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Studies on Properties of Micro-Nano ZrO_2 Particulate Metal Matrix Composites

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ABSTRACT:

A metal matrix composite (MMC) is a composite material with at least two constituent parts, one being a metal matrix and other is reinforcement. When at least three materials are present, it is called a hybrid composite. Aluminium is widely used in aerospace and automobile industries due to its low density and good mechanical properties, better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The aim involved in designing MMC materials is to combine the desirable attributes of metals and ceramics. This project is aimed at development of MMC having aluminium metal matrix with micro-nano particulate zirconium oxide reinforcement. Here aluminium (LM25) has been selected as base metal along with 12% ZrO_2 (micro), 12% ZrO_2 (nano) and 12% ZrO_2 (6% micro + 6% nano) have been taken as reinforcements to produce MMC. The composite has been produced by liquid metallurgy technique (stir casting). The properties of chosen composite are compared with base metal for tension, wear, hardness, density and microstructure analysis. For the combination of Al-LM25 with 12% zirconium oxide (6% micro + 6% nano) the tensile strength (TS) and hardness had increased when compared to that of base metal and are between that of the micro and nano reinforced composite. The density of MMC cast is almost relevant to theoretical densities. For MMC, the wear rate increases for an increase in the speed for a given constant load and time. The microstructure study reveals that Al-LM25 and zirconium oxide have been distributed uniformly throughout the casting with less porosity.

KEY WORDS:

Aluminium LM25; Micro-nano zirconium oxide; Stir casting; Metal matrix composites

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1. Introduction

For most of the engineering application main requirement is the selection of materials, which have better properties. But usually the material with unusual combination of properties cannot be obtained from regular metals or metal alloys, using conventional production method. Thus, it is essential to obtain desirable properties of materials, which can be obtained from composite materials. Therefore, the composite materials are widely used in aerospace industries, transportation, marine and military equipments. The materials for this kind of application should be off low density and yet to be strong enough to with stand the load, which cannot be obtained from conventional production technique. Also, the impact resistance and structural arrangements of materials has been changed. Most of the engineers are always involved in research of better combination of materials having desirable properties. The answer obtained by research from past few decade is that the composite materials pose great extent of opportunity, which should be used in better manner for the given application, also considering the cost and process economy into account.

The process of combining dissimilar characters of two or more materials and obtaining a material having a phase difference can be examined only under better magnification of micro-macro scope level. This process is quite different and contrast from regular metallic alloys. This experimental technique is used to obtain desirable attributes of both matrix phase and reinforcement phase. The new generation of materials is produced to fulfil the actual demands for automobile and aircraft industries. Various theories have been formulated to determine the theoretical aspects of the heterogeneous materials obtained from different production technique. The testing procedure for this kind of materials has been found as the standards of procedure. This also includes the design of experiment, properties measurement using various test methods, testing and analysis.

The materials in which two or more materials are tailored together, in which one being least metal and other is reinforcement is known as metal matrix composites (MMC). This different constitute of combination can be achieved using composite technique only [1]. The production of composites involves various steps: such as melting, introducing the reinforcement, casting, preparation of samples and testing. The metal matrix used in engineering combination consisting of continuous fibre or reinforcement, whiskers or particles of ceramics to obtain the higher specific modulus and specific strength. The composite should also have other properties like good thermal conductivity, resistance to corrosion, low co-efficient of thermal expansion and so on. MMC are non-equilibrium combination of metal and ceramics. There is also restriction for volume fraction of reinforcement to be added for base metal, due to thermodynamic properties and physical properties of metal and ceramics. Even the size and shape of reinforcement should be taken into account for production of composites. The properties of composite also depend on isotropic and anisotropy of the materials.

2. Material selection and experiments

The aluminium (LM25), whose specifications as given in Table 1, has been selected as the base material and the reinforcement used is zirconium oxide (ZrO2) in micro size and nano particles size. The aluminium has been reinforced with ZrO2 with different volume fraction and the desirable attributes of both metal and particulate properties would be achieved using stir casting method. ZrO2 mainly increases the strength, tribological and corrosion properties of the base material. MMC is mainly used in ball bearings, cylinder liners and also in drive shaft. The crucible with aluminium LM25 has been kept inside a three-phase electrical resistance furnace. When mains were switched on, the alloy ingot will melt slowly. The crucible is made up of clay and graphite. Stir casting setup is shown in Fig. 1. The temperature of the melt inside the furnace was noted. The temperature was checked with an alumel-chromel thermocouple before the crucible taken out of the furnace. The crucible was taken out of the furnace at the melting temperature of 850°C. The molten metal was degassed using hexa-chloroethane (C_2CL_6) tablets as degasifying agent (0.5% weight of the metal). The tablet was plunged in to the metal and held at the bottom to enable the chlorine gas to purge through the melt and to remove the solid particulate impurities, gaseous impurities, primary aluminium oxides and other dissolved gases.

