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Study Of Mechanical Properties Of LM-4 Reinforcement With Zro2 For Structural Application

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ABSTRACT
Composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. Composite materials are highly utilized in various fields like aerospace structure, marine, automobile, etc. The present study deals with the investigation of effect of reinforcement (Zirconium dioxide) particles on mechanical properties of Aluminium alloy (LM4) composites, fabricated by stir casting method. The MMC's specimens were prepared by varying weight fraction of the reinforced particles as 0 Wt.%, 3 Wt.%, 6 Wt.%, and 9 Wt.%, 12 Wt.%, 15 Wt.% and keeping all other parameters constant. The microstructure and mechanical properties of fabricated MMC's were analyzed. Microstructural studies of the MMC's reveal a uniform distribution of zirconium dioxide (ZrO_2) particles in the Aluminium (LM4) matrix. The mechanical properties like Micro structural properties, Hardness, Tensile strength and Compression test, were improved with the increase in weight fraction of zirconium dioxide particles in the Aluminium matrix. It was observed that the elongation decrease with increase weight fraction of zirconium dioxide particles in the Aluminium matrix.
Keywords - Aluminium matrix, Hardness, Tensile strength and Compression.

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I. INTRODUCTION

Composites are two or more materials with markedly different physical or chemical properties categorized as "matrix" or "reinforcement" combined in a way that they act in concert, yet remain separate and distinct at some level because they don't fully merge or dissolve into one another. The automotive industry recognizes that weight reduction and improved engine efficiency will make the greatest contribution to improved fuel economy with current power trains. This is evidenced by the increased use of aluminum alloys in engine and chassis components. Aluminum and magnesium castings in this sector have grown in leaps and bounds over the past five years to help engineers design and manufacture more fuel efficient cars. The low density and high specific mechanical properties of aluminum metal matrix composites (MMC) make these alloys one of the most interesting material alternatives for the manufacture of lightweight parts for many types of vehicles. With wear resistance and strength equal to cast iron, 67% lower density and three times the thermal conductivity, aluminum MMC alloys are ideal materials for the manufacture of lightweight automotive and other commercial parts. MMC's desirable properties result from the presence of small, high strength ceramic particles, whiskers or fibers uniformly distributed throughout the aluminum alloy matrix.

Aluminum MMC castings are economically competitive with iron and steel castings in many cases. However, the presence of these wear resistant particles significantly reduces the machinability of the alloys, making machining costs higher due mainly to increased tool wear. As a result, the application of cast MMCs to components requiring a large amount of secondary machining has been somewhat stifled. Most components do not require the high performance capability of aluminum MMCs throughout their entirety. An un-reinforced cast alloy may accommodate the stresses in these areas. Reinforcement of only the high stress regions of a component is referred to as selective reinforcement. This approach to component design and manufacture optimizes the material for the application, reduces the cost of the cast MMC part and lowers machining costs.

Aluminum (lm4) alloy is found wide applications for cylinder-heads, crank-cases, junction boxes, gearboxes, clutch-cases, switch gear covers, instrument cases, tool-handles and household fittings, office equipment and electrical tools etc.

But due to their low melting point and low hardness they will wear and deformed easily. The metal Aluminum cannot meet all the Aluminum based materials that could have all combined properties satisfying all our engineering requirements. ZrO2 can be considered as ideal reinforcements, due to its high strength and thermo-mechanical properties. In the present study, effect of Zirconia (ZrO2) the reinforced was added to Aluminum (LM4) to study the mechanical properties of the composite developed. The composite specimens were prepared using the liquid metallurgy technique and the percentage of ZrO2 was varied from 0-15 wt% in steps of 3 wt%. Different tests were conducted to evaluate their mechanical properties of the composite developed. The results of the tests revealed that the ZrO2 reinforced composites exhibited higher strength/stiffness, lower wear rate compared to unreinforced alloy specimen and also it is also observed that there is uniform distribution of ZrO2 in the LM4.

