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The Effect of Rotation Speed on the Microstructure and Hardness of Synthesized Al-WC Nano-Composite by Centrifugal Casting

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ABSTRACT

The aim of this work was WC distribution in base Al-Si-Mg (A356) alloy as reinforcing agent. WC Solid particles in the sub-23-nm size range added to melted alloy by centrifuge casting. The cylinder tube without gap was obtained. FESEM and OPM results show that the distribution depends upon the rotational speeds of the mould and centrifugal casting conditions. According to the MAP results, during solidification, Nano size WC phase, by the Eutectic Silicon and around primary Aluminum phase, was precipitated and distributed significantly. The wear tests were carried out using pin on disk method. Results revealed the 0.0272g wear rate by 500gr load at 1200 m for samples that are casted at 1500RPM centrifugal casting speed. According to SEM micrographs, the sliding load transfer by Nano WC particles occurred.

1. INTRODUCTION

Recently, metal-matrix composites have been studied intensively. The metals which have been used as matrix, are lithium, magnesium, silicon, aluminum ,titanium, copper, nickel, zinc, lead, etc [1]. The strength to density ratio of these metals are remarkable. One of the cheapest and fabric able metals used as matrix belongs to aluminum group for applications at temperatures below 700 ° C [2]. Aluminum matrix composites have great potential in terms of new materials design because of its properties as stiffness, strength, density, thermal and electrical properties. All Required properties can be reached by variation of materials which used as matrix, volume and shape of the reinforcement, its site and manufacturing. The accumulation of high strength, high modulus refractory particles to a ductile metal matrix leads to a material which has mechanical properties between the matrix alloy and the ceramic reinforcement. Although Metals have suitable properties like high strength, ductility and high temperature resistance, they have low stiffness, on the other hand ceramics have high stiffness and strength, but they are too brittle [3,4]. Aluminum and silicon carbide are two example which prove this claim, their Young's modules of 70 and 400 GPa ,thermal expansion ,coefficients of 24×10^{-6} and 4×10^{-6} °/C, and yield strengths of 35 and 600 MPa, respectively. A metal matrix composite (MMC) with the Young's modulus of 96.6 GPa and the yield strength of 510 MPa can be made by merging these materials, e.g. A6061/SiC/17p (T6 condition) [5].

Tungsten carbide reinforced aluminum matrix composites have attracted considerable attention in recent years because of their potential to exhibit enhanced mechanical properties [6]. However- the effect of Nano WC particles and process parameters on the integrity of hardness and wear resistance of this composite have not reported yet.

By horizontal centrifugal casting method, electric motor rotors, yokes, gear blanks, pulley sheaves, impellers, valve bodies, wheels, plugs, brackets generally can be produced [7]. This method has a wide application in components producing.

By using vertical centrifugal casting method, components, that are not cylindrical, or symmetrical, can be produced having a high cleanliness and homogeneous micro structures is a characteristic of centrifugally casting parts, and furthermore they do not display the anisotropic behavior apparent in rolled/welded or forged slices [8,9].

2. EXPERIMENTAL PROCEDURES

The aluminum alloy used as a matrix material .The aluminum A356 alloy was selected, (Table .1 shows the added composition of composite) the silicon content

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between 6.5 and 7.5% wt. and 0.3%wt magnesium in an aluminum matrix material can prevent or delay the chemical reaction and Al_4C_3 formation by using WC[7]. The Al_4C_3 formation in the case of Al-SiC composites were reported, so in the case of Al-WC composites these undesirable reactions of Al-WC probably can degrade the mechanical properties of our samples [14]. The alloy of matrix was used as small pieces. Nano size WC and Magnesium as a wetting agent of WC used in Aluminum casting [15, 16].

TABLE 1. The chemical composition of the A356

Cu %	Mg %	Si %	Ti %	Mn %	Zn %	Fe %
0.2	0.20-0.40	6.5-7.5	<0.25	0.1	0.1	<0.2

3. METHODS

A furnace was used for melting and casting the samples. The pouring temperature of the alloy was 700 °C, this temperature was selected to provide enough superheat to facilitate the semisolid material flow into the mold.
The WC particles originally are incorporated in the Al matrix alloy and remain in their solid state in the aluminum liquid matrix when it is mixed with Al alloy to obtain as a result overall composite composition of Al-50wt%WC.
The mold rotate around the central axis. A charge of 200 gram of material was used in each experiment.
The molten aluminum was transferred into the mold cavity while the mold was rotating round the axis of the machine. The rotational speeds were, 1000, 1200, 1300 and1500 RPM. The resulted ingots denoted by S1000, S1200, S1300, S1500. The schematic figure of the casting process is presented in Fig. 1.

