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Experimental study of Wear and Mechanical properties of Al7075/SiC MMC processed by Powder Metallurgy

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ABSTRACT

Powder metallurgy is one of the established manufactured processes which allow products of complex geometries to be produced with tailor made properties like high strength and tolerances. P/M has replaced conventional metal forming operations due to added benefits like high material utilization, low energy consumption, less material wastage and reasonable cost, because of which it is extensively used in automobile, aerospace and many other industries. In this project Al7075 is selected as matrix alloy and silicon carbide particles are selected as reinforcement. Powder metallurgy (P/M) technique is employed to fabricate composites. Specimens were prepared by varying reinforcement content (0%, 3%, 5%, 7% and 10%) and compaction load (50 KN, 60 KN, 70 KN, and 80 KN). Mechanical properties like compressive strength, hardness, density and tribological (wear) behavior of composite was studied. Taguchi technique was employed for wear analysis. Three levels (high, low, and medium) and four control factors (%reinforcement, speed, load and distance) were chosen. Results revealed that there were significant changes in mechanical properties and enhancement of wear behavior was noticed due to incorporation of reinforcement (SiCp) particles.

***Keywords*: AMCs, SiC, powder metallurgy, AA7075, wear behavior, mechanical properties.**

I. INTRODUCTION

A composite material or composition material is basically a kind of structural material produced by mixing two or more distinct materials, where the properties obtained by mixing of these materials, are unattainable by individual materials alone. The constituents individually do not serve the required function by themselves but they did it when they were put together [1]. Composites are classified into three main categories depending on the chemical nature of matrix phase- Polymer matrix composites, Metal matrix composite and Ceramic matrix composites [2]. Metal matrix have attracted the researchers due to excellent mechanical and physical properties like high specific strength, stiffness, specific modulus, damping capacity, wear resistance and low coefficient of thermal expansion. Metals are usually reinforced to decrease or increase their properties to suit the needs of design. One of the difficult tasks for researchers today is to select material which has low weight and high strength. Aluminium is one such material. It is light weight, strong, ductile, highly corrosion resistant, and excellent conductor of heat and electricity. Also it is recyclable, odourless, long lasting and has good reflective properties. Aluminium alloys are alloys in which alluminium is predominant metal. The primary alloying elements include copper, magnesium, silicon, zinc and manganese. Aluminium alloys are mainly classified into two main categories namely casting alloys and wrought alloys and further both are subdivided into the categories heat treatable and non heat treatable. Selection of right alloy for given application requires considerations like tensile strength, density, ductility, formability, workability corrosion resistance etc. [3]. AMMC's exhibit higher strength, hardness, temperature resistance, abrasion and wear resistance etc because of which AMMC's are extensively used in space, military, automobiles, aerospace, sports, marine, transportation etc. Composites are gifted with good tribological properties due to presence of hard reinforcements. AMMC's became popular due to the improved tribological properties which replaced their monolithic counter parts mainly in automotive and aerospace sector [4]. Composites are manufactured using different techniques such as powder metallurgy, stir casting, mechanical alloying, compocasting, spray decomposition, liquid metal infiltration. Among this powder metallurgy (P/M) is one of the highly developed methods for fabricating composites. P/M is a material processing technology which has grown with expansion of several industries. The basic operations involved in powder metallurgy are selection of appropriate powder, mixing, compacting, sintering and post treatment process [5]. In P/M technique powder of reinforcement particles and metal matrix powder are blended for proper distribution of reinforcement particles in metal matrix. Later this blended mixture is compacted and subjected to sintering. One of the biggest benefits of P/M is its ability to shape powders directly into its final component form (net shaping) or a component near to its final form (near net shaping). P/M has succeeded in replacing other traditional methods of metal forming operations because of low energy consumption, high quality, maximum material utilization, low capital cost and its ability to fabricate complex parts economically. As a result P/M has found applications in aerospace, automotive and other manufacturing industries. Distinct properties and microstructure can be produced using P/M technique, which cannot be produced by other metal working techniques. The mechanical properties here are mainly dependent on the final density of sintered P/M alloys. It was identified that main factors responsible for the reduction of mechanical properties of P/M alloys are presence of voids or porosity in compacted performs and sintered products [6-7].

