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Research Article

WEIBULL DISTRIBUTION OF ELECTRICAL CONDUCTIVITY OF A356 ALUMINIUM ALLOYS VIA VIBRATIONAL CASTING

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ABSTRACT

Mechanical vibration is the easiest and cheapest way to enhance properties of the castings, such as mechanical, electrical, chemical. Also, chemical agents such as grain refiners could assist to improve the casting properties. In this study, coupled actions of mechanical vibration and grain refiners were applied to the castings to investigate the electrical conductivity of Al7Si0,3Mg (A356) aluminium alloy. Grain refiner, Al5Ti1B, was added to Al7Si0.3Mg alloy in the form of three different addition of 0.1, 0.2, and 0.3 wt.%. The castings were carried out with and without grain refiner on vibrational casting technique. Another investigation of this study is to demonstrate the effect of excess grain refiners on the microstructure having solidified under vibrational forces. The results were evaluated by means of electrical conductivity with Weibull Distribution, and SEM micrographs. Reliable and reproducible results were found in the middle section of 0.1 wt.% Ti grain refined samples which had a Weibull Modulus of 512 and 33.73 IACS%. It is demonstrated that vibrational casting has no effect on the distribution of grain refiners in the microstructure.
Keywords: Weibull distribution, electrical conductivity, vibrational casting, aluminium alloys, grain refining.

1. INTRODUCTION

In the original paper of Weibull, 1951, he introduced a statistical perspective into materials science, especially on the mechanical properties [1]. Some researchers [2-9] coupled this statistical perspective to the foundry applications. Since melt quality is the root cause, hence most of the casting defects are associated with it and its processing, a wide range of researchers were focussed on the reliability of the melt quality measurements [2-4, 8]. Dispinar, et. al [2,3] used Weibull analysis to assess melt quality, while Tunçay and Bayoğlu [6], Zahedi, et. al [7], and Tan, et. al. [8] tried to estimate the tensile properties of different aluminium alloys. Also, Yüksel [9] carried out Weibull analysis from a different point of view in order to interpret the properties of cast metals, such as fluidity. Timelli, et. al [10] characterized the pressure tightness of the aluminium radiators with Weibull distribution and they have found the probability of the failure under the exact pressure. Another application of Weibull Analysis was demonstrated by Ku, et. al. [11]. They investigated the effect of tool rotational speed on 7075 aluminium alloy with 1230, 1450 and 1670 rpm in friction stirred welding technique, and found that 1230 rpm has the lowest

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scatter, and is the best choice. Chen and Griffiths studied a four-point bend test to estimate the effect of double oxide defects in aluminium alloys. Localized double oxide, especially the upper side of the casting parts, had a high deteriorated effect on the casting parts having low Weibull modulus.

The two-parameter Weibull distribution is used to define any data by:

$$P = 1 — \exp[—\left(\frac{x}{H}\right)^{m}] \quad (1)$$

where P is the probability or the fraction of samples failed below x, H is a characteristic value of x, and m is Weibull modulus [9, 13].

In the literature, there are several methods to determine Weibull parameters. In this study, the linear regression technique is used. If logarithm of Eq. (1) is taken twice, hence the equation becomes;

$$\ln(\ln(1/(1-p))) = m \ln(x) — m \ln(H) \quad (2)$$

Then, Eq (2) becomes a linear plot of ln(x) and ln(ln(1/(1-P))). The slope of this linear plot is m (Weibull Modulus) and the interception of —m ln(H) is the characteristic value [9, 13]. There are numerous calculations to obtain probability, P, in the literature [14-16]. Kirtay and Dispinar [13] is proposed that the most stable technique to procure P is the Hazen estimation, and it is determined by;

$$P = \frac{i — 0{,}5}{n} \quad (3)$$

where i is ascending order of the rank and n is the number of the total specimen number in Eq (3).