II. LITERATURE SURVEY

Sachin Malhotra et.al, [1] observed that influence of varying weight percentage of zirconia (5% and 10 %) and fixed percentage fly ash (10%) reinforced Al6061 metal matrix composite by stir casting method. It was identified that hardness and ultimate tensile strength increase with increase weight fraction of reinforcement material. A better hardness 94HV and tensile strength 278 MPa for 10% zirconia and 10% fly ash reinforced composite material. Aluminium alloy 6061 had the determinate elongation of 21.66%, which was significantly reduced to a range of 85% to 90% due to the addition of reinforcement material.

K. B. Girisha et.al, [2] investigated the effect of different weight fraction of zirconium oxide nanoparticle (0.5%, 1%, 1.5%, and 2%) reinforced Al356.1 metal matrix composite by stir casting method. It was observed that particle agglomeration in composite due to high content of zirconium oxide nanoparticle. Hardness and wear properties increase with increase weight fraction of zirconium dioxide nanoparticle.

J. Jenix Rino et.al, [3] investigated the mechanical behaviour of Al6063 alloy composite strengthened by zircon sand and alumina particle with an overall reinforcement in 8 Wt.% by stir casting method. It was observed that homogenous distribution of the reinforcement in Al6063 matrix material. Hardness and tensile strength of the composite having the higher value at the composite sample having the reinforcement mixture of 4wt.% ZrSiO4+4wt.% Al2O3.

K. L. Meena et.al, [4] observed that mechanical properties of the developed SiC reinforced Al6063 metal matrix composite material using the melt stirring technique. The experiment was performed by varying the reinforced particle size as 200 mesh, 300 mesh, 400 mesh and different weight percentage, 5%, 10%, 15%, and 20% of SiC particle reinforced composite material. The stirring process was conceded at 200 rpm using a graphite impeller on behalf of 15 min. A homogenous dispersion of SiC particle in the aluminium matrix was observed. Tensile strength, hardness and breaking strength improved with the enlargement in reinforced particulate size and weight percentage of SiC particles. Percentage elongation, percentage reduction area and impact strength decrease with the rise in reinforced particle size and weight percentage of SiC particles. Maximum hardness (HRB) 83, and impact strength 37.01 Nm was achieved at 20% weight percentage of SiC particles.

Sandeep Kumar Ravesh et.al, [5] studied the effect of the different weight fraction of SiC (2.5%, 5%, 7.5%, and 10%) and 5% fly ash reinforced 6061 aluminium matrix composite by stirring casting technique. Tensile strength, hardness and impact strength increased with growth in weight fraction of SiC particles. A better tensile strength 115 N/mm2, hardness 93 RHN and toughness value 7.8 for a 10% SiC and 5% Fly ash reinforced composite material was obtained.

III. OBJECTIVES OF PROJECT

1. To develop a manufacturing methodology for pure composite material of metallic base.
2. Characterization of developed pure composite material for Tensile, Hardness and Compression properties.
3. To understand the deformation and fracture behavior of pure Zirconium dioxide (ZrO2) with Aluminium (LM4).
4. To study the fracture pattern by visual observation.

IV. EXPERIMENTAL WORK

Elem ents	Al	Si	Cu	Fe	Ti	Mg
Wt%	89 .7	4. 95	3.1	0.72	0. 16	0.113

Table 4.1: Chemical Composition of Aluminum Alloy LM4

Oxide/Particle Type	Purity (%)	Density (g/cm3)	Supplier
ZrO2	99.87	5.89	Leo Chemicals Ltd.

Table 4.2: Specifications of Zirconium-dioxide (ZrO2) Powder

In the present research fabrication and testing of Aluminum alloy[LM4] reinforced with ZrO2 particle cast at (680 0C), varying the dispersoid content by weight percentage in the steps of 3 to 15 Wt% in steps of 3 Wt% has been cast. Mechanical properties and Microstructure studied are performed to for the above cast composite. In the present investigation, Al (Lm-4) was used as the matrix for the synthesis of particle reinforced metal matrix composites. In this investigation, Zirconium dioxide (ZrO2) of average particle size 25μm was used for reinforcement. The purity and density of ZrO2 powders used are shown in Table4.1.

