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Experimental Investigation of Tribological Behaviour of Aluminium Alloy Based Metal Matrix Composites

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Abstract: Metal Matrix Composites are a class of advanced composites with graded properties that bring a new concept in material design and are widely used in the aerospace and automotive industry. These materials have the properties of both the matrix as well as the reinforcement materials. They are known to have little residual and thermal stress. This concept imparts improved adhesive bonding strength between metals and ceramics. Aluminium alloy with silicon carbide is applicable where hardness and toughness are the requirements. Metal Matrix Composites are designed in order to have the combined properties of both metals and ceramics. The specimens are fabricated for various proportions of the materials. In the fabrication of these materials, begins with Aluminium alloy and Silicon carbide. The specimen is subjected to different mechanical tests, and the experimental result is the pure aluminium undergoes more wear when compared to the reinforced specimen.

Keywords: Metal Matrix Composites, Aluminium, Wear

1. Introduction

The term composite broadly refers to a material system which is composed of two materials that is a metal and a ceramic distributed evenly throughout the cross section. Composite materials are classified on the basis of the physical or chemical nature of the matrix phase, e.g. metal matrix, metal matrix, and polymer matrix composites. The composite material is one in which the individual components retain their individual characteristics and to exhibit only their advantages and not their drawbacks, in order to obtain an improved material.

Metal Matrix Composites (MMC) are composed of a metallic metal mostly aluminium, magnesium, iron, cobalt and copper and a ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. When three materials are identified in a composite, it is called a hybrid composite. Metal Matrix Composites are made of dispersing a reinforcement material into a metal matrix. The reinforcement surface is coated in order to prevent a chemical reaction with the matrix.

The matrix is the single block material into which the reinforcement is dispersed and is completely continuous throughout the surface. The matrix material is usually a lighter material metal like Aluminium or Magnesium or Titanium and provides complete support for the reinforcement.

The reinforcement materials were embedded into the matrix, which is used to change the physical properties like friction coefficient, wear resistance and thermal conductivity. The reinforcement is made neither continuous nor discontinuous.

Aluminium alloy metal matrix composite (AMMC) offers designers with many added benefits, as they are particularly suited for applications requiring good strength, good structural rigidity, dimensional stability and lightweight. MMCs provide enhanced properties over monolithic alloy. In Aluminum alloy metal matrix composites (AMMC) one of the major constituents is aluminum /aluminum alloy, which forms porous surface and is termed as matrix phase. The other constituent is embedded in this aluminum /aluminum alloy porous matrix and serve as reinforcement, which is usually a nonmetallic and commonly ceramic such as Silicon Carbide or Aluminium Oxide. Properties of AMMCs can be tailored by varying the nature of constituents and their volume /weight fractions.

2. Literature Review

Jaya Prasad Varmaet al. (2018) studies the effect of the addition of SiC reinforcement on microstructure, mechanical and wear properties of Al5083-SiC by adding the SiC 3,5 and 7 wt.% through stir casting.by adding 7 wt.% of SiC particles to aluminium alloy the maximum hardness value, maximum ultimate tensile strength and tribological properties were improved due to a fair distribution of SiC particles in aluminium matrix [1].

Johny James et al. (2014) prepared a hybrid aluminium metal matrix composite by reinforcing the Silicon carbide and Titanium diboride and the results shows that addition of reinforcement upto 15% wtreveles the reduction of the hardness value and its tensile test results in reduction of strength to 50-60% is by TiB_2 but the addition of TiB_2 increases the wear resistance of composite, maximum addition of TiB_2 is limited to 2.5% because 5% leads to porosity and affects the hardness value [2] .

Kandan et al. (2017) fabricated a MMC by stir casting method and investigated the tensile strength, compression strength and hardness by reinforcing Al 8011 matrix with boron carbide(B_4C) and aluminium oxide (Al_2O_3) particles and summed up that with increase in wt.% of reinforcement particles increased the mechanical strength while the composite with 90%Al+5%B_4C+5% Al_2O_3 have greater mechanical properties than the other samples prepared [3].