Table 1: Chemical composition of aluminium (LM25)

Element	%by weight	Element	%by weight
Copper	0.1max.	Zinc	0.1max.
Magnesium	0.2-0.6	Lead	0.1max.
Silicon	6.5-7.5	Tin	0.05max.
Iron	0.5max.	Titanium	0.05-0.2
Manganese	0.3max.	Aluminium	Remainder
Nickel	0.1max.		

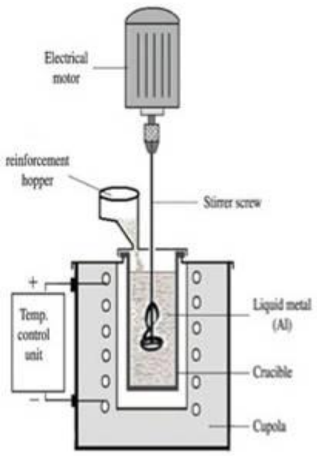

Fig. 1: Stir casting

The aluminium alloy was melted in an electrical furnace. The stirrer was introduced to perform the mixing process when the molten temperature reached 850°C. The stirring was carried out for 45 minutes at the rate of 200 rpm. ZrO2 particles were preheated to 200°C and introduced into the molten alloy [2-3]. The pouring temperature of molten mixture was 850°C and molten metal was poured into the die [4-5]. Then MMC was ejected from the die at a temperature of 150°C and it is allowed to cool in air. The aluminium composites matrix which is circular in nature is machined using lathe machine to perform the tensile test. The materials were turned according to ASTM E8 standard. Here the high-speed steel has been used as a tool for turning the material. The gauge length of the specimen is 26mm, diameter is 12.5mm, specimen length is 51mm and gauge diameter is 6.25mm. The wear test specimen was machined to a length of 50mm and diameter of 10mm. The hardness test specimen was machined to a diameter of 20mm and thickness of 15mm.

3. Results and discussion

Fig. 2 shows the stress vs. Strain curves of tensile test samples. It is evident from Table 2 that the tensile strength (TS) was increased for the combination of Al-LM25 with 12% ZrO2 (Micro). For the combination of Al-LM25 with 12% ZrO2 (Nano), the TS was increased and is better than the previous combination. For the combination of Al-LM25 with 6% ZrO2 Micro and 6% ZrO2 Nano, the TS was increased and it is between the micro and nano ZrO2 reinforcements. The UTS of all three MMCs are higher than the UTS of base metal.

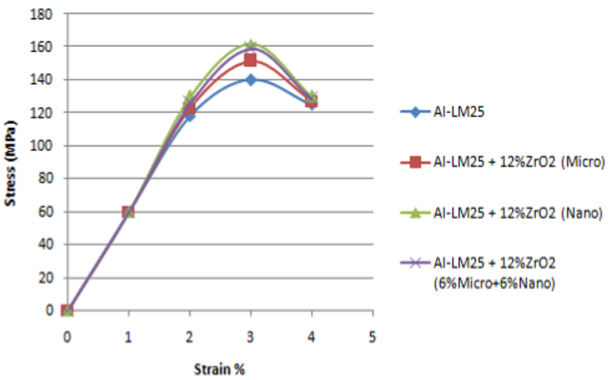

Fig. 2: Stress strain diagram

Table 2: Tensile test results

Composition	UTS (MPa)
Al-LM25	140.00
Al-LM25 + 12%ZrO2 (Micro)	151.14
Al-LM25 + 12%ZrO2 (Nano)	161.55
Al-LM25 + 6% ZrO2Micro+6% ZrO2Nano	158.77

As presented in Table 3, the hardness was increased for the combination of Al-LM25 with 12% ZrO2 (Micro). For the combination of Al-LM25 with 12% ZrO2 (Nano), the hardness was increased and is better than the previous combination. For the combination of Al-LM25 with 6% ZrO2 Micro and 6% ZrO2 Nano, the hardness was increased and it is between the micro and nano reinforced composite. The hardness of all the three

MMC is higher than the hardness of base metal [6-7]. The samples were weighed and the density was calculated by knowing the volume. The densities compared in Table 4 shows that the density of MMC cast is almost relevant to the theoretical densities.