2. EXPERIMENTAL PROCEDURE

The Al7075 was chosen as base matrix and SiC particulates were chosen as reinforcement phase. Table 2.1 gives chemical composition of Al7075. Powder metallurgy technique was employed for fabrication of specimens. Die was designed and fabricated based on the required dimensions of the specimens to be tested. D2 tool steel was used as die material. Powders are mixed thoroughly and calculations are made to find the amount of powder required for preparing a specimen of 20mm diameter and 35mm length. Specimens were prepared by compaction process where large loads are applied to the powder mix. Uni-axial compression testing machine (CTM) is used for preparation of green compacts. Specimens are prepared for four different combinations of loads (50 KN, 60 KN, 70 KN, and 80 KN) and five different combination of varying reinforcement content (0%, 3%, 5%, 7%, and 10%). Sintering is carried at constant temperature of 560^0 C approximately for three hours and specimens were cooled in the furnace itself for 24 hours. Tests were conducted on prepared specimens.

Element	Chemical composition
Zinc	5.1-6.1
Magnesium	2.1-2.9
Copper	1.2-2
Iron	0.5
Silicon	0.4
Manganese	0.3
Chromium	0.18-0.28
Titanium	0.20
Aluminium	Balance

Table 2.1 Chemical Analysis of Al7075

3. RESULTS AND DISCUSSIONS

3.1 Hardness test

Hardness test here was performed on Rockwell hardness tester. Each specimen is subjected to hardness test with 2.5 mm ball indenter, 100kgf load and 20 seconds of dwell time. Experiments are conducted for varying wt. fraction of silicon carbide reinforcement (0%, 3%, 5%, 7% and 10%) and by varying load 50 KN, 60KN, 70KN, and 80KN (load applied to prepare green compacts).

Figure3.1 shows variation in hardness of prepared composite with respect to increased wt% of SiC content and compaction load. Improved hardness of the prepared composite (Al7075/SiCp) was noticed with increase in the wt% of SiC content. The increased hardness can be because of presence of silicon carbide reinforcement particles which are basically very hard. The uniform distribution of SiC in the formed composites is also responsible for increasing hardness of the Al7075/SiCp composite [8]. Another reason for increased hardness is increased density of the composites. The density of base material (Al7075) is 2.81 g/cc, whereas the density of SiC is 3.21 g/cc. incorporation of SiCp reinforcement in Al7075 matrix increases density of the composite which intern increases hardness of the Al7075/SiCp composite.

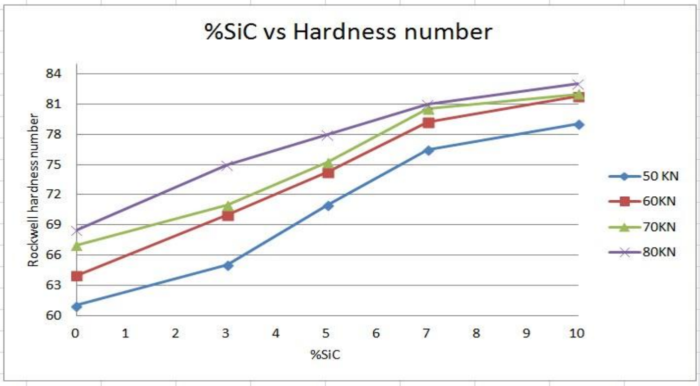

Fig.3.1Hardness number variation with %SiC

3.2 Density measurements

The theoretical density (ρ_t) of sintered specimens was calculated by rule of mixtures. Calculation of experimental density is done by basic formula using mass and volume relations. From the figure 3.2, it can be noticed that the theoretical density of reinforced Al7075 is increasing linearly with increase in the amount of SiC reinforcement. In this work theoretical density was maximum for 10%SiC/Al7075 for all the loads that is specimen prepared by using different loads. Figure 3.3 show that experimental density increases with increasing SiC content. The reason behind increased theoretical as well as experimental density is attributed to addition of reinforcement particles SiC which has high density compared to base metal Al7075 [8].