Okayasu et al. (2011) studied the long term naturally aging die-cast of Al-Si-Cu alloys that in absence of non-corrosive environment the material increases over 10 year period and change in microstructure affects the mechanical properties. The cause for change in microstructure is mainly of high casting pressure and rapid cooling process but in Al alloy heavy walls the change in microstructure not occur strongly even after natural aging [4].

Montasser et al. (2010) proposed an investigation on the effect of the addition of SiC to the Al alloy upto 60% SiC on the composites. The porosity of the composites is reduced and microscopically its found to be homogeneous in distribution [5].

Pugalenthi et al. (2015) evaluated the mechanical properties of aluminium alloy 7075 reinforced with SiC and Al_2O_3 hybrid metal matrix composites with 3,5,7,9 wt% of Al_2O_3 and 2 wt.% of SiC by stir casting method and concludes that ductility alone decreases while hardness and tensile increases with their addition and the sample containing the highest percentage of Al_2O_3 exhibit high tensile strength and hardness with a minimum % of elongation [6].

Rajesh Agnihotri et al. (2017) investigated the mechanical properties of Al-SiC MMC's by stir casting route and stirring the MMC slurry in semi-solid state helps to incorporate ceramic particles into alloy matrix properly while holding temperature, stirring speed, size of impeller and the position of impeller are the important factors to be considered while casting of these composites since they have an impact on the mechanical properties and the wear rate tends to decrease with the increase in weight percentage of SiC and these materials can be used in high elevated temperatures, for better wear resistance and corrosion resistance [7].

Rajesh Purohit et al. (2012) fabricated Al-SiC composites with 5% to 30% weight of SiC using powder metallurgy process and its various tests results were measured. Alloying of composites for 12 hours of milling resulted in homogeneous powder structure and the quality of the final product depends upon the initial compact. Resulted in the increased hardness, compressive strength, density by the reinforcement of contents from 5% to 30% weight of SiC [8].

Subramanyareddy et al. (2017) investigated the aluminium alloy metal matrix composite by stir casting method for various compositions of boron carbide and silicon carbide, and concluded that 96% Al, 2% SiC and 2%B_4C has a higher strength due to higher quantity of carbides in composite and for different casting method its mechanical properties can be found [9].

Vijayaramnath et al. (2014) presents an overview of Aluminium matrix composite of the effect on addition of reinforcements in aluminium alloy with different mechanical properties like a tensile test, strain, hardness,and wear are discussed. It concludes that SiC reinforced have high wear resistance and compressive strength compared to other reinforcements like Al_2O_3 and B_4C in MMC [10].

3. Materials and Sample Preparation

Aluminium and its alloys possess excellent properties such as low density, good plasticity and ductility, and good corrosion resistance. They find extensive applications in aeronautics, astronautics, and automobile and high-speed train fields. However, low hardness and poor impact resistance result in their limited application in heavy-duty environments. Like all composites, aluminium-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieve required properties. Regardless of the variations, however, Al composites offer excellent thermal conductivity, high shear strength, excellent abrasion resistance, high-temperature operation, non-flammability, minimal attack by fuels.

The chemical composition of 8011 aluminium alloy consists of various materials as listed in Table 1.

Table 1 Chemical Composition of 8011 aluminum alloy

Material	Weight %
Fe	1
Si	0.9
Mn	0.2
Zn	0.1
Cu	0.1
Ti	0.08
Mg	0.05
Al	97.5

Silicon carbide (SiC) is composed of tetrahedra of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. SiC is not attacked by any acids or alkalis or molten salts up to 800 °C. In the air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. SiC ceramics with little or no grain boundary impurities maintain their strength to vary.

SiC particles reinforced Aluminium, are one of the widely known composites because of their superior properties such as High strength, Hardness, Stiffness, Wear and corrosion resistance, Low weight high strength ratio.

3.1 Sample Preparation

Table 2 shows the samples with different weight percent proportions of 8011 Al alloy and SiC that are casted.

