EXPERIMENTAL STUDY OF THE MECHANICAL AND METALLURGICAL BEHAVIOR OF ALUMINUM XSIC COMPOSITE

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ABSTRACT

The objective of this research is to produce metal matrix composite (MMC) by using pure Aluminum as a matrix and (Sic) particulates as reinforced particles with different %wt fraction (5, 10, 15, 20).

Stirring casting technique was employed to produce the samples, Si particulates were preheated to 700 °C before was added to improve the bad wettability of Al-Sic particulates, were also preheated to 900 °C before added, Degasser was added to molten while mixing to minimize gas content. Metal mould was used to produce the samples.

The results show the improvement of wear resistance, and hardness number but also the results show the decreasing of impact strength. The addition of Si particulate improves the wettability property which leads to improve the mechanical properties (wear resistance, hardness) and the successful of stirring casting to produce the (MMC) samples.

Microstructure examination, wear resistance behavior, and impact strength tests were carried out. The results show that the addition of Sic particulates in to a matrix alloy decreased the wear rate, impact strength and increasing of hardness number value.

Keywords: Composite material, wear rate, microstructure examination, impact strength

INTRODUCTION

Metal Matrix Composite (MMC) is engineered combination of metal (Matrix) and hard particles (Reinforcement) to tailored properties. Metal Matrix Composites (MMC's) have very light weight, high strength, stiffness and exhibit greater resistance to corrosion, oxidation and wear. These properties are not achievable with light weight monolithic titanium, magnesium, and aluminum alloys. Particulate metal matrix composites have nearly isotropic properties when compared to long fiber reinforced composite, but the mechanical behavior of the composite depends on the matrix material composition, size, and weight fraction of the reinforcement and method utilized to manufacture the composite. The distribution of the reinforcement particles in the matrix alloy is influenced by several factors such as rheological behavior of the matrix melt, the particle incorporation method, interaction of particles and the matrix before, during, and after mixing [1].

Aluminum matrix composites reinforced with Sic have attractive properties for structural and non-structural applications both at room temperature and relatively high temperatures However; massive commercialization of Al/Sic composites (where the suffix p stands for particles) has been hindered both by technological barriers and high processing costs. However, when Al/Sic composites are fabricated by the route with aluminum in liquid state there exist the potential for the development of the aluminum carbide (Al_4C_3) phase by the dissolution of Sic. For instance, the stir casting route is more suitable for low volume fractions (< 20%), whilst the infiltration routes are more appropriate for high volume fraction of the reinforcement (> 40%). [2].Among the most prominent applications of this type of complexes are in spacecraft applications, aeronautics and medical and engineering applications [3].

An attempt has been made to study the two body abrasive wear behavior of LM13 alloy and LM13–15 wt.% SiC composite by *(S.Sawla&S.Das,2004)[4]*, in cast and heat-treated conditions, as a function of applied load. The wear constant (*K*) was calculated based on the wear rate data, which signifies the probability of formation of wear particles during abrasive wear process. It was observed that the wear constant decreases with load. In the case of cast alloy the value of wear constant was higher than that of the heat-treated alloy and composite. The wear surface and the subsurface were studied using scanning electron microscope (SEM). The wear surface and subsurface studies indicated that at low load regime the fragmentation of the wear surface is more by cracking, however, at high load regime plastic deformation is dominated. During the wear process, the cracks are mainly nucleated at the Al/Si and Al/Sic interfaces and joining the cracks forming the wear debris. Heat-treated alloy and composite showed better strength and hardness, resulted in less propensity for crack nucleation and showed enhancement in wear resistance. The subsurface studies showed plastic deformation and formation of mechanically mixed layer consisting of Sic particle, silicon and deformed Al. The subsurface deformation clearly depicts the propagation of cracks in longitudinal as well as in transverse directions in low load condition. However at high load, the Sic particles are seen embedded in the plastically deformed matrix.

Al and Al–Sic composites coatings were prepared by oxyacetylene flame spraying on ZE41 magnesium alloy substrates by *(P.Rodrigo &et als, 2009) [5]*. Coatings with controlled reinforcement rate of up to 23 vol.% were obtained by spraying mixtures containing aluminum powder with up to 50 vol.% Sic particles. The coatings were sprayed on the magnesium alloy with minor degradation of its microstructure or mechanical properties. The coatings were compacted to improve their microstructure and protective behavior. The wear behavior of these coatings has been tested using the pin-on-disk technique and the reinforced coatings provided 85% more wear resistance than uncoated ZE41 and 400% more than pure Al coatings.

