical, sonic or ultrasonic vibration, to a mould during solidification has some effects on the mechanical properties of the casting products. The main advantages of vibration might be increased density, grain refinement, low shrinkage and dimensional change, degassing, and distribution of the second phase [2-4]. In conventional gravity casting, there might be several defects, such as porosity, short flow, leak testing failure, low strength, blow holes, low hardness, varying microstructures, and so on. Therefore, these defects can be avoided using mould vibration technique during solidification of casting products. In the present investigation, the effect of applying vibration of mould (i.e., made of cast iron) during pouring of aluminium alloy was analyzed. Therefore, in the present study, we differentiate the physical, microstructural, and mechanical properties of vibration moulding aluminium-silicon 10 magnesium (Al-Si 10Mg) cast product from the conventional gravity cast product. Both the casting techniques have very good dimensional precision. The main advantages of this study are the used vibration technique is very cheap compared to the previously used sonic and ultrasonic methods and it is very much effective than the normal mechanical agitation method.

2. Materials and Methods

Commercial graded aluminium-silicon 10 magnesium (Al-Si 10Mg) alloy was used as a raw casting material. The alloy was first melted in a muffle furnace at 670°C. Then the melt was solidified by two methods, one by conventional casting and another by vibration moulding techniques. In the conventional casting technique, the melted alloy was poured in a suitable cast iron mould without using any vibration during solidification. But in vibration moulding technique, the melted alloy was poured in a cast iron mould with a constant vibration (frequency: 30 Hz, amplitude: 1mm) during solidification process by tightly clamping on a vibration table. A concrete vibrating equipment was employed for mounting the mould on the vibration table. The effect of applied vibration of mould during pouring of this aluminium alloy on the casted samples was evaluated by material characterization techniques. The molten Al-Si-10Mg alloy made ready for conventional gravity casting without vibrating the mould and the alloy made ready pour in a cast iron mould tightly clamped on a cheap concrete vibration table for vibration casting are depicted in **Figures 1a** and **1b**, respectively. Various properties of the vibration cast product were then compared with the conventional gravity cast product. The conventional gravity cast sample is denoted by AlG1 and with mould vibration cast sample is denoted AlV1 in the present study.

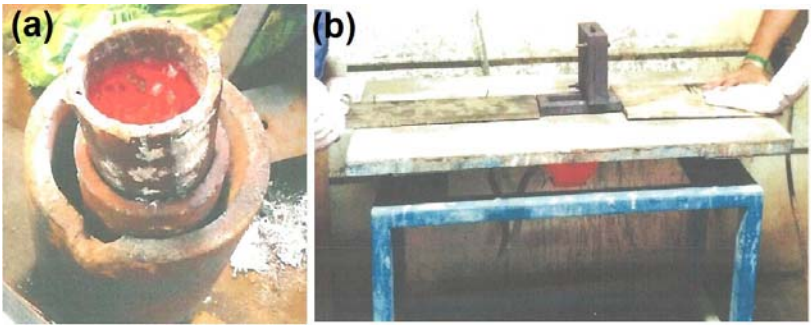

Figure 1. Molten Al-Si-10Mg alloy **(a)** made ready for conventional gravity casting without vibrating the mould and **(b)** ready pour in a cast iron mould tightly clamped on a cheap concrete vibration table for vibration casting. Note: In the vibration method, the entire mould is set into vibration and it is one of the best available methods due to cheapest, simplicity, and rigidness of the equipment for inducing vibrations.

The finished products of gravity casting are shown in **Figure 2a**, G refers to the gravity casting without vibration and in **Figure 2b**, V refers to the casting with mould vibration.

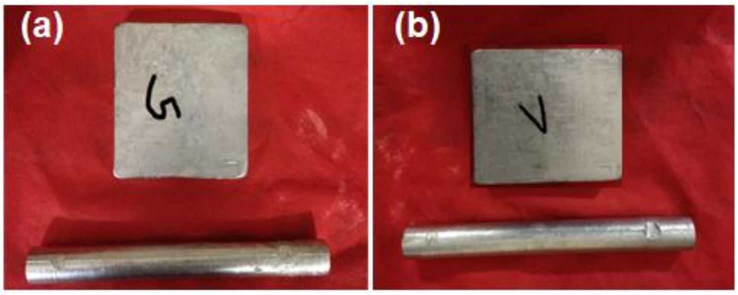

Figure 2. Finished product from the casting: **(a)** conventional gravity cast (AlG1) and **(b)** with mould vibration cast (AlV1).