Table 2 Weight Percent of Samples Prepared

Samples	Aluminium	Silicon carbide
1.	100%	-
2.	90%	10%
3.	80%	20%
4.	70%	30%

Total weight of each sample = 145.8 g.

MMC can be a fabrication by using several techniques which can be a solid, liquid and vapor state. Stir casting (Liquid state) techniques always used to manufacture AMMCs. In stir casting method, MMCs are produced by introducing reinforcement into molten matrix material by applying stirring action and pouring in the die and then solidified as shown in Figure 1. To produce the large size of MMC components in the stir casting processes it very simplest and the most cost-effective method in the liquid state fabrication.

Figure 1 Die for Casting

4. Experimental Method

The prepared composite samples are investigated for their mechanical properties and are compared with the pure aluminium.

4.1 Tensile Test

Tensile test also is known as tension testing, is a fundamental material science test in which a sample is subjected to a controlled tension until failure. Properties that are directly-measured from the tensile test are ultimate strength, maximum elongation, and reduction in area.

As per the ASTM B557 standards, the prepared samples as shown in Figure 2 were subjected to tensile test and the results were noted.

Figure 2 Samples for Tensile Test

4.2 Hardness Test

Hardness is the resistance of a material to localized deformation. The term can be applied from indentation, scratching, cutting or bending. Hardness measurement is done in Vickers Hardness Testing Machine.

The microhardness test was carried in Micro Vickers Hardness Tester which has a testing load range of 10 grams to 1 kg load and testing scale used is HV. The prepared samples were subjected to a load of 0.5 kg with dwell time 10 sec in three locations of each sample.

4.3 Wear Test

Wear is related to interactions between surfaces more specifically the removal and deformation of material on a surface as a result of mechanical actions of the opposite surface. Wear test was carried in Pin on disc for ASTM G99 standard with the samples shown in Figure 3.

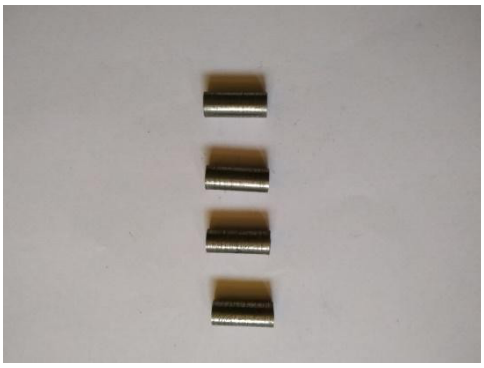


Figure 3 Wear Test Samples

5. Results and Discussion

The experimentation on the prepared samples are conducted and the results are discussed as follows.

5.1 Tensile Test

Figure 4 shows that the casted pure Al 8011 alloy has the ultimate tensile strength of 142.8 MPa. By adding 10% SiC particles to the Al 8011 alloy, the ultimate tensile strength of the 90% Al 8011-10% SiC metal matrix composite has become 146.13 MPa as shown in Figure 5. This shows there is a slight increase in the tensile strength of the composite. In the same manner, Figure 6 shows the ultimate tensile strength of 20% SiC to 80% Al alloy particles as 155.63 MPa. The 70% Al 8011-30% SiC metal matrix composite has the maximum strength of 162.61 MPa than the other composites and pure alloy as shown Figure 7 because of the uniform dispersion of the SiC particles, this 70% Al 8011-30% SiC has the highest tensile strength.