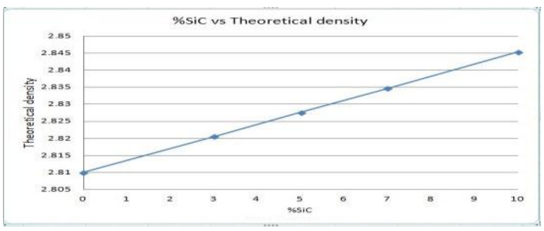

Fig.3.2 Variation in theoretical density with varying %SiC

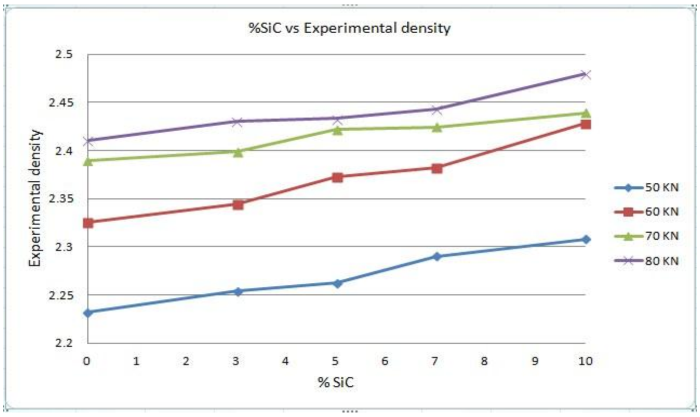

Fig.3.3 Variation in experimental density with varying %Sic for different compaction loads

3.3 Compression test

The sintered specimens were subjected to compression test. For carrying test "computerized universal testing machine (UTM)" was used. All the tests here were carried at the room temperature. Since the UTM was computerized one it was able to get accurate readings of ultimate compressive strength. All tests were carried with 0.5 mm/min cross head speed. The specimen was placed on base plate and load was applied until the crack was noticed. The reading of load applied to cause a crack in specimen was noted. Same procedure was adapted for all other reinforcement content and compaction loads.

Figure 3.4 shows that variation of ultimate compressive strength with varying compaction loads and reinforcement content. It was found that compressive strength increased till 7% SiC content and for 10% SiC it decreased. With addition of SiC particles till 7% the mechanical strength increased, this might be mainly because Al7075/SiC composite becomes tougher with increasing %SiC content. For %SiC content above 7% matrix phase cannot lodge particles without distortion, since SiC particles are hard and brittle which may cause dispersion hardening of matrix. SiC particles in matrix resist the motion of dislocations as a result composite is hardened [9]. Minimum compressive strength was recorded at 0%SiC content and 50KN compaction load and maximum compressive strength was recorded at 7%SiC content and 70KN compaction load.

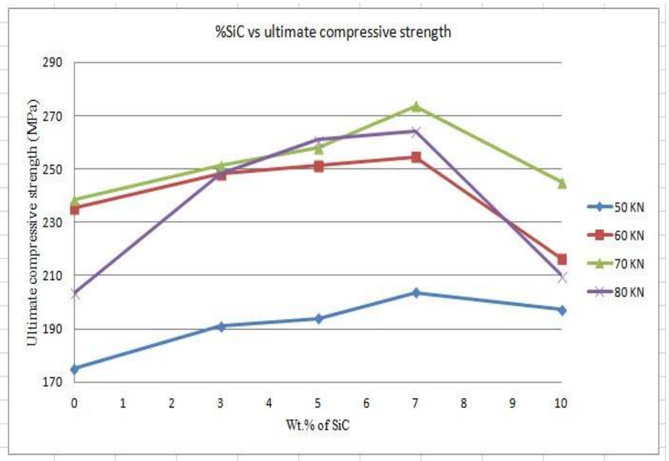

Fig.3.4 Variation in ultimate compressive strength with varying %SiC for different and loads

3.4 Wear test

Tribolgical experiments were performed to understand wear behavior of Al7075/SiC composite on pin-on-disk machine. Wear tests (dry sliding) were conducted on "pin-on-disc wear tester" for 3%SiC, 5%SiC, and 7%SiC. EN31 is counter disc material. Before initiating the test, the surface of disk is to be cleaned thoroughly with acetone. Wear tests were performed by using "Design of Experiments" approach. Taguchi technique is being employed for optimization of best conditions. Al7075+3%SiC, Al7075+5%SiC and Al7075+7%SiC are material 1, 2, and 3 respectively.