(Guo & Yuan, 2009)[6], it was reported that the aging behavior of the composites is similar to that of the 6013Al showing two peak hardness during artificial aging at 191 ^{o}C. The composite reaches its peak hardness in shorter time and exhibits a smaller increase of hardness. Moreover, during natural aging, the composite reaches stable hardness in longer time than does the matrix alloy, with lower increase of hardness. There was evidence that low fractions of graphite powders affect the aging behavior and mechanical properties of aluminum matrix composites with Sic particulate reinforcements.

Al–Sic composites containing four different weight percentages 5%, 10%, 20% and 25% of Sic have been fabricated by liquid metallurgy method by *(Manoj S.&et als,2009)[7]*. Friction and wear characteristics of Al–Sic composites have been investigated under dry sliding conditions and compared with those observed in pure aluminum. Dry sliding wear tests have been carried out using pin-on-disk wear test rate normal loads of 5, 7, 9 and 11 Kgf and at constant sliding velocity of 1.0m/s. Weight loss of samples was measured and the variation of cumulative wear loss with sliding distance has been found to be linear for both pure aluminum and the composites. It was also observed that the wear rate varies linearly with normal load but lower in composites as compared to that in base material. The wear mechanism appears to be oxidative for both pure aluminum and composites under the given conditions of load and sliding velocity as indicated by scanning electron microscope (SEM) of the worn surfaces. Further, it was found from the experimentation that the wear rate decreases linearly with increasing weight fraction of silicon carbide and average coefficient of friction decreases linearly with increasing normal load and weight fraction of Sic. The best results have been obtained at 20% weight fraction of 320 grit size Sic particles for minimum wear.

This work is production of aluminum matrix composite by powder metallurgy method by *(Mohammed S. &Mofak M., 2009) [8]*. The samples have done when aluminum powder was used as a matrix in purity of (9.99%) and silicon carbide(α-Sic) as reinforcement material, the particle sizes were used which (125μm) at weight percentage (7.5% - 10% - 15%) from silicon carbide for each particle size. The purpose is to improve the hardness and wear properties of matrix .It was found that the hardness is increased with increasing of the amount of added particles, due to the hardness of silicon carbide particles. From the wear test, it is found that the wear resistance increase with increasing the weight percentage of Sic particles, but the wear rate increase when the applied load increase for all the particles size and additional percentage. Also, it is found that when the sliding velocity increases, the wear rate also increases, but the best results were found in samples reinforced with (Sic) particles.

The aim of this work is to use centrifugal casting process in production of composite materials reinforced in selected regions, and study the effect of process parameters on the microstructure and mechanical properties of composite materials by *(Nawall E. & etals 2010)[9]*. The composite material was fabricated by dispersing Sic with (53-75) μm particles in the Al-Mg melt alloy and stirred using vortex technique. Weight fraction of (5, 10, 15%) preheated Sic particles were added to the melt alloy and manually stirred until the particles were completely wetted, . The composite slurry was then reheated to around 750 ^{o}C and agitated by means of electrical stirrer .After that the composite slurry was poured in centrifugal casting preheated die, rotate at different rotating speeds (900, 1400, 1800) r.p.m. Microstructure examination shows that the most of Sic particles settled in the outer region of produced composite cylinders, but the volume fractions for these particles are different depending on process parameters Also the thickness of reinforced region of produced composite cylinders increases with decreasing rotating speed and with increasing weight fraction of the added Sic% particles. Hardness test results show significant increase in composite hardness compares with matrix alloy .The Wear resistance of composite cylinders was higher than that of matrix.

(K.L.Meenal&etals, 2013) [10] study the Metal Matrix Composites (MMC's) have evoked a good interest in recent times for potential applications. Advance composite materials like Al/Sic metal matrix composite is gradually becoming very important materials in manufacturing industries e.g. aerospace, automotive and automobile industries due to their superior properties such as light weight, low density, high strength to weight ratio, high hardness, high temperature and thermal shock resistance, superior wear and corrosive resistance, high specific modulus, high fatigue strength etc. In this study aluminum (Al-6063)/Sic Silicon carbide reinforced particles metal-matrix composites (MMCs) are fabricated by melt-stirring technique. The MMCs bars and circular plates are prepared with varying the reinforced particles by weight fraction ranging from 5%, 10%, 15%, and 20%. The average reinforced particles size of Sic are 220 mesh, 300 mesh, 400 mesh respectively. The stirring process was carried out at 200 rev/min rotating speed by graphite impeller for 15 min. The microstructure and mechanical properties like Proportionality (MPa) limit, Tensile strength upper yield point (MPa), Tensile strength lower yield point (MPa), Ultimate tensile strength (MPa), Breaking strength(MPa), % Elongation, % Reduction in area, Hardness

(HRB), Density (gm/cc), Impact Strength (N.m) are investigated on prepared specimens of MMCs. It was observed that the hardness of the composite is increased with increasing of reinforced particle weight fraction. The tensile strength and impact strength both are increased with rising of reinforced weight fraction. Different mechanical tests were conducted and presented by varying the particle size and weight fractions of Sic.