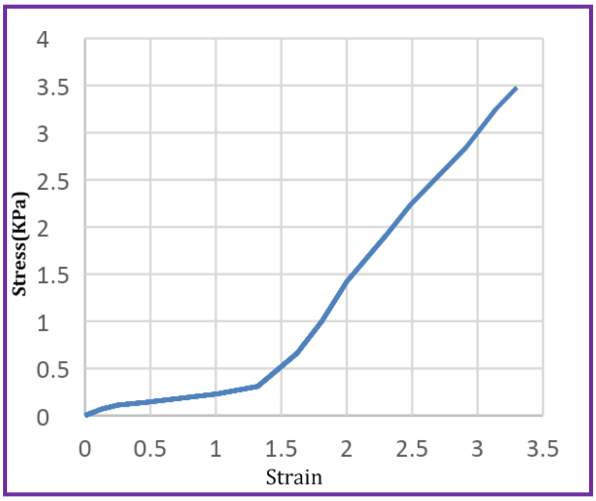


Figure 4 Stress vs Strain for Pure 8011 Aluminium

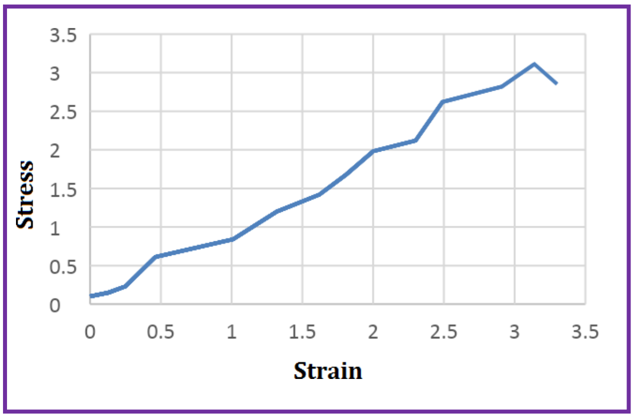


Figure 5 Stress vs Strain for 90%Al+10% SiC

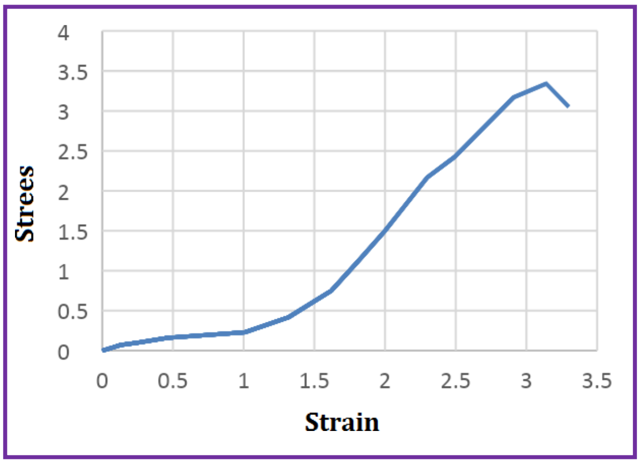


Figure 6 Stress vs Strain for 80%Al+20%SiC

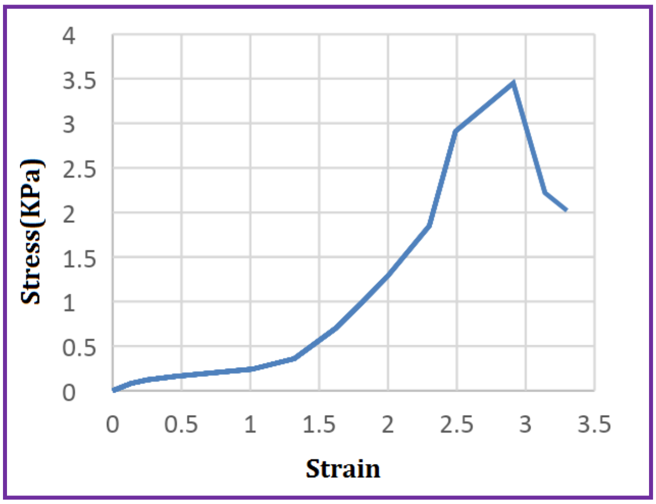


Figure 7. Stress vs Strain for 70%Al+30%SiC

5.2 Hardness Test

The microhardness test was carried in Micro Vickers Hardness Tester which has a testing load range of 10 grams to 1 kg load and testing scale used is HV. The prepared samples were subjected to a load of 0.5 kg with dwell time 10 sec in three locations of each sample. Figure 8 indicates the mean value of micro hardness was improved with the addition of weight percentage of SiC particles to the aluminium matrix.

