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Properties of 12% reinforced Aluminium Based Metal Matrix Composites

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Abstract: It is always endeavor of ongoing research in material science to take advantage of specific or particular properties of the constituent material present in a composite material. Aluminum based metal matrix composites have been developed to tailor the properties. Aluminum is a preferred choice for metal matrix composites (MMC) for several reasons like low density, high thermal and electrical conductivity and good damping capacity. Al-MMCs exhibit improved mechanical properties, when reinforced by ceramics like Al_2O_3 and SiC.

This paper presents an experimental study to produce Al-MMC by powder metallurgy process in which fine aluminum powder reinforced by ceramic particles like SiC and Al_2O_3 by 12% of its total weight. The green compact is produced using a set of die and punch and necessary compaction of blended powder is obtained using a mounting press. Sintering of green compact is carried out at temperature of 95% of melting point of matrix material for 1 hour. The study of density, hardness, compressive strength and dry sliding wear capability of fabricated MMC is attempted. The average hardness of MMC is found to be increased 2-3 times as compared to pure commercial aluminium with deviation of 11% in the density obtained experimentally.

Keywords : Al-Metal Matrix Composites, powder metallurgy, wear resistance

I. INTRODUCTION

Extensive research in the domain of material science and engineering has come with such materials which are of high performance and yet lighter in weight as compared to existing materials.Compsite materials are examples of such materials. One of the family of such materials are Metal Matrix composites which has gained a lot of attention of researchers owing to properties such as light in weight, high strength ,high stiffness, creep resistant, at the same time properties of MMC can also be tailored, hence these material became of Interest of sectors like sporting goods industries, marine, automobile and aerospace engineering.

II. METAL MATRIX COMPOSITES

A metal Matrix composite (MMC) is such composite that contains a continuous metallic matrix and a reinforcement that represents at least a few percent of the material by volume.[2]

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The reinforcement used in MMC can be continues fiber or discontinues fibers or may be whiskers.[pm2]. Continuously reinforced MMC does exhibit better specific strength, but their processing is too costly at the same time secondary processing of such MMC hence efforts of research have been found diverted toward development of MMC with discontinuous reinforcement, which are of lower cost and processing methods are convenient and adaptable. However properties of such

MMCs are comparatively lower than those having continuous type reinforcement. Aluminium based MMCs have been of focus of many researchers, as aluminum as compared to other matrix material such as copper, tungsten and titanium offers numerous advantages. Most AL-MMCs have ceramic particles like SiC or Al_2O_3.

Ceramic particulate reinforced MMC does have following advantages along with very modest change in density.

- Enhanced wear and erosion resistance
- Increased stiffness
- Higher damping
- Reduced thermal expansion
- Better creep resistance

However higher cost, lower ductility and lower toughness are the major draw backs of MMCs which should be taken care of .these drawbacks are because of fact that a very brittle and stiff phase is added to ductile matrix.[2]

III. METAL MATRIX COMPOSITES AND POWDER METALLURGY

Sebastian Weber et al. [7] undertook a for sintering of composites. Effect of sintering temperature on relative density was studied. Effect of sintering atmosphere i.e. vacuum & nitrogen was also studied.In their study the method of processing was P/M Sebastian Weber et al.[7] Studied experimentally sintering of composites. Effect of sintering temperature on relative density was studied. Effect of sintering atmosphere i.e. vacuum & nitrogen was also examined. They suggested that The reactions between the matrix and the hard particles during sintering play an important role for the process. Further they revealed that For low reactivity only the sintering behavior of the matrix, is relevant for densification, otherwise in case of high reactivity, hard particle may change the composition of matrix. They fabricated MMC at 1200° C and pressure range was 100-200Mpa.

S.Vaucher et al[8].used gas atomized Aluminium powder with 20% of SiC. Selective laser sintering was applied Residual porosity was the key issue which was studied. They found that at low laser power porosity was found finely dispersed.