EXPERIMENTAL WORK

Materials

Pure Al of (99.9999) purity was used as a matrix material, Sic of ≤63µm were used as reinforcement particles and (Si) particles of also 63µm were used for increasing the solubility of Al. molten and to improve the wetability of (Sic).

Experimental Procedure

The composite material fabricated by dispersing (Sic) particles of (≤63mm) with (0, 5, 10, 15, 20) %wt in Al-melt of 900 °C. (Si) element with 10% wt was added to overcome the problem of (Sic) particles poor watability, (Si) particles were heated to (700) °C before added to avoided high drop of Al-melt temperature, after that the melt and added particles were manually stirred using vortex teqnique until the particles were completely wetted.

The composite slurry was then reheated to around 750 °C by electrical furnace. After that, the composite slurry was poured in metal mold of cavity dimension (Ø 15*100) mm and after (5) minute, the sample was shakeout.

Specimens of (Ø 10*10) mm were prepared for microstructure test, Brinell hardness test, and also specimens of (Ø 10*20) mm were prepared for both impact strength test and were resistance test.

Wear Measuring Device

The device consists of an electric motor of (1.5) hp, arm with rectangular section for sample hanging, turntable of steel (45 HRC) and the speed of turntable can be controlled by transmission belts. All tests were done in normal atmospheric air and room temperature as shown in figure (1).

Figure 1. Wears Apparatus

Wear Calculation

Prepared samples were tested by using applied loads (5,10,15,20,25) N and fixed sliding distance of 3000 m and also were tested by using fixed load of (40)N and sliding speed of (2,3,4,6) m/s for the same sliding distance (3000 m).

The wear rate was calculated by using the following equation:

$$W_R = \frac{\Delta m}{2\pi rnt} = \frac{m_1 - m_2}{2\pi rnt} \quad \text{..................} (1)$$

Where:-

W_R:- wear rate (g/cm)

Δm:- Weight lost (gm) which is the difference in mass of the samples before and after the test that the mass loss.

m_1:- Mass of the sample before the examination (gm)

m_2:- Mass of the sample after examination (gm)

t:- Sliding time (examination) minutes

r:- The radius of the sample to the center of the disc

n:- Disk rotational speed (r / min)(540 RPM).

RESULTS AND DISCUSSION

Hardness Test

Figure (2) shows the hardness of pure Al was (25 HB) and was increased due to (50 HB) at 15% Sic, and then decreased to (47 HB) at 20% Sic. The increasing of hardness number to the reaction of dislocations with Sic particles, and the grains refinement with increasing wt% of (Sic) particles.

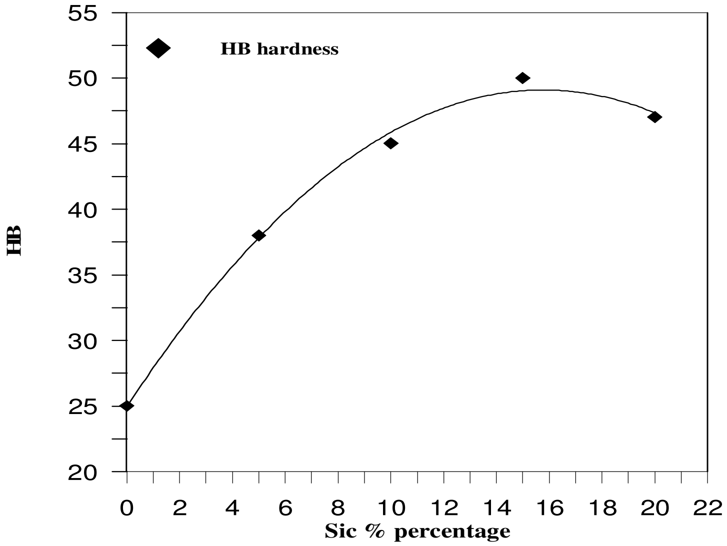

Figure 2. The relationship between Sic% and Brinell hardness

Wear Test

Figure (3) shows the relationship between the effect of wt% of (Sic) on the wear resistance behavior at different sliding speed at fixed load (40 N) and sliding distance (3000 m), from above we show that higher wear rate of pure aluminum occurred at sliding speed of (2-4 m/s) and slowly decreasing with increasing of wt% of (Sic) addition, and higher wear rate occurred at sliding speed of (4 m/s).we observed too increasing of wear rate with Sic addition comparison with pure aluminum at maximum sliding speed (6 m/s) because the generated heat and vibration at this speed lead to increase of wear rate.