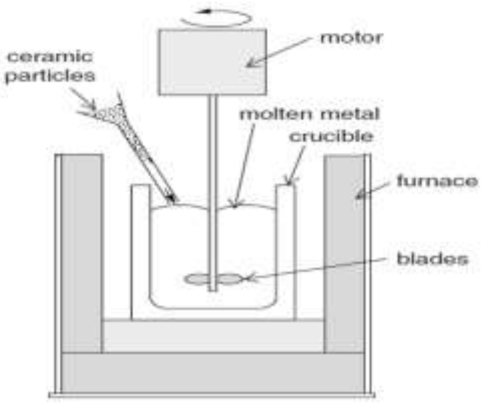

Fig 4.1: Experimental set-up for stir casting

Fig 4.2: Pouring of Molten Metal to Die

Fig 4.3: Casting Specimen

A batch type stir-casting furnace cum pouring set-up as shown in Figure 1 has been used for solidification processing of Lm4 based composites. In this study, Lm 4 was used as the matrix material and ZrO2 particles are added as reinforcements in amounts of 3, 6, 9, 12 and 15wt%. About 650 gm of Lm 4 alloy was melted and superheated to a desired processing temperature in a clay-graphite crucible inside the furnace. Before any addition, the surface of the melt was cleaned by skimming. The weighed amount of ZrO2 particles was added into molten Lm 4 at a processing temperature of 9000°C and the rate of addition of ZrO2 particles was controlled at an approximate rate 6-8 g/min. A coated pitched blade stirrer was used to disperse the ZrO2 particles in the melt. Anon-contact type speed sensor was used to measure the constant stirring speed of 300 rpm. The temperature of the melt was measured by using a digital temperature indicator connected to a chromel alumel thermocouple. When the desired time of the stirring elapsed, reduce the stirrer speed. After completion of processing steps, the graphite stopper at the bottom of the crucible is removed by using the lever to pour the melt-particle slurry into sand mould of cavity of size 25X25 mm for wear sample and length of 150 mm for hardness and microstructure are provided in the mould. Mould is kept right below the graphite stopper, the mold containing that cast ingot is allow to cool in air, in order to achieve better uniformity in distribution of the particles throughout the casting.

Designation of Matrix (LM 4) in gm	ZrO2Particle (wt %)
AP	0
AP	3
AP	6
AP	9
AP	12
AP	15

Table 4.3: Nominal Compositions of the Composites

Different composites is as shown in Table 4.3 have been designated on the basis of its constituents and the first letter A indicates the base metal LM 4 and the next P indicates the ZrO2 powder, followed by the number indicating the wt% of Zirconia added.

V. TEST CARRIED OUT

Micro Structural Examination

Microstructure characterization was conducted on all the polished specimens with Keller's reagent using OLYMPUS metallographic microscope to investigate morphological characteristics of grains, reinforcement distribution and interfacial integrity between matrix material and the reinforcement. It is observed from the above set of photomicrographs that the molten material of MMC solidified under cryogenic condition suffers a severe super cooling. This results in high rate of heat transfer and rapid cooling of the hot melt in MMCs samples. Hence the critical size of the solidified melt is reduced and a greater number of nuclei are generated causing a finer microstructure. In addition to the super cooling of the melt, the stirring action of reinforcement segregated reinforcement particles do not have time to settle down due to the density difference between matrix material and the dispersiod and this result in more uniform distribution of Nano ZrO2 particles in the matrix material. The cryogenic effect during solidification causes stronger bonding between the matrix material and the reinforcement. This shows the wettability was good between the particles and the matrix material with the cryogenic cooling. These two factors lead to improved mechanical properties of the MMCs. Thus the strong bonding between the dispersoid and the matrix material causes more effective load transfer. Figures 5.1a, 5.1b, 5.1c, 5.1d, 5.1e and 5.1f shows microstructure of matrix material (LM 4).