Wetting for the ceramic by the molten matrix was found exceptionally good.According to themSLS can be a promising for the processing of light metal MMC

In the experimental work of Nazik et al.[9] Al-MMC with B4C as reinforcement was prepared through mechanical alloying & P/M.Weight proportion of reinforcement was kept as 10% wt.Effect of milling time of powder on hardness, density etc was studied.They found that change in particle size was observed with increase of milling time.Density was not greatly affected by the duration of milling time.In their work hardness was found to be increasing with increase in milling time.,as increasing milling time, fractures coarse particle into fine it results into homogeneous distribution and work hardening of ductile phase are the reasons for the increase in hardness Gaad et al.[10] in their experimental work took a mixture of Invar 36-powder and TiC.TiC was added by 30,60 & 80% of weight.MMC was prepared by Direct metal Laser Sintering. Specific wear rate was investigated Influence of powder mixture on microstructure, porosity & crack formation were studied. DMLS can be successfully used to prepare MMC.Spherical particles formation was found, due to poor wetting and excess amount of liquid phase.

Melting of both metallic phase and ceramic phase took place.CTE of MMC was found increased with increase TiC content.

Radhakirshna et al.[11] Studiedf MMC as potential armor material.Al 2124-SiC MMC with 5% to 25% volume fraction and MMC were prepared through P/M.also they carried out astudy of high strain rate flow behavior. Prepared samples were impacted through gas gun with a WC ball of 4.67 mm over a range of velocities Hardness of MMC was evaluated.

Layered MMC can divert the crack path and leads to crack bridging. Ballistic efficiency was better in 20% SiC composite as compared to Aluminium alloy 6061-T6. According to them Continuous metallic phase can improve the toughness and damage tolerance.

In the Experimental work of Asuquo et al.[12] Alloy of 75Pb-15Sb-10Sn was reinforced with 15%SiO_2 v/v and Stir casting was the processing method. Objective of their experimental was to improve the hardness of this bearing material so that it can be used for heavy duty application Hardness was improved(alloy-27.7HRB & MMC-32-34HRB).This was due to SiC particles.Ageing had little impact on in the improvement of hardnessMorphology of micrographs were found confirming the improvement in hardness and prolonged ageing reduced the hardness.

Mimoto et al[4]. in their experimental investigation took Titanium powder and reinforced with carbon black nano particle.MMC was fabricated through P/M route and Spark plasma sintering was done and hot extrusion was also carries out. In their study strengthening mechanism of P/M Ti-CB composite was investigated. Some CB nano particle was found dissolved into Titanium matrix and MMC showed better properties than those of conventional Ti-6Al-4V. They suggested that strength of MMC was increased due to solid solution hardening by solute carbon atoms. Experimental findings were very close to theoretical estimation.

Zhao et al.[5] fabricated Nickel based MMC reinforced by $Al_{50}W_{50}$ by powder metallurgy (P/M) process. Sintering was done at 1480°C after cold compaction. In their study sintering duration was 60 minutes and during sintering pressure in the die was kept 40MPa.UTS of Composite was found to be increasing with increased content of Nickel. However hardness could not follow the same as surplus Nickel in the matrix could not contribute. They obtained Stress strain curves and MMC with higher content was found tougher than others.

Chen et al.[6] in their experimental study used AlN particles used as reinforcement in magnesium matrix and the Processing method was powder metallurgy(P/M).Compaction of blended was done at 200MPa, further sintering was carried out at 550 °C, 585°C and 620°C. Lattice parameter of Mg in Mg-Al alloy and Mg-Al/AIN MMC was compared.

Lattice parameter was found to be decreasing in Mg-Al alloy and Mg-Al/AIN MMC. Maximum shrinkage of 2.24% was observed in Mg-Al alloy while it was 1.89% in Mg-Al/AIN. MMC solid solubility of Al in α-Mg was found 4.94% because of P/M process.

IV. METHODOLOGY & EXPERIMENTAL

Al-MMC was prepared with proportion of reinforcing element as 10%(by weight) The choice of reinforcing element was made on the basis of literature survey and its availability in local market with reasonable purity and uniformity. Hence Silicon Carbide and Aluminum oxide were taken in this experimental study as a reinforcing element. At the same time the range of weight proportion was also determined by studying existing and ongoing research work.As composite material in this study was prepared through powder metallurgy method, hence die and punch was fabricated. The bore diameter of die is 25 mm and its height is 100 mm while its outer diameter is 65 mm, while a punch of corresponding dimensions was also fabricated. The dimensions of punch and die were decided looking to the specification of mounting press available at the laboratory of the institute. Hence after carefully going through each and every aspect like method, process variable , time available and other facets Powder Metallurgy was decided as a processing method for synthesis of Al-MMC. Reinforcing element was added on weight percentage basis hence required quantity were obtained through, carefully weighing the powder on a digital weighing machine which had a least count of 0.01 gm.