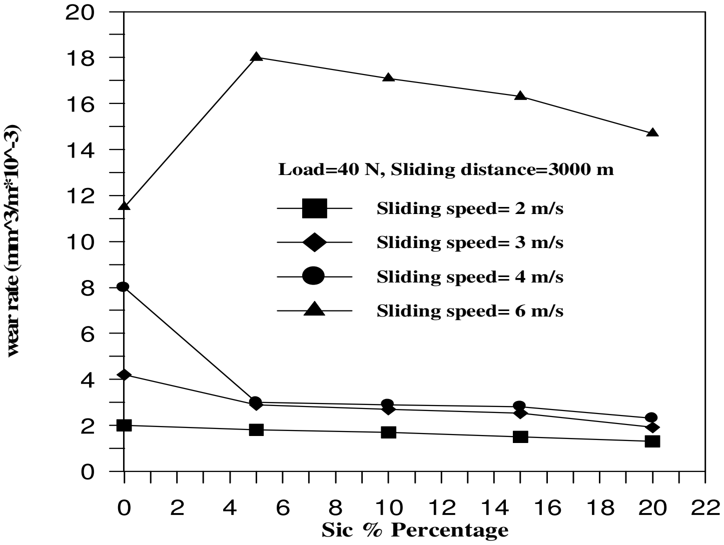

Figure 3. The relationship between Sic% and wear rate at fixed Load (40N) and sliding distance of 3000m

These results indicate the effectives of (Sic) particles on the decreasing of Al wear resistance , also the same results were observed with fixed sliding distance (3000 m) and variables loads (10-50 N). If the applied load was increased the wear rate was increased also as shown in figure (4).

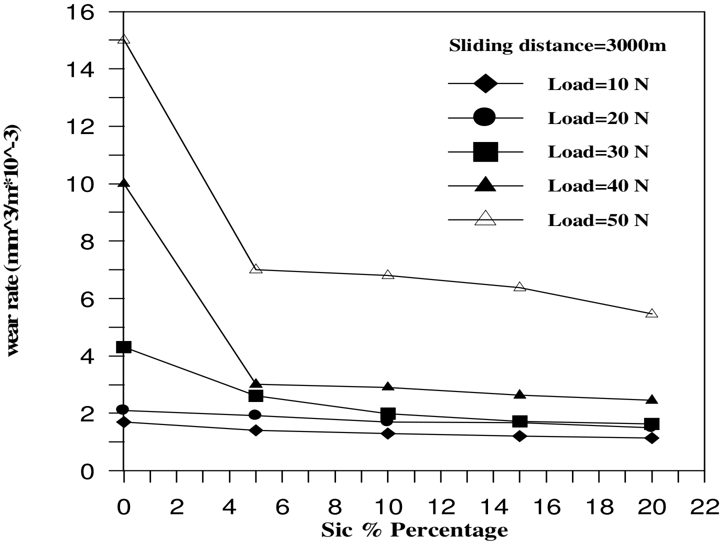

Figure 4. The relationship between Sic% and wear rate at fixed sliding distance of 3000m

Impact Test

Impact strength (N.m) are investigated on prepared specimens of Al-xSic as shown in figure (5) it was found that the impact strength decreases by Increasing the wt% of (Sic) particles, because as the percentage of Sic particles increases, the ductility of Al matrix decreases and the hardness value increase.