3. Experimental

3.1. X-ray diffraction

X-ray diffraction (XRD) study was conducted in the range of diffraction angle, $2\theta = 10 - 80°$ of Cu Kα radiation using x-ray diffractometer (model: XPert Pro, make: PANalytical, country: UK) at normal scanning.

3.2. Density

Density of the AlG1 and AlV1 samples was conducted by Archimedes' principle using equation **Eq.1** and bulk volumetric using equation **Eq.2** methods using a weighing machine of resolution ±0.0005g as reported elsewhere [5]. At least 3 identical specimens were used to calculate the mean density of both the samples.

$$\rho_{Arch} = (W_1/W_2) \times \rho_{water} \quad (1)$$

$$\rho_{Bulk\ volumetric} = (W_1/V_{bulk\ volume}) \quad (2)$$

Where, ρ_{Arch} is Archimedes' density, W_1 is weight in air, W_2 is the weight in water, ρ_{water} is density of water at room temperature (25°C), and $V_{bulk\ volume}$ is bulk volume of the sample (i.e., width × breadth × thickness).

3.3. Microstructure

Microstructure of the gravity cast and with mould vibration cast specimens was viewed by light optical metallurgical microscope (model: BX-KMA-LED, make: Olympus, country: Japan) at different magnifications.

3.4. Hardness

Surface hardness property of the gravity cast and with mould vibration cast specimens was determined by Rockwell hardness tester (model: RASNE-3, make: Fuel instruments and engineers (P)LTD, country: India) using load 100 kgf load for 10 sec in HRB scale.

3.5. Tensile

Mechanical properties of the gravity cast and with mould vibration cast specimens were determined by tensile strength and elongation using universal tensile machine (UTM, model: TUE-CN-400, make: FSA (P) Ltd, country: India) at a cross-head speed of 1 mm/min. The rod shaped specimens of diameter 12 – 13 mm and length of 90 – 100 mm were used for the tensile test.

4. Results and Discussion

4.1. X-ray diffraction

XRD patterns of the gravity cast (AlG1) and mould vibration cast (AlV1) samples are depicted in the **Figures 3a** and **3b**, respectively. The face centered cubic crystal structure was observed for both the samples. The XRD patterns of this Al based alloy resembled with the peaks of standard Al of *JCPDS file # 00-004-0787*. A few extra peaks found around 27.6° and 55.45° attributed to Si and Mg. It has been noticed that the crystal growth of the Al-alloy has been changed from 111 (for AlG1) to 200 (AGV1) orientations due to the vibration of mould during solidification. The heterogeneous growth or different orientations crystalline growth was confirmed by XRD. It may improve elongation compared to conventional gravitation. In addition, peak intensity has significantly intense in case of with mould vibration cast (AlV1) sample compared to the conventional gravity cast (AlG1) sample. It clearly indicates the reduction of grain size due to the effect of vibration during solidification of this Al-alloy. Further, the crystallite size was calculated by Debye Scherer equation [6] as given in **Eq.3**.

$$t = \frac{0.9\lambda}{\Delta\theta_{\frac{1}{2}}\cos(\theta_{\mathrm{B}})} \tag{3}$$

Where, $\Delta\theta_{½}$ (in rad) is the full-width at half-maxima (FWHM) of $2\theta_B$ and θ_B (in degree) is the Bragg's angle. The instrumental broadening is considered by using a standard XRD of silicon wafer sample. Using the Debye Scherer equation, it has been found that the crystallite sizes of the gravity cast (AlG1) and with mould vibration cast (AlV1) samples are 26 nm and 20 nm, respectively. It also follows our prediction by XRD peak intensity analysis.