Mulazimoglu, et. al [17] reported that electrical conductivity could be useful to quantify eutectic modification for non-destructive testing of materials via microstructural evaluations. They have found that Sr-containing alloys have higher electrical conductivity vis-à-vis not having strontium. Argo, et.al. [18, 19] carried out an electrical conductivity technique to measure the dendrite arm spacing (DAS) and modification in aluminium-silicon alloy castings. They have often used Al7Si0.3Mg (A356) aluminium alloy to reveal the efficiency of the method, and demonstrated that electrical conductivity could be operated for aluminium alloys as a non-destructive test (NDT) for microstructural examination [20]. Green and Campbell [21] cast test specimens under three different conditions, namely top filling, turbulent bottom filling, and turbulence-free bottom filling, in dry sand moulds to investigate the statistical distributions of specimens with respect to mechanical properties, such as tensile test. They found that turbulence-free bottom casting having Weibull modulus of 37.7 was by far the best. On the other hand, Weibull modulus of 20 was the best among the turbulent bottom and top filling conditions. Nyahumwa [22] investigated the effect of oxide films on the fatigue crack in aluminium casting. By using two-parameter Weibull analysis, he reported that young oxide films are much detrimental than old oxide film on the fatigue life of the casting parts.

2. MATERIAL AND METHOD

In casting studies, primary Al7Si0.3Mg aluminium alloy was melted. Table 1 shows the chemical composition of the alloy.

Table 1. Chemical composition of the aluminium ingot

Si	Mg	Ti	Mn	Fe	Zn	Al
7,20	0,392	0,12	0,001	0,18	0,005	Balance

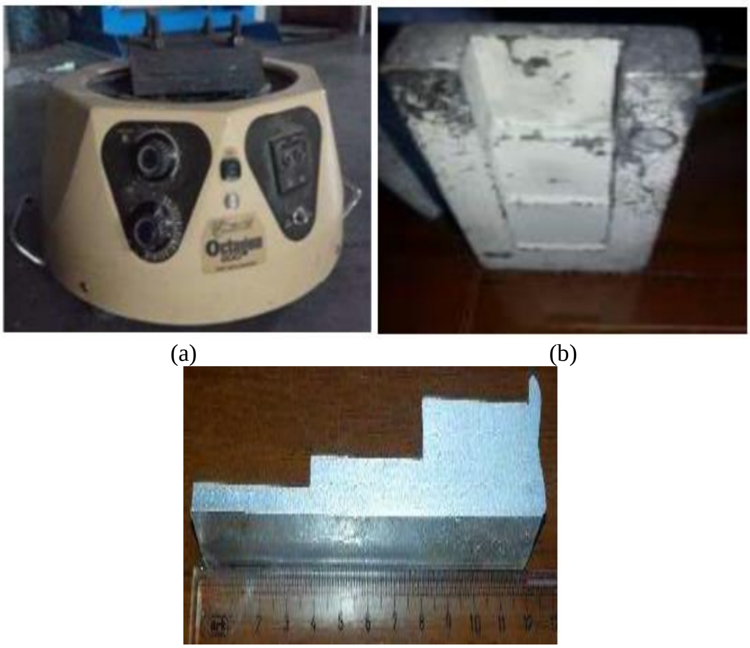
It is aimed to produce finer grains on Al7Si0.3Mg alloys to investigate the effects of grain refining on electrical conductivity. Thus, Al5Ti1B grain refiner was added to the main alloy for this purpose. The chemical composition of grain refiner is also given Table 2.

Table 2. Chemical composition of Al5Ti1B

Ti	B	Fe	Si	Al
5,12	1,09	0,10	0,081	Balance

In melting procedures, an electrical resistance furnace was used to melt the alloys in SiC crucible at 730 °C. In terms of grain refiner, casting having 0.1, 0.2, and 0.3 wt.% grain refiner was cast under vibrational casting with the same frequency of 50 Hz and amplitude of 1.5 mm used a shaking machine, providing vibration for the casting process, shown in Figure 1a. Thus, three different castings with grain refiner and three of without grain refiner were produced.