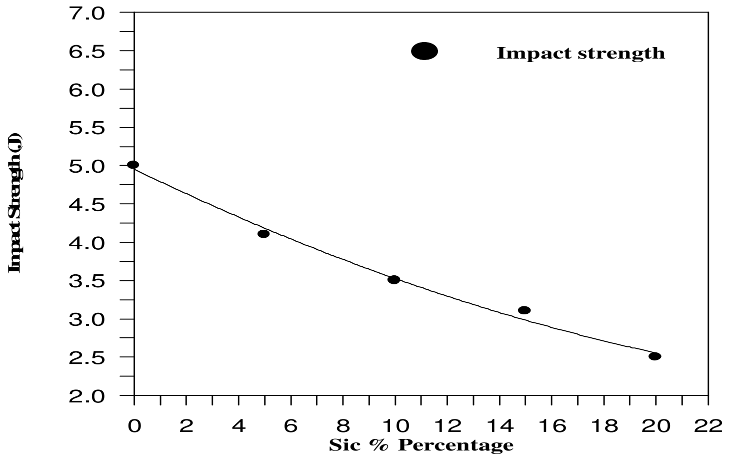

Figure 5. The relationship between impact strength and Sic%

Microstructures Test

Microstructures test was done by using optical microscope at a magnification of x50 to observe the distribution of (Sic) carbide in the casting samples. Figure (6) indicates the distributions of particles across the casting samples and this means that the method of stirring casting was successful to distribute the particles within the matrix.

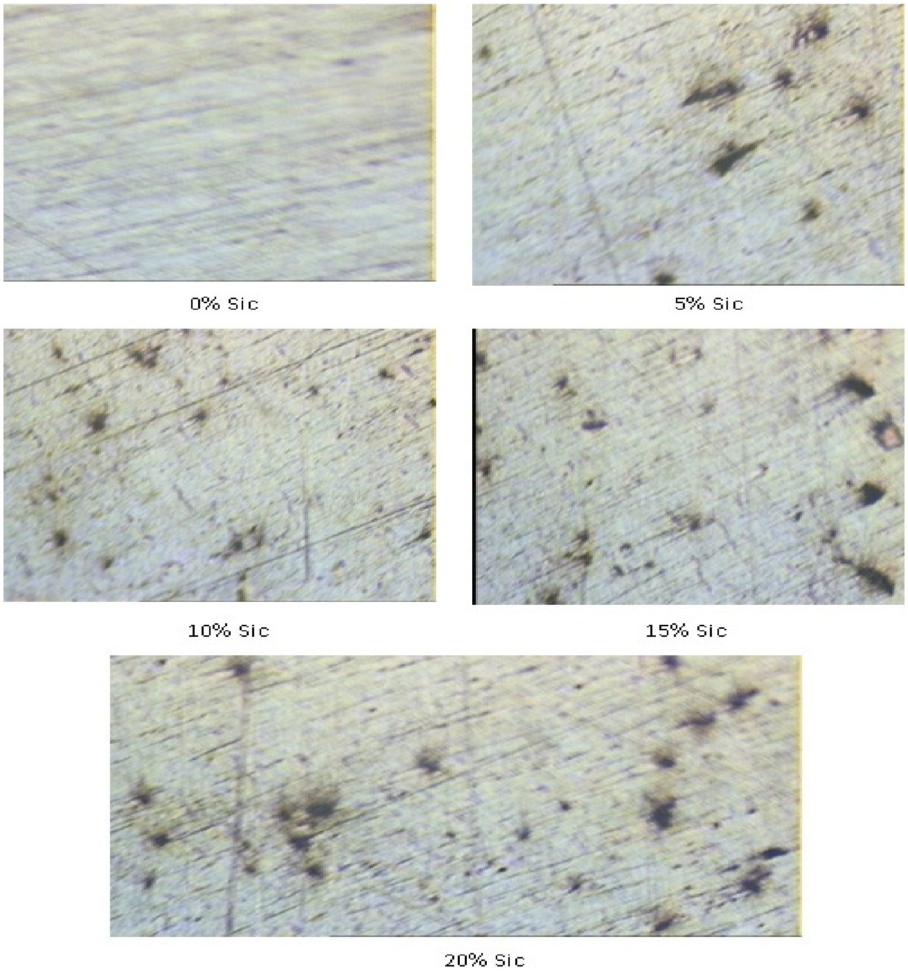
0% Sic
5% Sic
10% Sic
15% Sic
20% Sic

Figure 6. Photograph of MMCs microstructure at X50

CONCLUSIONS

1. The increasing of hardness with the increasing of (Sic) particles refer to the intersection between (Sic) particulates and dislocations
2. The addition of (Sic) particulate improved the mechanical and metallurgical properties of pure (Al) due to good wettability of (sic) particulates with (Al) molten and the generated wettability also gives a better distribution of added particulate through (Al) molten
3. The only disadvantages of (Al + X Sic) composite is the decreasing of impact strength due to decrease of ductility by added particulate of (Sic)
4. 4.the addition of (Si) to (Al) molten before stirring casting improved the wettability action between (Sic) particulate and (Al) molten
5. 5.(Al-Sic) composite has many applications in industrial and structural applications where light weight and high strength are required

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