Microstructure characteristics of hydraulically pressed MMCs are discussed in terms of distribution of reinforcement and matrix-reinforcement interfacial bonding. Micrograph reveal uniform distribution of the reinforcement with very limited clusters, good reinforcement-matrix material interfacial integrity, improved grain refinement with minimum porosity. At the same time, due to gravity of ZrO2 associated with parameters such as good stirring action in the molten stage of LM 4, good wetting of the preheated nano ZrO2 by the melt of the material. Metallographic studies of the hydraulically pressed samples revealed that the matrix material is fully recrystallized.

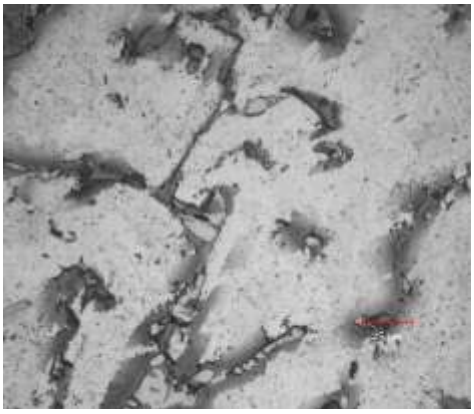

Fig 5.1a: Base material

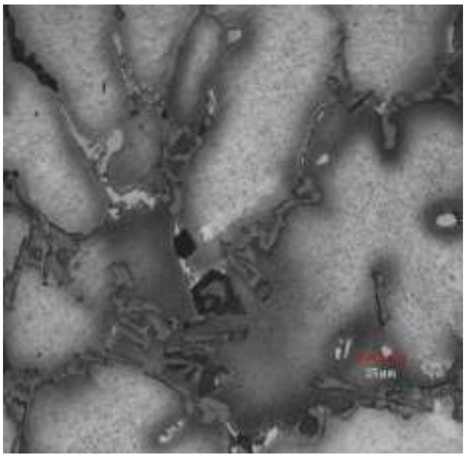

Fig 5.1b: 3Wt% Reinforcement

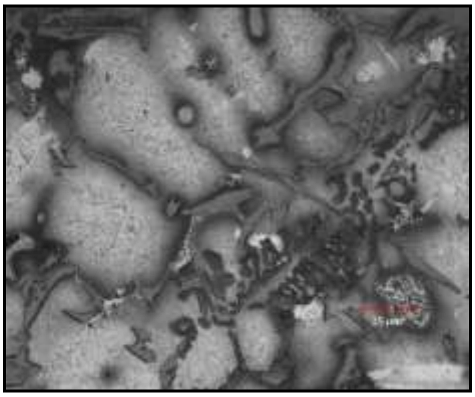

Fig 5.1c: 6Wt% Reinforcement

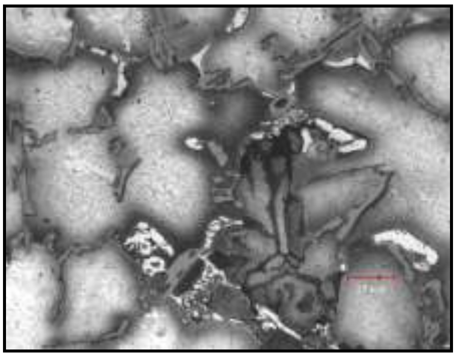

Fig 5.1d: 9Wt% Reinforcement

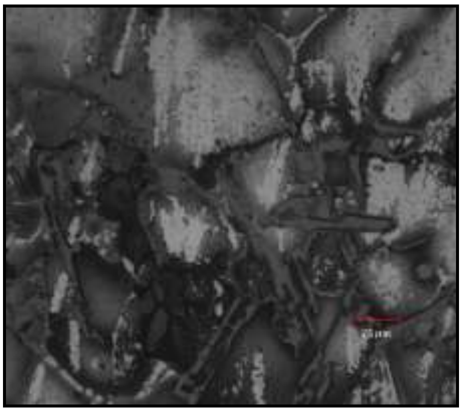

Fig 5.1e: 12Wt% Reinforcement

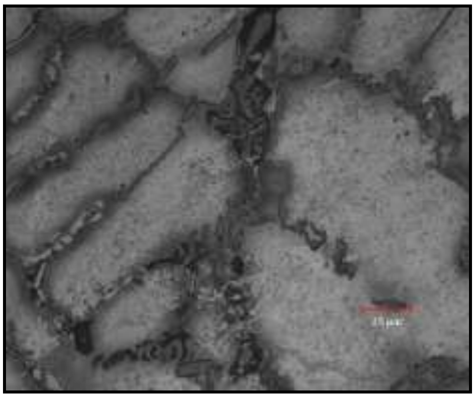

Fig 5.1f: 15Wt% Reinforcement
Fig 5.1: Micro Structure of ZrO2 Reinforced with Al alloy MMC