Also, a casting mold, in Figure 1b, having three different thickness of 5, 10, and 20 mm, was used to cast alloys. It has the same dimensions of width and length with 40 x 40 mm. Mould was preheated to 400 ºC. All castings were poured into the preheated mold and carried out in a vibrational casting technique with 90 secs to allow melts solidifying. And casting specimen were obtained as shown in Figure 1c.



(a) (b) (c)

Figure 1. (a) Shaking machine, (b) Mold, (c) Cast specimen

3. RESULTS AND DISCUSSION

Eisaabadi, et.al. [24] used Weibull distribution to determine the effect of melt quality and filters on tensile strength and elongation of Al7SiMg aluminium alloy. They obtained from Weibull analysis of the tensile test data that 10 ppi filter has 72% effective for trapping the bifilms with a linear trend. Dispinar, et. al [3], and Dispinar and Campbell [4] tried a novel method, Bifilm Index, to assess the melt quality via evaluating Weibull distribution. They have shown the correlation between tensile test results and melt quality using Weibull distribution. An increase in bifilm index due to the hydrogen level of the melt seems to steeper trend. This is because if the liquid metal has enough bifilm, sufficient hydrogen could diffuse into these oxide films to flatten them. But if there are insufficient hydrogen levels, bifilms could not be flattened. Thus, results could be scattered and have lots of min and max values of the tensile test. Similarly, Nyahumwa [22] has demonstrated that old and young bifilms (oxide films) were directly affect on the fatigue life of the casting parts, also added that if the casting is free of bifilms, slip mechanism is the actor and will have to operate. Nashwan and Griffiths [23] were looked into cast iron defects. They reported that turbulence filling is much effective on grey cast iron castings than spheroidal cast iron castings. Furthermore, Weibull plots of grey cast iron castings show high scattering over spheroidal cast iron castings and they also found this sharp difference was occurred due to bubble trial formation on grey cast iron castings. The root cause of the scattering of electrical conductivity values is oxide films, namely bifilms. Most researchers associated bifilms with the properties of castings. Although excess grain refiners directly affect the electrical conductivity, because of Ti if it is found on the solid solution or not, bifilms are the dominant parameter of all alloy castings in this work.

In this work, high slopes of Weibull distribution could be obtained for each three Ti addition values (Fig. 2). As can be seen in Figure 2, melt having 0.1 wt.% Ti has the highest slope in the middle section with 512.30 of Weibull modulus, conversely, grain-refined alloy in the heavy section has the lowest slope with Weibull modulus of 133.60.

In Figure 3, the highest Weibull modulus of alloys is non-grain refined alloy in the thin section with a value of 494.69 and the lowest is grain-refined in heavy section with a value of 96.60. In addition to these, in Figure 4, an alloy having the highest Weibull modulus is grain-refined alloy in the middle section with a value of 899.16 and the lowest one is grain-refined alloy in the heavy section having a Weibull modulus of 75.61.

In all castings of the Weibull distributions, the most reliable, reproducible, and robust option is grain-refined with 0.3 wt.% in the middle section (10 mm) having all-time the highest value of 899.16. On the contrary, the worst, insecure and unreproducible one is the grain-refined with 0.3 wt.% in the heavy section having Weibull modulus of 75.61.

In Figures 5-7, the characteristic values of specimens are shown. In this study, characteristic values are electrical conductivities. Thus, from the figures, it is easily seen that grain refinement enhances the electrical conductivity of alloys. Also, from graphics of characteristic values, in all castings for characteristic values, it could be understood that the best choice is the grain refined with 0.1 wt.% Ti in the thin section having close to 35 IACS%. In addition to this, in graphics of Weibull distributions, the grain refined with 0,1 wt.% Ti in the thin section having Weibull modulus of 266.53. Similarly, for Weibull modulus investigation, the best one is the grain-refined with 0.3 wt.% in the middle section having Weibull modulus of 899.16, but this option has an electrical conductivity of 32.21 IACS%.