Control parameters		Levels	
	I	II	III
Load (N)	10	20	30
Distance (m)	125	250	375
Speed (rpm)	100	200	300
Material	1	2	3

Table 3.1 Levels and Control parameters

L9 Orthogonal array was selected. 3 levels (high, low and medium), and 4 control parameters (material, speed, abrading distance, and load) were used in this project.

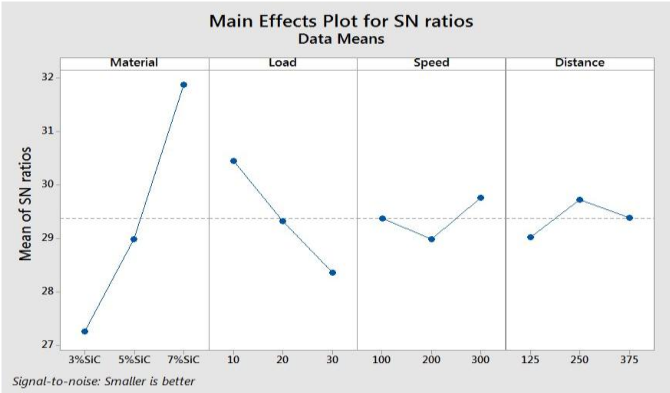

Fig.3.5 Wear response plot for S/N ratio of test specimens

3.5 Influence of different parameters on wear behaviour

3.5.1 Effect of reinforcement content

The higher wear resistance of prepared SiC/Al7075 is mainly due to hard SiC particles which act like load supporting elements. Increase in addition of SiC particles restricts the flow or restricts deformation of base material with load. Coarser the SiC particles, lower will be the wear rate or the other way. For coarse SiC particles, silicon carbide is expected to be embedded within the matrix phase until they are broken down to small particles. In case of fine particles there is large area for particle matrix interface. This increases the chance for pulling out of tiny particles from matrix phase [11].

3.5.2 Effect of load

The rate of wear of prepared composite is dependent on applied load and volume fraction simultaneously. Wear rate has direct relation with applied load. At constant load, rate of wear tends to decrease with rise in SiC content which clearly implies that SiC particles can improve load bearing properties during sliding of AA7075 alloy. Wear rate keeps on increasing from 10N to 30N and reason for this may be because of in-elastic deformation of material. For lower loads, the rise in temperature over sliding surface has least effect on plastic deformation. At higher loads, there is rise in temperature over sliding area that to at very low velocities. Because of this high temperature, in-elastic deformation of surface occurs which is responsible for adhesion of the pin surface on disk. Adhesion is highly responsible for removal of material and as a result there is drastically increase in wear rate [4].

3.5.3 Effect of speed (sliding)

Wear mechanism also depends on sliding speed to high extent. At higher sliding speeds, higher wear rates are observed and vice versa. This may take place mainly because at higher speeds, microthermal softening of the base material might take place, and this again decreases the bonding capacity of SiC with the matrix phase. Because of its low bonding strength silicon carbide particles are bound to pull out easily from matrix phase under such sliding conditions. At lower sliding speeds the bonding of silicon carbide particles seems comparatively better and hence wear rate is less [4].

3.5.4 Effect of distance

With increase in distance, rate of wear is found to be decreasing. This might be caused due presence of hard SiC reinforcement particles which acts as the sharp asperities over surface of prepared composite. Initially for small distances, SiC particles bulge out of prepared composite surface and reduce the area of contact in between disk and test specimen resulting in increased rate of wear. With the increase in distance, compaction of these asperities take place between sliding surfaces causing them to become blunt and leading to increase in the contact area in between these sliding surfaces, which might be the cause for increased wear behaviour of composite under large distance [4].

3.6 Wear analysis

Wear analysis was studied using Minitab software (version 17) to find out the predominant factors which are responsible for wear. Response table for S/N ratios and rankings were found out using the software. “Smaller the better “was chosen as characteristic type. From figure 3.5 it is inferred that reinforcement content is the most predominating factor responsible for wear rate. Next dominating factor on wear behaviour was applied load, which is followed by sliding speed. It is found that in this test sliding speed has least importance on wear rate. From table 3.2 we observe that Al7075 with 7% SiC, 10 N load, 300 speed, and 250 m distance has least wear.