Hardness Test:

Fig 5.2: Brunel Hardness Test Machine

Brunel micro hardness(strength) testing is as shown in figure 5.2, were conducted after the microscopic study on all the MMCs specimen using metsuzawa MXT50 digital hardness tester using 25gf indentation load in accordance with ASTM E18-94 standards. The results of micro hardness test conducted on all hydraulically pressed MMCs samples revealed an increasing trend in matrix material with increase of reinforcement up to 12Wt%. Results of hardness measurement revealed that increase in the reinforcement content leads to a significant increase in the hardness. Because of the presence of Nano ZrO2 particles in the matrix material lead to higher resistance to the localized deformation during indentation effect.

Universal Tensile Strength (UTS) Test

Figure 5.3 shows that UTS are higher for all the MMCs as compared against the molten matrix material (LM 4). When the reinforcement content Nano ZrO2 increases from 3 wt% to 15 wt. %. The UTS values also increases with varying ZrO2. UTS of the LM 4 is 135 MPa. It is also observed that MMCs containing 12 wt. % invariably has the highest tensile strength.

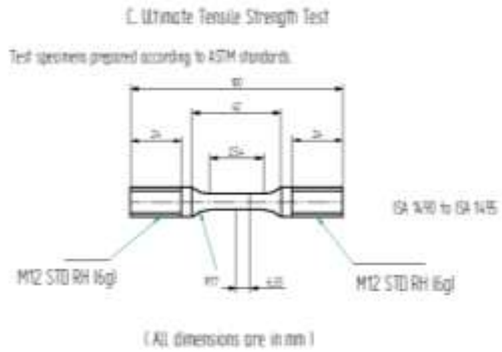

Fig 5.3: Drawing of tensile test specimen (ASME Standard)

Fracture Toughness Test

Fig 5.4: Fracture Toughness Machine.

Fracture toughness tests were conducted on all MMCs by using a closed loop INSTRON servo hydraulic material testing system. This method involves 3-point bend testing (in accordance with ASTM E399 1990 standard) of machined specimen which was pre-cracked by fatigue loading. The fracture toughness machine of the MMCs with varying reinforcement content are shown in Figure 5.4 and indicates the values increasing from 3 wt. % to 15 wt. % of the reinforcement in the increasing trend. Comparing these results it can be seen that increasing the reinforcement content seems to have an effect of fracture toughness on the cast composites. It is also observed that MMCs containing 12 wt. % invariably has the highest fracture toughness. Further it is observed that fracture toughness value decreases when 15 wt. % reinforcement were present. These results show that the matrix material (LM 4) dense, stronger and accommodate the reinforcement (nano ZrO2) rigidly. There was a strong bonding between the matrix material and reinforcement (up to 12 wt. %) and this could lead to a greater strength and fracture toughness of the MMCs compared with the monolithic alloys. The mechanism which controls the variation of fracture toughness of the MMCs dependent on microstructure and strain range. Fracture toughness of the LM 4 is 4.0 MPa

VI. RESULTS AND DISCUSSION

Hardness Test

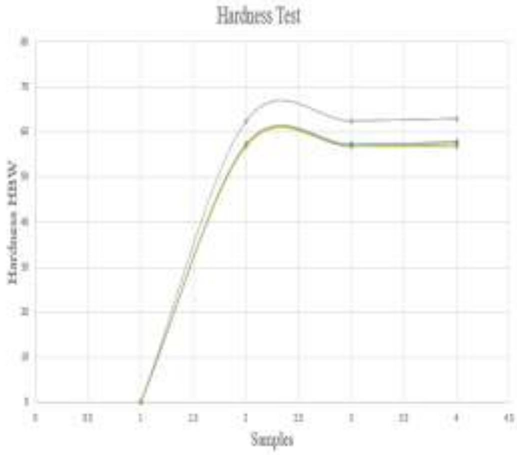

Fig 6.1: Hardness Test (Hardness v/s Samples)