For this reason, separating the wheat from the chaff, graphics of both characteristic values, and Weibull distribution should be interpreted together to get the best experimental choice. Thus, optimum, typically, the reliable choice seems to be grain refined with 0.1 wt.% Ti in the middle section having Weibull modulus of 512.30 and 33.73 IACS%.

Figure 8 shows an example of SEM micrograph of the specimen. In SEM investigations, all specimens have the same structures. Practically, in conventional castings, researchers [25] offer that grain refiner addition to alloy not to exceed 0.1 wt.% Ti to success. In this figure, white phases are Ti-rich regions. Thus, vibrational casting has no effect scattering the grain refiners and this study has demonstrated this situation. Çelikaslan, et. al. [26] has shown that different amplitude of vibration has an effect on electrical conductivity without any grain refiner. But the electrical conductivities of their study never reached to even 25 IACS%. This could be due to the effect of grain refiner.

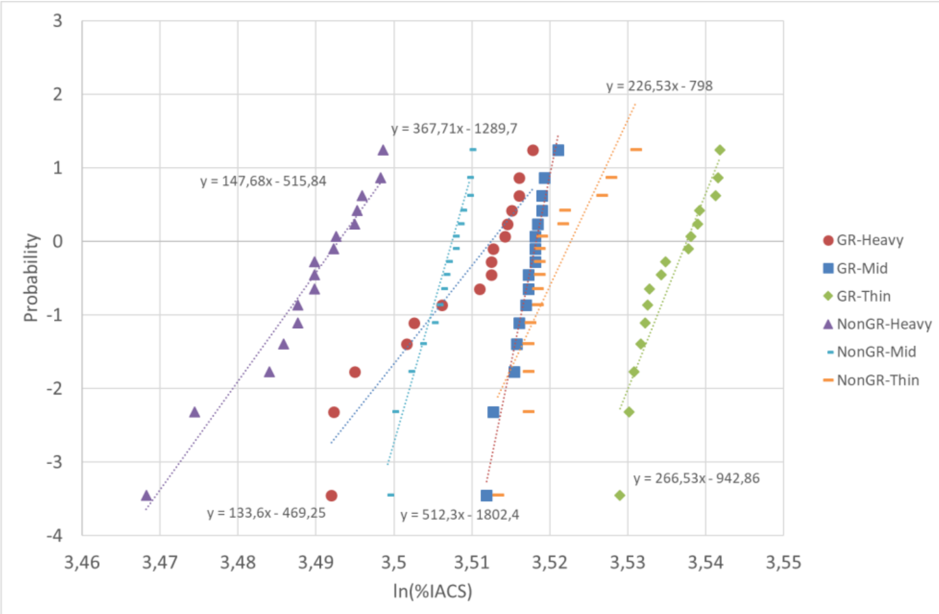


Figure 2. Weibull distribution of grain refined (GR) with 0.1 wt.% Ti and non-grain refined (NonGR) alloys.