Table 3: Hardness test results

Composition	BHN
Al-LM25	50.00
Al-LM25 + 12%ZrO2 (Micro)	60.73
Al-LM25 + 12%ZrO2 (Nano)	65.59
Al-LM25 + 6% ZrO2Micro+6% ZrO2Nano	62.9

Table 4: Density results

Composition	Theoretical density (g/cm^3)	Experimental density (g/cm^3)
Al-LM25	2.68	2.6
Al-LM25 + 12%ZrO2 (Micro)	3.018	2.99
Al-LM25 + 12%ZrO2 (Nano)	3.018	2.95
Al-LM25 + 6% ZrO2Micro+6% ZrO2Nano	3.018	2.98

The wear rate and frictional force results for different speeds for the combination of Al-LM25 + 12%ZrO_2 (Micro), Al-LM25 + 12%ZrO2 (Nano) and Al-LM25 + 6% ZrO2Micro+6% ZrO2Nano are shown in Fig. 3 and Fig. 4 respectively. The wear rate increases as the speed increases. The wear rate increases proportionally to the frictional force. At 600 rpm and after 400 seconds, the wear rate of Al-LM25 + 12%ZrO_2 (micro) has shown higher wear than the other two MMCs. The maximum frictional force is also observed fro Al-LM25 + 12%ZrO_2 (micro) MMC [8-9].

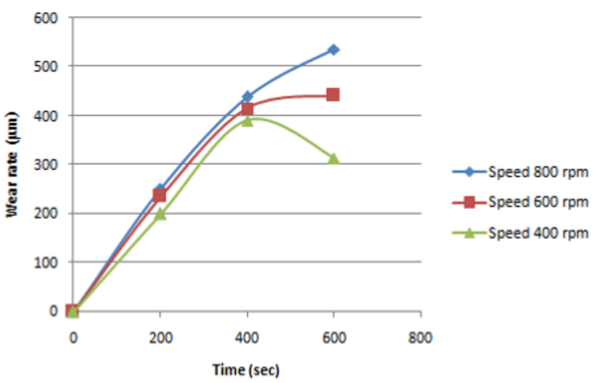

Fig. 3(a): Wear rate vs. Time - Al-LM25 + 12%ZrO_2 (Micro)

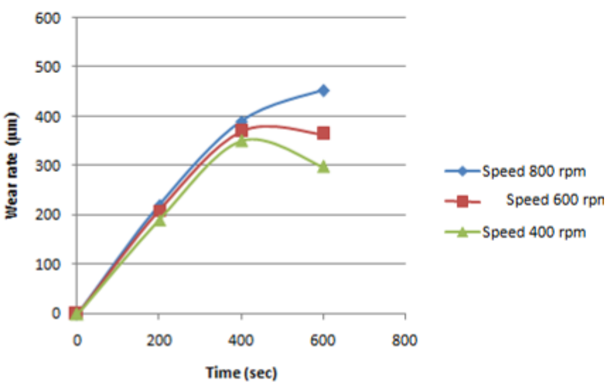

Fig. 3(b): Wear rate vs. Time - Al-LM25 + 12%ZrO_2 (Nano)