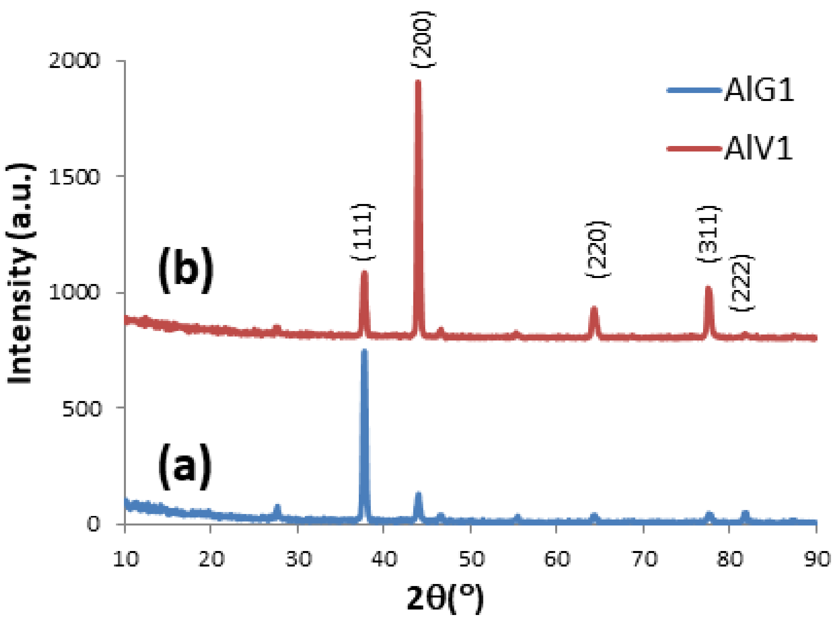

Figure 3. XRD of the **(a)** AlG1 and **(b)** AlV1 samples.

4.2. Density

Density of the gravity cast and with mould vibration cast specimens was conducted by Archimedes' principle as well as volumetric method using a weigh machine of resolution ±0.0005g are illustrated in **Table 1**. At least 3 identical specimens were used to calculate the mean density and their standard deviation (Stdv) of both the samples.

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Table 1. Density of AlG1 and AlV1 samples

Sample	Archimedes' Density Mean±Stdv (g/cc)	Volumetric Density Mean±Stdv (g/cc)
AlG1	2.5872±0.0879	2.5886±0.0143
AlV1	2.5955±0.0972	2.6000±0.0068

4.3. Microstructure

It has been found that the grain size of the AlG1 and AlV1 samples under optical micrographs are shown **Figures 4a** and **4b**, respectively. The average grain size in the AlG1 and AlV1 are computed as 12.5 μm and 7.5 μm, respectively. Grain size has significant effects on the mechanical properties of alloys [7, 8].

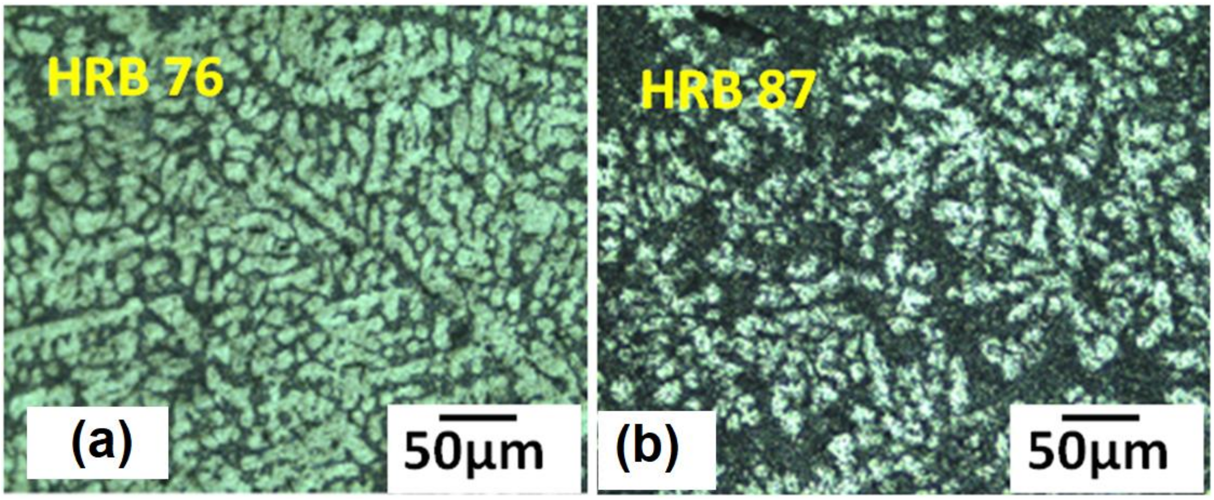

Figure 4. Optical micrographs of **(a)** AlG1 and **(b)** AlV1 having Rockwell hardness HRB 76 and HRB 87, respectively. Note: grain refinement occurred via mould vibration during solidification of the Al-Si-10Mg alloy.

4.4. Hardness

Average Rockwell surface hardness property of the AlG1 and AlV1 specimens was found to be HRB 76 and HRB 87, respectively as depicted in the **Figure 4a** and **4b**. It indicates the significant effect of mould vibration during solidification. This hardness value increased due to the grain refinement happed due to the mould vibration as revealed in the **Figure 4b**.