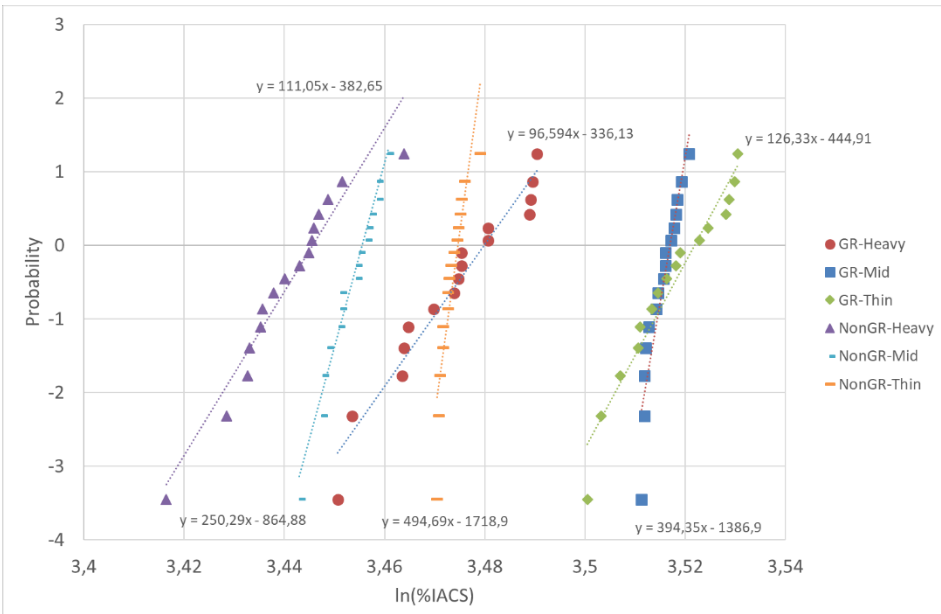


Figure 3. Weibull distribution of grain refined (GR) with 0.2 wt.% Ti and non-grain refined (NonGR) alloys.

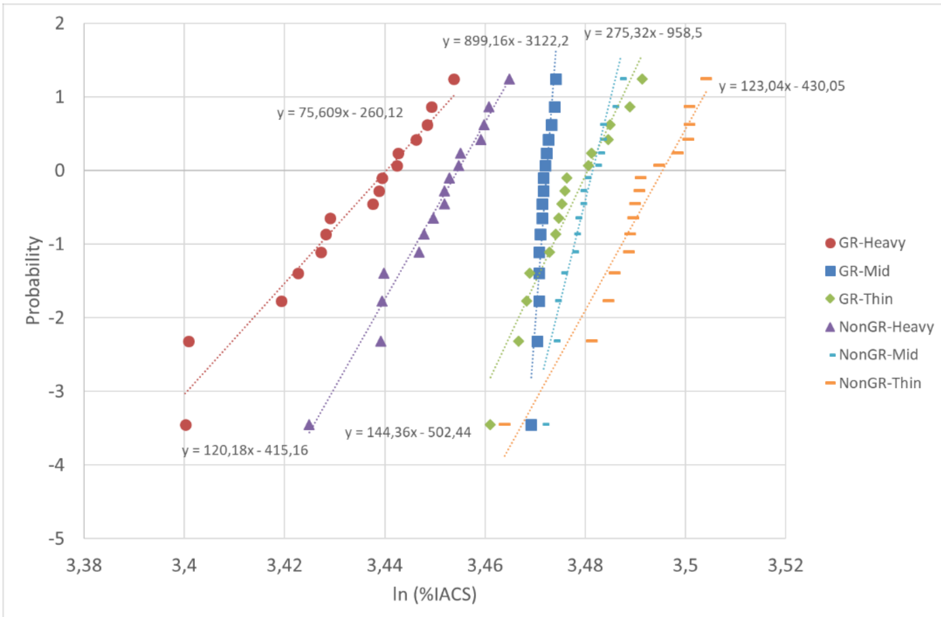


Figure 4. Weibull distribution of grain refined (GR) with 0.3 wt.% Ti and non-grain refined (NonGR) alloys.