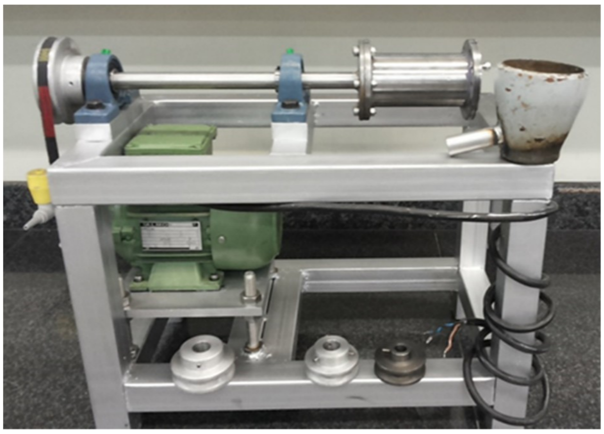

Figure 2. Schematic centrifugal casting machine

The melt was poured into the mold manually. Three specimens from each casting were cut in order to compare the mechanical properties of the aluminum alloy in different places of the ingot. Two round specimens were machined from each casting for the hardness and wear analysis.
In order to compare the different points hardness of sample, a cylinder from the radial plane was cut and the edges hardness from inside to out were measured (Fig. 2).
The hardness tests of samples were performed by indentation load of 25 g for 15 s. By taking five indentations on each sample the hardness was evaluated and averaging of only three middle values. According to ASTM –C1327-08 and the results were presented in Table 2.
Pin-on-disk test was used in order to estimating of wear properties. In this test, coated sample was disk [10-12].

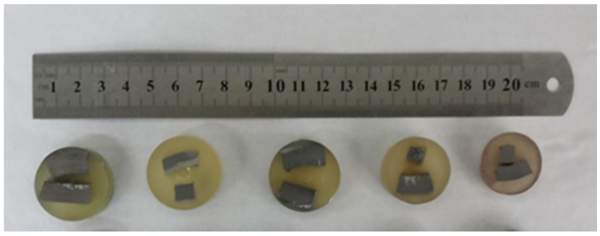

Figure 3. Samples are cut and mounted in a radial direction of the tube

Wear test was performed according to ASTM:G99-95a for wear testing with a pin. The wear rate of the materials were determine at a load of 500 grams, rotating speed was 120 RPM, sliding distance was 1200 m. a pin mad from ball bring steel 52100 (micro hardness 66 Rockwell C). The wear rate expressed in (mg/cm) is calculated as follows:

$$W.R = \frac{\Delta w}{S} \quad (1)$$

where: Δw is the wear rate, weight loss in (mg.), sliding distance in (m). Wear coefficient (K) is estimated by below relation:

$$K = \frac{Vol}{Load \times Slidingdis\tan ce} \times \frac{(mm)^3}{N-m} \quad (2)$$

All of the tests were conducted at ambient atmospheric condition at room temperature (25) ˚C and 23% humidity. Lubrication is not applied to avoid the complication of thermochemical effects [12].
Microstructural analysis was performed using a Scanning electron microscopy (SEM: model Cambridge S360, 1990). The gradient microstructure was evaluated by optical microscopy (Olympus dp72) and FESEM (MIRA3 TESCAN). In order to observe the phase distribution EDX analysis were used as well.

4. RESULTS AND DISCUSSIONS

WC in powder form was added to the base alloy in 10wt% of whole mixture. The existence of WC increased the viscosity of melt caused to problematic pouring. In addition, because of high density of WC this phase was precipitated at the bottom of crucible and the reinforced phase was wasted, so instead of 10wt% WC the amount of this phase changed to 5wt%. (Just the experience and observation made us to change the second phase weight %)

TABLE 2. Hardness of sample (Micro Vickers)

Hardness of outer area (micro Vickers)	Hardness of middle area	Hard indoor (Micro Vickers)	Rotational speed	sample
133.1	129.9	131.7	900	1
84.0	240.6	83.1	1000	2
122.4	99.2	87.9	1200	3
418.2	102.1	64.4	1300	4
542.7	161.5	94.4	1500	5

The gradient cylinder were prepared by 1000, 1200, 1300, 1500 rpm rotational speed with Al-5%WC. Fig. 3 shows the casted specimens.