The hardness of the composites obtained from the micro Vickers hardness tester are represented in a Line graph as shown in Figure 6.1. From the results it is observed that the composite with 6 wt.% Zirconia is the hardest among the three and the hardness value is 62.4 and the composite with 3wt.%, 9wt.%, and 15wt.% Zirconium exhibits least hardness 57.3 in the Vickers scale.

Tensile Test

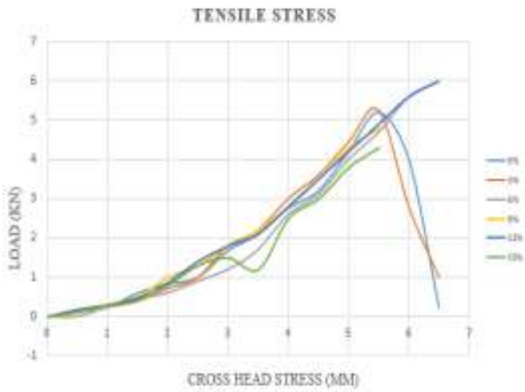

Fig 6.2: Universal Tensile Test (Load v/s Cross Head Stress)

From the above Figure 6.2, it is clearly obserbed that Tensile Test increases when the Incresing in percentge of ZrO2 upto 12% and Reduses after Increasing 12% of the ZrO2.

Compression Test

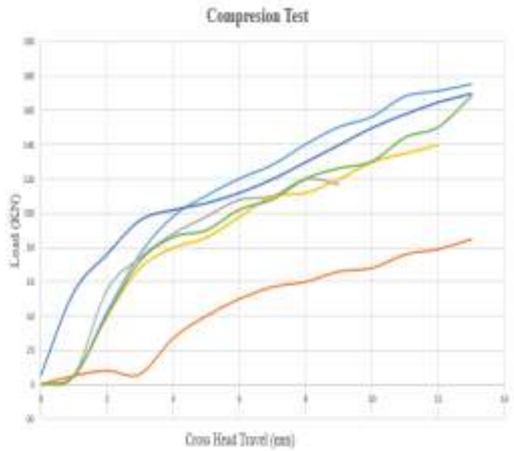

Fig 6.3: Compression Test (Load v/s Cross Head Stress)

From the above Figure 6.3, it is clearly obserbed that Compresion Test increases when the Incresing in percentge of ZrO2 upto 12% and Reduses after Increasing 12% of the ZrO2.

VII. CONCLUSION.

Stir casting technique used for the fabrication of ZrO2 composites reveals the following:

a) Microstructures of composites are finer than that of the matrix material.
b) The interfacial bonding between the matrix material and the reinforcement is stronger of the composites.
c) Hardness shows the best results when the Zirconium-dioxide (ZrO2) is employed at 3% weight percent.
d) Hardness observed that the composite with 6 wt.% Zirconia is the hardest among the three and the hardness value is 62.4 and the composite with 3wt.%, 9wt.%, and 15wt.% Zirconium exhibits least hardness 57.3 in the Vickers scale.
e) Tensile Test increases when the Incresing in percentge of ZrO2 upto 12% and Reduses after Increasing 12% of the ZrO2.
f) Compresion Test increases when the Incresing in percentge of ZrO2 upto 12% and Reduses after Increasing 12% of the ZrO2.
g) Fractography analysis revealed that the fracture behaviour of FCC structured Al matrix alloy has changed from ductile mode of fracture to cleavage mode because of the presence of ZrO2.

VIII. SCOPE FOR FUTURE WORK.

The study can be extended by the addition of other materials with Aluminium (LM4). Wear and corrosion studies can also be carried out. Also it would be interesting to note the results of MMC that would be prepared with other methods e.g. ball milling, with the same %wt. of the particulate other than stir casting technique.

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