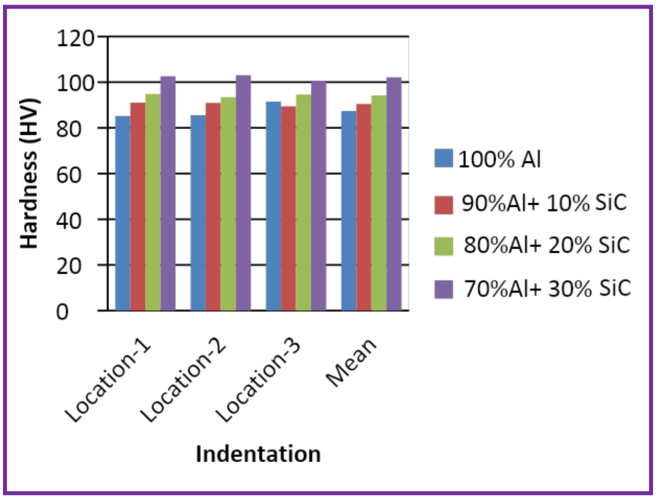
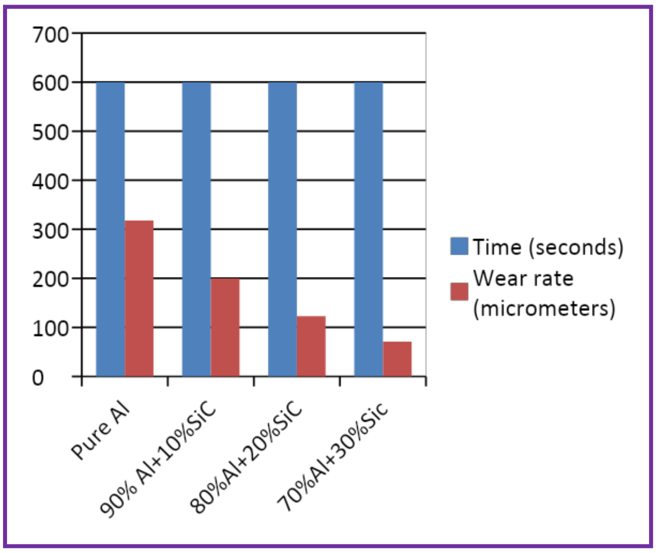


Figure 8 Hardness values of samples

5.3 Wear test

Tribological properties are evaluated by conducting tests on Pin and Disc Tribometer. A load of 9.81 N was applied for a period of 600 seconds throughout the experiment for all the samples. Casted Pure Al has a wear rate of 318 micrometers when subjected to a load of 9.81 N for a period of 600 seconds with a coefficient of friction of 0.320 as shown in Figure 5.5. The wear rate of 200 micrometers was drastically reduced as shown in Figure 5.6 by adding 10 wt. % of SiC particles to Aluminum matrix from the Pure Al alloy. Again with 20 wt.% of SiC and 80 wt.%Al8011 alloy a wear rate of 123 micrometers is observed Figure 5.7. The minimum wear rate of 71 micrometers was observed in Figure 5.8 for 30 wt.%SiC and 70 wt.% Al8011 alloy composite material. The wear resistance of the composite material was enhanced by increasing the addition of wt.%SiC to Aluminium matrix due to the self-lubricating property of SiC.



6. Conclusion

Aluminium - Silicon Carbide Metal Matrix Composite have successfully fabricated by die casting. The addition of silicon carbide particles to the pure metal improves the mechanical properties like tensile strength, hardness and wear resistance of the composites. From this experimental study, it is noted that the higher the percentage of reinforced SiC, the higher is the tensile strength and hardness value with lower wear rate is observed. The sample with 70% Al + 30% SiC has the tensile strength of 162.61 MPa and hardness of 103.1 H.V with the wear rate of 71 micrometers is observed.

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