Since blending of metal powder with reinforcing element is important, a tumbling fixture was fabricated to ensure proper and uniform mixing. After mixing well the blended powder was filled in die contour. Each time 40 grams of blended powder were filled in to the die. The die and punch used in this case study is shown in figure 1.

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Figure 1. Set Of Die And Punch

Using a mounting press available in the laboratory the powder was compacted while applying a pressure of 50MPa (500kg/cm2) and then specimen were ejected from the die.subsequently all the samples were sintered in a muffle furnace at 595° C for 1hour.During sintering inert atmosphere in the muffle furnace was maintained by passing argon into heating chamber at the pressure of 2 bars. This was done to reduce the reactivity of aluminium which is the base metal of composite material. After sintering specimen were finished and their dimensions were measure to evaluate the experimental density. Hardness of each specimen was measure on Rockwell B scale using a steel indenter of 1.587 mm and by applying a load of 100kg.Moreover compressive strength and indirect tensile strength was evaluated using UTM machine. For compression test l/d (length to diameter) ratio
was kept 1.25 and for determination of indirect tensile strength diameter to thickness (d/t) ratio was kept as 2. (d=diameter of specimen and t=thickness of specimen}.Microstructure examination was also carried out for one specimen from each composition. In one of the experiment the blended powder was heated to 600 C° for 20 minutes and then compacted in a die at the same pressure which is used during cold compaction of powder i.e. 50MPa pressure . This was done to fabricate composite material through hot compaction of powder to see the effect of temperature on its properties. The specimen prepared by the method explained above are shown in Figure 2

Figure 2. Al-MMC specimen

V. RESULT & ANALYSIS

Density analysis: Density analysis provides an idea about the effectiveness of the compaction of powder in powder metallurgy process. After preparation of Al-MMC theoretical and experimental density for each composition were calculated and tabulated as follows.

Table I. Density Of Al-Mmc

Composition	Theoretical Density (gm/cm^3)	Experimental Density (avg.) (gm/cm^3)	% deviation from Theoretical Density
12%SiC+Al	2.75	2.46	10.55
12 Al_2O_3+Al	2.82	2.54	9.93
12%SiC+3%Cu+Al	3.32	2.71	18.37
12%SiC+Al hot compacted	2.76	2.53	8.33

comparison were also made by keeping the proportion of reinforcing element as 12% and varying or changing the other parameters like, change in reinforcement from SiC to Al2O3, adding 3% copper with 10%SiC, and compacting the hot powder in die , i.e. Hot compaction followed by sintering. Again the average deviation from the theoretical density is found to be 10.05% except for the composition in which copper were added by 3% The deviation for the composition in which 3% copper were added is large this may be due to fact that density of copper is very high as compared to aluminum and SiC.The density of composite is also less than the theoretical value for the reason that due to wall friction in die the densification is not uniform hence average density would be less than the theoretical density. However this problem can be minimized by applying pressure from both top and bottom simultaneously. However some literature suggest that 90% density can be achieved in case of aluminum based P/M product through cold compaction , hence looking to this fact, density of different composition of MMC, obtained in this experimental study seems to satisfactory at this level.

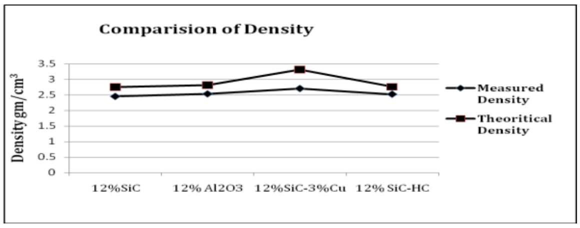

Figure 3. Comparison of density

Hardness Measurement: As one of the objective of this experimental study was to achieve / impart sufficient hardness in the composite material so that being a light weight material it can be sufficiently strong enough for engineering applications. Following table shows the average hardness obtained in each case.

Table II. Hardness of AL-MMC

Sr no	Composition	Range of Hardness	Average Hardness HRB
1	12%SiC+Al	54-98	71
2	12 %Al_2O_3+Al	32-526	42
3	12%SiC+2%Cu+Al	92-98	96
4	12%SiC+Al Hot compacted	45-82	78

As one of the objectives of this experimental study is to test mechanical properties, hence all the samples/specimens of different weight proportion of SiC in aluminium matrix were tested for compressive strength. The compression test was done on UTM Machine.