Level	Material	Load	Speed	Distance
1	27.26	30.45	29.38	29.02
2	28.99	29.33	28.99	29.72
3	31.88	28.35	29.76	29.32
Delta	4.62	2.09	0.77	0.70
RANK	1	2	3	4

S/N ratio : Smaller is better

Table 3.2 Wear response for S/N ratios

4. Microstructural features

For micro-structural studies the specimens were cleaned and polished thoroughly. These specimen’s microstructure was studied using scanning electron microscope of resolution of 3nm at 30 KN (high vacuum) and high magnification of 5X to 1000X was used.

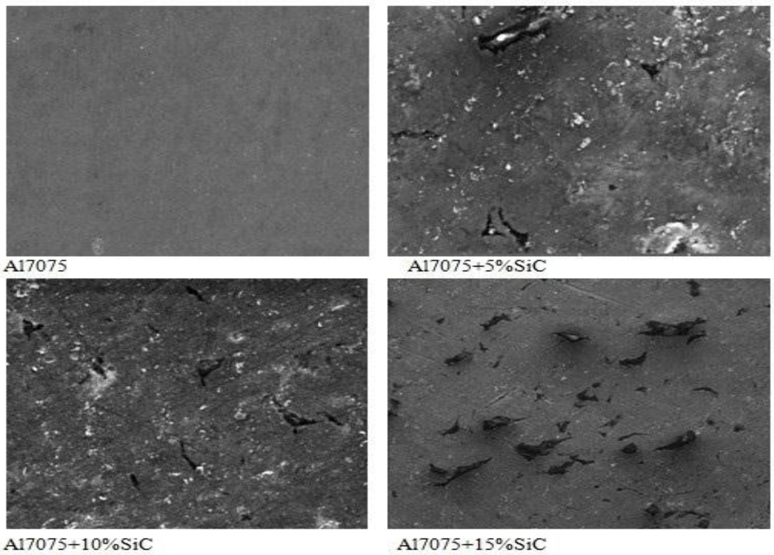

Fig. 4.1 Microstructure observations 0% SiC, 3% SiC,5% SiC and 7% SiC reinforced with AL7075alloy by SEM (200X)

Fig 4.1 shows 0%, 3%,5% and 7% SiC particles in Al7075 matrix alloy. SEM analysis revealed that there was near to uniform distribution of SiC particles in Al7075 matrix alloy. Among SiC particles there was no proper evidence of porosity, when they lye close to each other. It is known that with increase in reinforcement content there will be increase in porosity, but in microstructure images no porosity was seen which may be due to high compaction load applied while preparing the specimens.

5.CONCLUSIONS

An attempt was made to investigate properties of AMCs reinforced with silicon carbide. Powder metallurgy (P/M) technique was employed for composite fabrication. Al7075 is reinforced with different weight fractions of silicon carbide. Sintering temperature is kept constant at 560^{0}C. The following are the inferences of this study:

1. Al7075/SiC$_p$ composites were successfully fabricated by employing powder metallurgy (P/M) technique.
2. Hardness test results revealed that with increase in reinforcement content (from 0% to 10%), the hardness of fabricated composite increased when compared to base 7075 alloy matrix for all combination of compaction loads.
3. Density studies revealed there was increase in theoretical density (2.81 to 2.8454g/cc) with increase in %SiC content from 0% to 10%. Also for different combination of compaction load (50KN to 80KN) experimental density increased with increase in load and % SiC content.
4. Compression strength results revealed that ultimate compressive strength increases with increase in %SiC from 0% to 7% and decreases for 10% SiC.
5. Wear results showed that addition of wt% SiC increased wear resistance significantly. From Taguchi analysis it was found that least wear was noticed at 7% SiC, 10N load, 300 rpm speed and 250 m distance. Hence increment in content of reinforcement leads to improved wear resistance.
6. Overall we can conclude that Al7075/SiC showcase better tribological and mechanical properties than conventional monolithic metals.

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