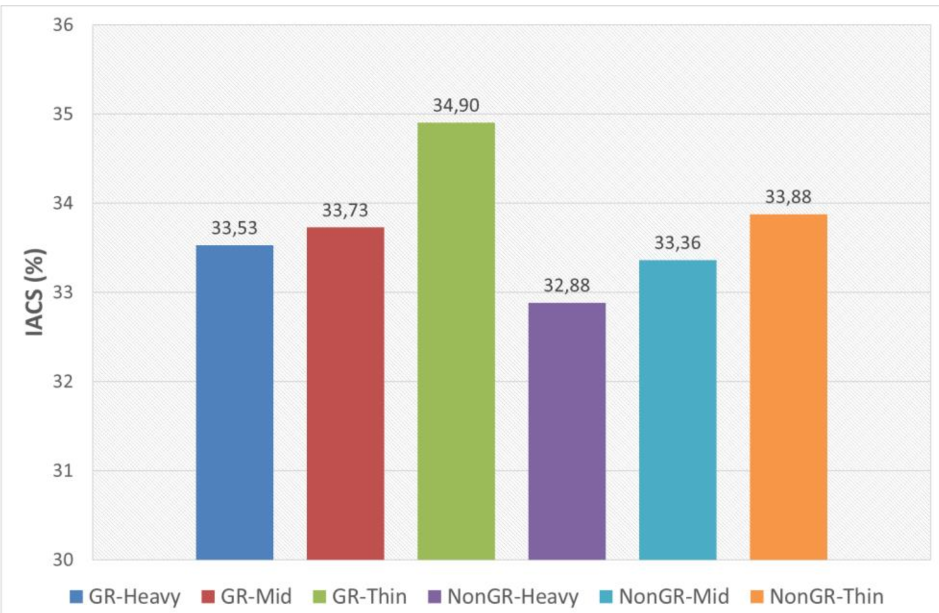


Figure 5. Characteristic values of grain refined (GR) with 0.1 wt.% Ti and non-grain refined (NonGR) alloys.

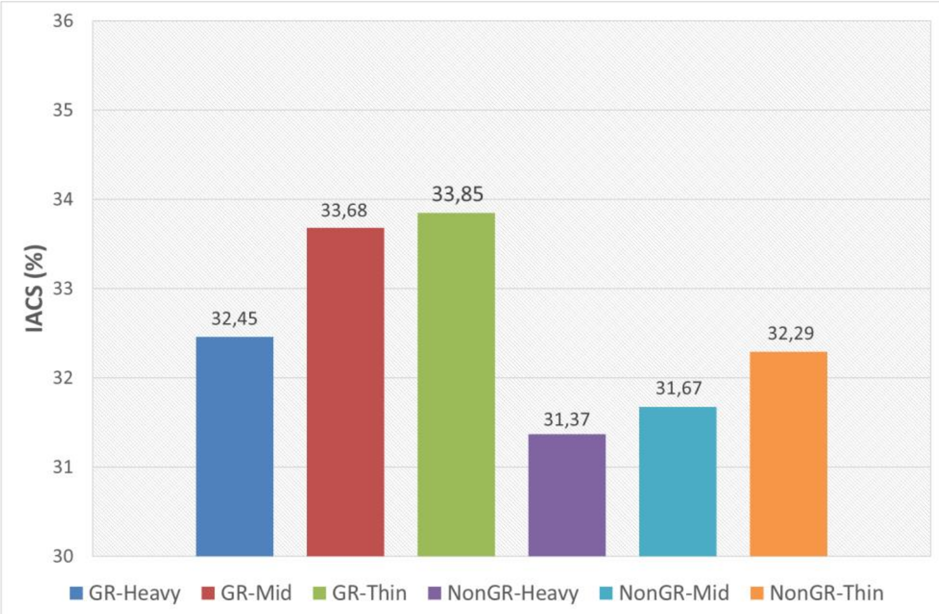


Figure 6. Characteristic values of grain refined (GR) with 0.2 wt.% Ti and non-grain refined (NonGR) alloys.