Figure 3. Casted specimens by different rotational speed

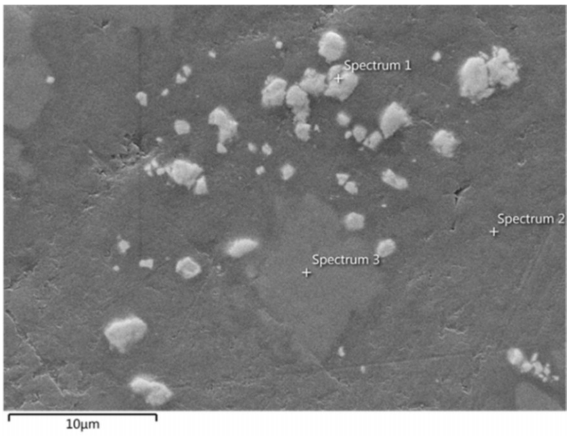

Figure 4. The analysed elements by EDS

The matrix and reinforcing phase were studied by FESEM, as shown in Fig. 4. The light and dark phases correspond to the WC and the matrix alloy respectively

Fig. 5-6. There are some gray phases which are detected by EDS probably related to the intermetallic aluminum phases. Al, Si, Zn were detected in point 2, Also, the Al, Fe, Si ,Cr were distinguished on gray phase Fig. 7, which considering other reported works can be related to Al_5FeSi[13].

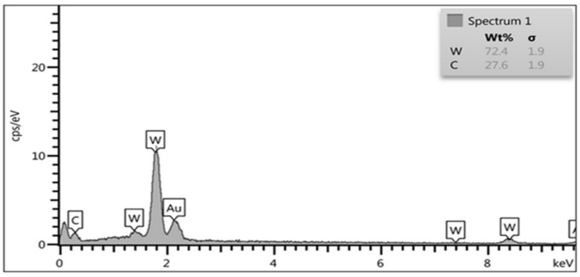

Figure 5. The analysed elements by EDS from light area

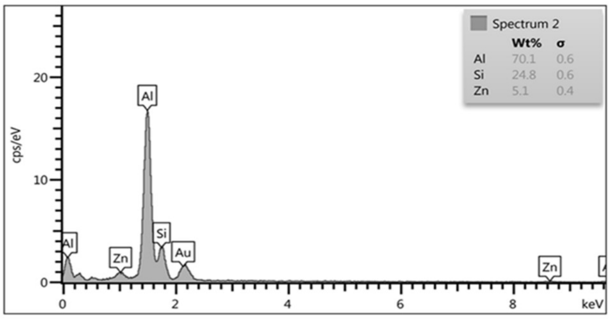

Figure 6. The analysed elements by EDS from dark area

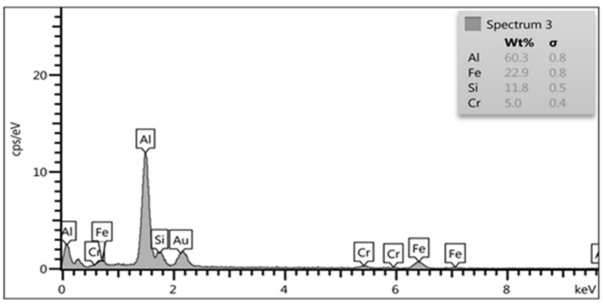

Figure 7. The analysed elements by EDS from gray area

Mg_2Si as dark particles were extended in matrix and the recognition was impossible without etching. The elemental analysis of sample by MAP was performed and existence of 2wt% Mg in this zone confirmed Mg_2Si (Fig. 8).