4.5. Tensile

Mechanical properties of the AlG1 and AlV1 samples under optical micrographs are shown **Figures 5a** and **5b**, respectively. The tensile mechanical properties of AlG1 and AlV1 samples are illustrated in the **Table 2**. It has been found that all the AlV1 samples have significantly higher yield stress, ultimate tensile stress, % elongation as well as % reduction in cross-sectional area compared to AlG1 due to the significant effect of vibration mould during solidification of Al-alloy casting product. The result of effect of vibration resembles with the other groups [9]. The increase in hardness and strength due to the grain refinement (see **Figure 4**)[10], together with increase in elongation might be attributed to the different orientations crystalline growth or heterogeneous grain growth during solidification of vibration mould. The mould vibration mainly enhanced the density, strength and hardness. On the other hand, the heterogeneous grain growth or different orientations crystalline growth, which was confirmed by XRD, would mainly responsible for the improved elongation compared to conventional gravitation. It is also incorporated in our revised manuscript. Therefore, it can be predicted that both strength and toughness can be improved by vibration having suitable frequency [8] of mould during solidification of Al-alloys in casting products.

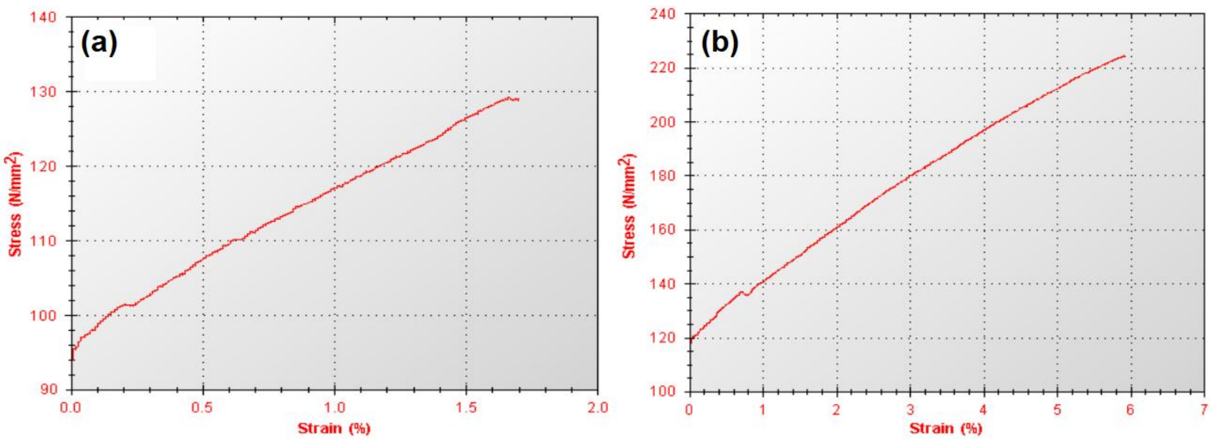

Figure 5. Tensile stress-strain curves of the conventional gravity cast (AlG1) and with mould vibration cast (AlV1) samples.

Table 2. Tensile mechanical properties of the AlG1 and AlV1 samples

Tensile properties	**Conventional gravity cast (AlG1)**	**With mould vibration cast (AlV1)**
Yield strength (MPa)	95	120
Ultimate tensile strength (MPa)	129	224
Elongation (%)	1.03	3.23
Reduction in cross-sectional area (%)	2.18	3.82

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5. Conclusions

In the present study, we investigated the effect of vibration on mould during pouring of aluminum based alloy (AlSi-10Mg) and its solidification. Significant difference in crystallite size, density, hardness, tensile strength, and micro structure has been observed for the specimens made by conventional gravity casting (AlG1) and with mould vibration casting (AlV1). It has been found that vibration given to mould while pouring molten metal led to different solidification process with distinct crystal growth in different orientation compared to conventional gravity casting without vibration. The grain refinement observed by XRD and microscopy in the AlV1 samples, which were given vibration, further enhanced density, hardness, strength as well as toughness significantly. The main novelty of this study is that the strength and toughness can be improved using an inexpensive mould vibration technique during solidification of this aluminium alloy compared to conventional gravity casting or other expensive casting techniques. Thus, this AlV1 material will have good thermal conductivity as well as excellent wear resistance. Therefore, this high strength and tough aluminium alloys developed by suitable vibration would perfect materials for manufacturing industries, such as medical instruments, 3D printer components, toys, and so on, where aluminium based alloys are used as mould materials.

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