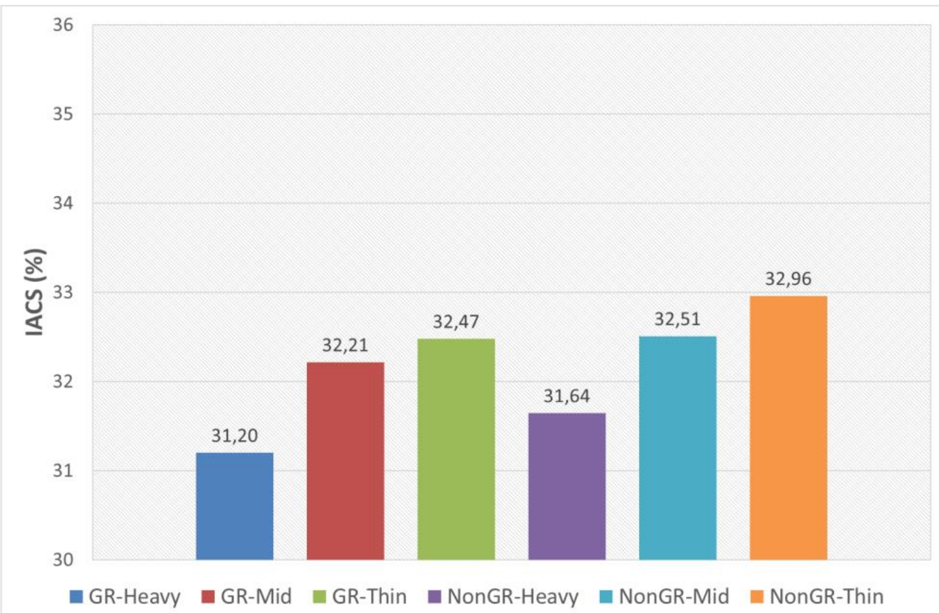


Figure 7. Characteristic values of grain refined (GR) with 0.3 wt.% Ti and non-grain refined (NonGR) alloys.

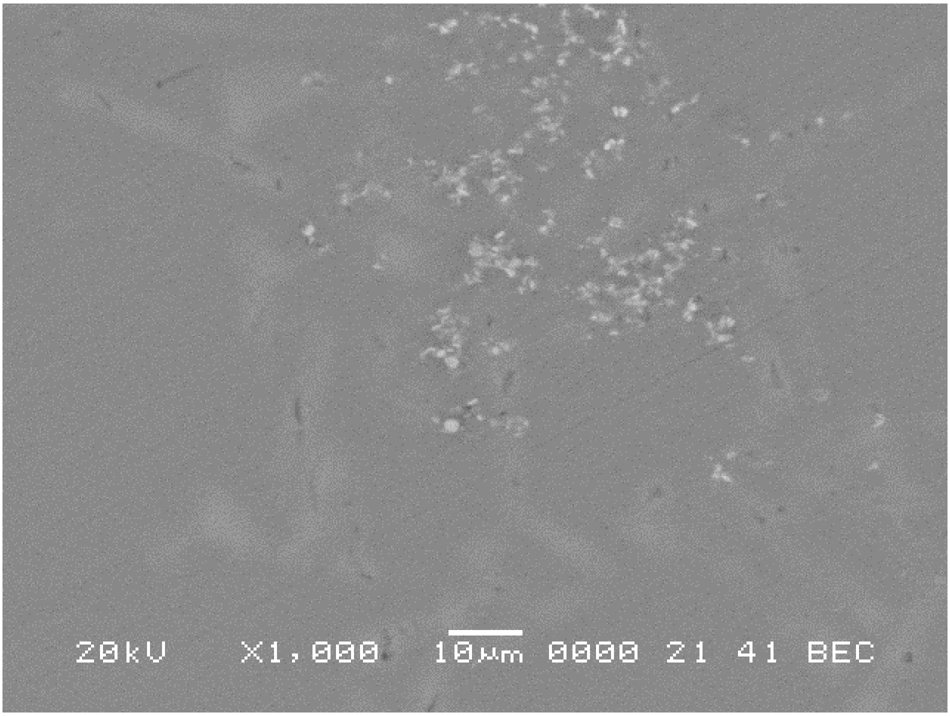


Figure 8. Micrograph of SEM refined (GR) with 0.3 wt.% Ti and non-grain refined (NonGR) alloys [27].

4. CONCLUSION

- Grain refiners enhance the electrical conductivity of Al7Si0.3Mg.
- Optimum, confidential, typically option is the grain refined with 0.1 wt.% Ti in the middle section having a Weibull modulus of 512,30 and electrical conductivity of 33,73 IACS%.
- Vibrational casting has no effect scattering of the grain refiners.

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