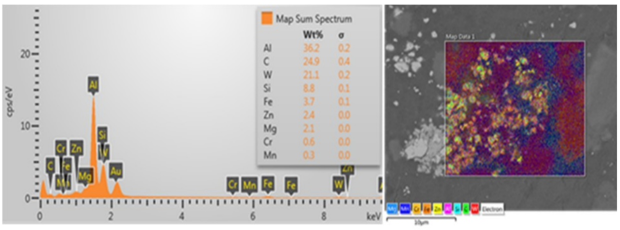

Figure 8. The total analysed elements by EDS from composite

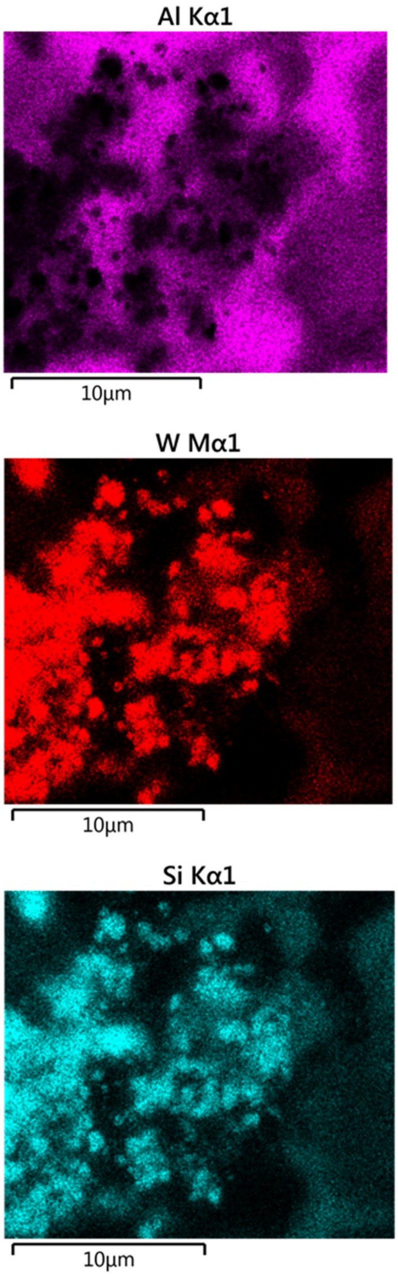

Figure 9. The element MAP of Al, W and Si taken by EDS

The elemental distribution of W, Si is similar, as known, the first phase which is densified, is the primary aluminum detected by pink color, the dark area without primary aluminum was overlapped by silicon. It is well known, the second phase is silicon, precipitate around aluminum dendrites. So it can be say that by solidification-precipitation of silicon particles, the WC phase was precipitated along the aluminum dendrites. Is shown in Fig. 9.

The samples were centrifugal casted by different rotational speed, and then the cylinders were cut form the radial plane in order to study the compositional gradient from inner to external diameter. It was expected that by increasing the rotational speed the WC particles in alloy move from inner to the external periphery. The matrixes of alloy with and without WC were shown in Fig. 10.

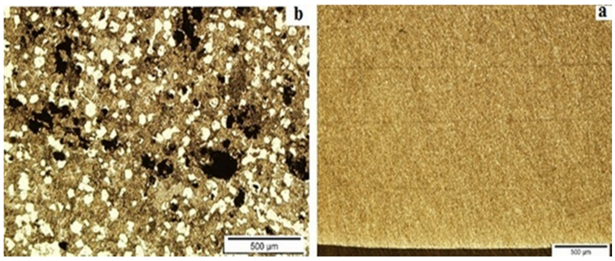

Figure 10. The optical microscopy image. (a) relate to the S1300 without reinforced phase, and the (b) relates to Al-5%WC before casting