The load on dial for which the specimens just bulges out was recorded and corresponding stress value was calculated.

Table III. Compressive strength of AL-MMC

Sr no	Composition	Avg. Load on failure (KN)	Compressive strength (MPa)
1	12%SiC+Al	78	162
2	12 Al_2O_3+Al	62	134
3	12%SiC+3%Cu+Al	120	230
4	12%SiC+Al Hot compacted	82	178

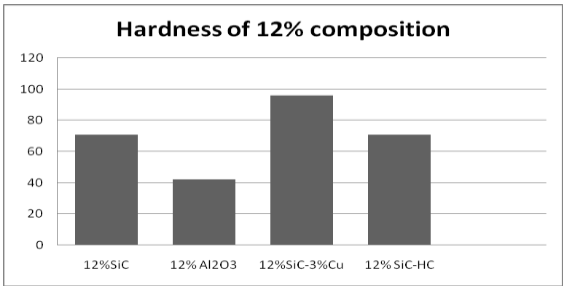

Figure 4. Comparison of Hardness of Al-MMC

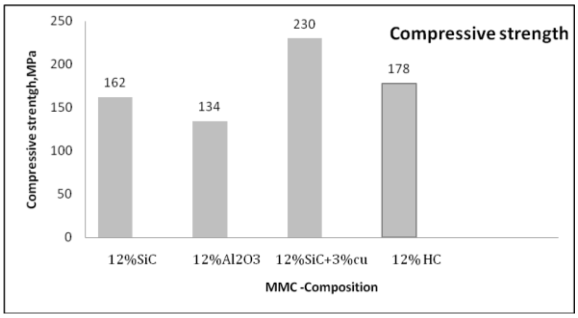

Figure 5. Compressive strength of Al-MMC

Apart from compressive strength test all the specimen of different composition were also tested for indirect tensile test, as with existing powder metallurgy process it is not possible to fabricate a long specimen which can be gripped into the machine and tested for tensile test, hence indirect tensile testing is done.

Table IV. Indirect Tensile strength of AL-MMC

Sr no	Composition	Avg. Load on failure (KN)	Indirect Tensile strength (MPa)
1	12%SiC+Al	18.2	38
2	12 Al_2O_3+Al	11.32	26
3	12%SiC+3%Cu+Al	14.48	32
4	12%SiC+Al Hot compacted	21.33	43

VI. CONCLUSION

From the experimental work and subsequent examination and investigation it is established that a potential exist for synthesis of Aluminium based Metal Matrix Composites. Powder metallurgy Method can be adopted for fabrication of Aluminium -Based Composites Density obtained in composites is less than the theoretical values by 12% on an average. Porosity is difficult to remove even after sintering of green compacts especially for base metal like aluminum which is very reactive. However post processing of sintered components/specimen and ageing process can improve the density and eliminate the porosity. Due to porosity value of hardness when measured is range bound with a adequate span, hence post processing can decrease the range and thus improvement is properties is possible. Substantial difference in the value of hardness of composite containing 12% Al2O3 instead of 12% SiC in observed. This may be due to the fact that there may be ineffective bonding among particles of aluminium powder and power of aluminium oxide. Reason of ineffective bonding among particles of aluminium powder and power of aluminium oxide might be the lack of affinity of pure metal with its own oxide. When copper was added by 2%, the hardness obtained is very high as compared to other cases of 12% Composition. Hence copper can be seen as a favorable additive in the SiC based Al-MMC.The hardness of Al-MMC (12% SiC) which is made from hot compaction is also appreciable. This value of hardness is achieved without sintering hence it shows a possibility that if hot compaction is done sintering may be avoided, but during heating of powder, inert atmosphere must be kept through the use of gas like argon or nitrogen.

Microstructure was also obtained and porosity was observed at some points. Elimination of porosity is proposed to be a new work and being undertaken by the authors.

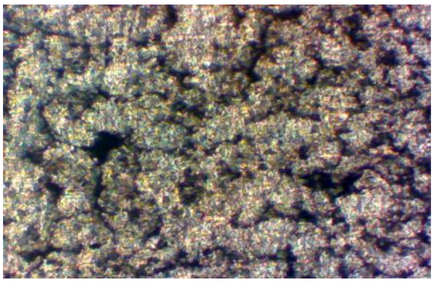

Figure 6. Microstructure of Al-MMC

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