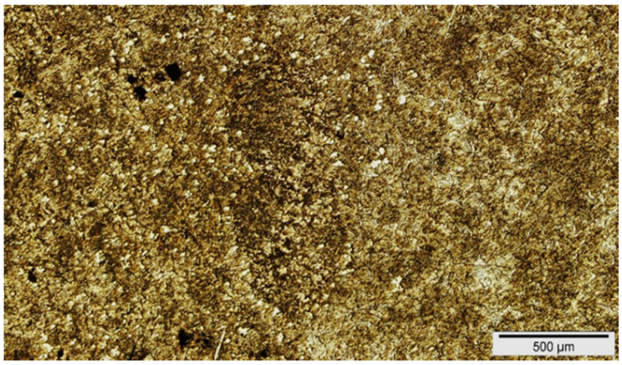

Figure 11. The optical microscopy image of composite S1000

Figure 12. The microstructural image of composite S1200

The microstructure of S1000 shows that the reinforcing agent spread over the outer region of cylinder so the centrifugal force did not cause the particles to appear in the outer periphery (Fig. 11). So, the particles contact was not occurred and the particles are separated.
In S1200, the centrifuge force could move the particles into the outer periphery, during movement the particles agglomerated and be coarser in the outer periphery of cylinder (Fig. 12).
In Table 2 the micro hardness of samples are shown. The loading force and time were 25gr. and 15 second respectively. The micro hardness were measured from interior, center and outer area of diameter. The hardness was specified on the base of location and distribution of reinforcing gradient phase.
The base alloy A356 without reinforcing phase by 900 RPM was verified and the micro hardness of this alloy was 131.6 HV.
Considering FESEM results in S1000, the centrifuge force, move the reinforcing phase to internal diameter. So the hardness of this part increased, but the hardness of outer and interior diameter are less than base alloy. It seems that the intermetallic and eutectic phase as a hardening agent with reinforcing phase displaced up to the internal diameter, so the interior diameter's hardness is less than base alloy and near to the pure aluminum hardness.
In the diagram of Fig. 13, the hardness trend from sample 2 to 5 are shown. By increasing the rotational speed, the centrifuge force and hardness of outer surround increased so that the S1500 shows the highest hardness.

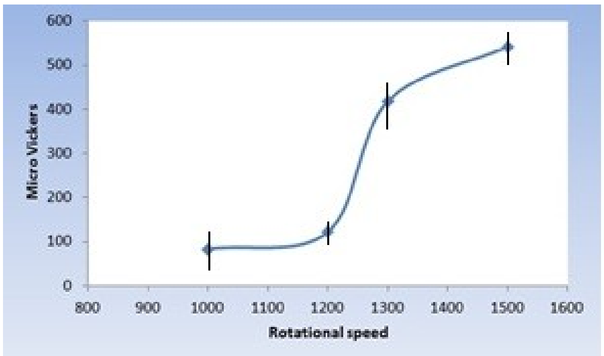

Figure 13. The hardness trend from sample 2 to 5

TABLE 3. The weight loss of samples after the wear test at 1200m.distance

Weight loss of samples	Samples weight before wear test	Samples weight after wear test	Rotational speed (rpm)	sample
0.0659	20.3250	20.3909	1000	S1000
0.0441	20.0544	20.0995	1200	S1200
0.0444	15.4366	15.4810	1300	S1300
0.0272	14.6452	14.6724	1500	S1500

3cm of the cut lateral surface of cylinder was evaluated with a 2.36 rotation diameter. The weight losses of samples were presented in Table 3.
Also the wear results were shown in Fig. 14. The samples, which are casted in 1000 RPM rotation speed, has soft surface without reinforcing phase on the outer plane. So shows the most wear behavior. Whereas, the samples by 1500 RPM speed which has dense reinforcing phase shows the less wear, corresponding to the improved tribological properties.

5. CONCLUSION

Because of Mg presence in the casted Al-Si-Mg alloys these alloys could be wetted by WC reinforcing phase.
Through solidification, the Nano size carbide, precipitate beside the eutectic phase with significant distribution around aluminum dendrites, the obtained composite shows the wear resistance properties.

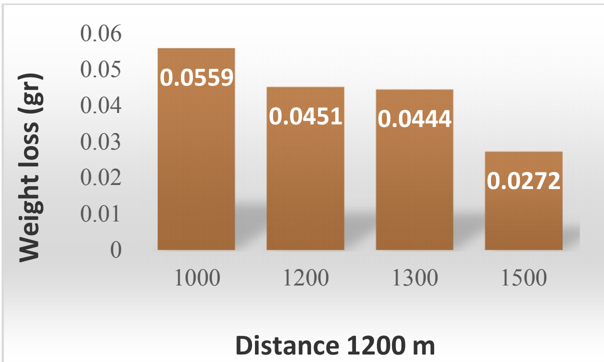

Figure 14. The obtained samples weight loss after the wear test at 1200 m distance

The A356 casted alloys shows good flow ability in casting and the centrifuge casted samples which have been produced by 1500 RPM could result perfect cylinders. Due to the different density of WC and Al, the reinforcing phase gradient distribution of WC would not significant in 1000RPM.

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