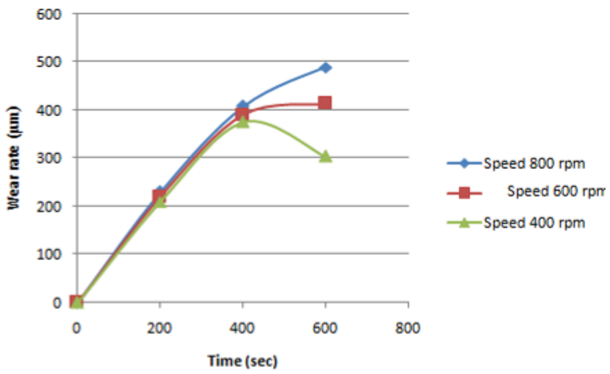

Fig. 3(c): Wear rate vs. Time - Al-LM25 + 6% ZrO2Micro+6% ZrO2Nano

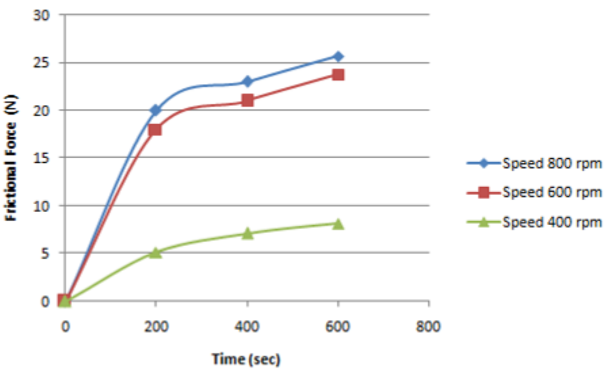

Fig. 4(a): Friction force vs. Time - Al-LM25 + 12%ZrO_2 (Micro)

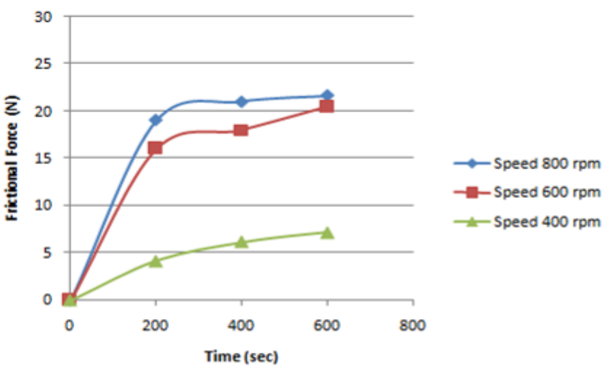

Fig. 4(b): Friction force vs. Time - Al-LM25 + 12%ZrO_2 (Nano)

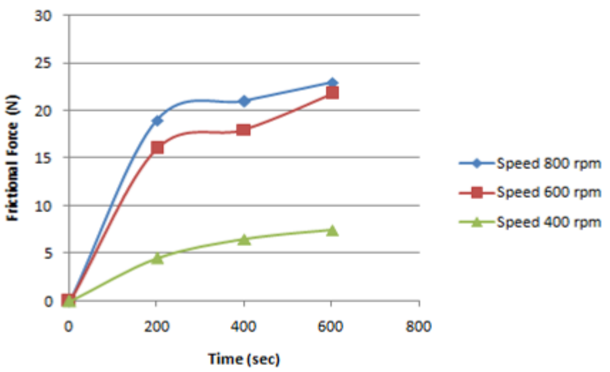

Fig. 4(c): Friction force vs. Time - Al-LM25 + 6% ZrO2Micro+6% ZrO2Nano

4. Microstructure analysis

The micro structural analysis has been carried out to examine the distribution of matrix phase and reinforcement phase in MMC [10]. The properties depend upon the grain structure of the material and hence the analysis of microstructure plays an important role. The polished and etched specimen is used for microstructural study. The optical micrographs for all the combinations are shown in Figs. 5 to 7 for different magnifications. The micrographs are taken at 50X, 100X and 200X magnifications. The dark and light areas are present in the micrograph of the composite represent ZrO2 and aluminium respectively. The aluminium matrix phase and the reinforcement phase were dispersed uniformly. In the micrographs we can observe that ZrO2 particle is in the form of rod, network like structures and also needle like morphology.

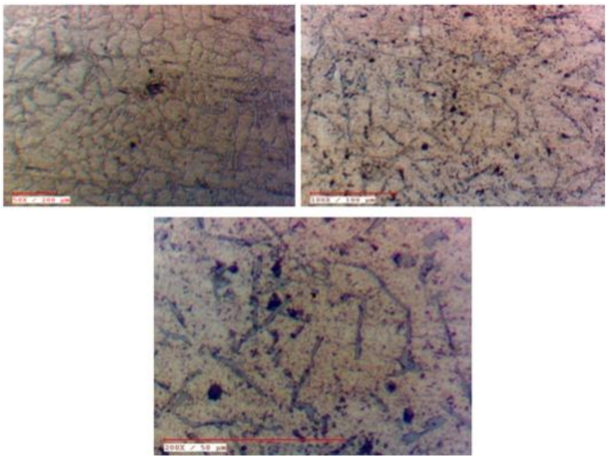

Fig. 5: Optical micrographs of Al-LM25 + 12%ZrO_2 (micro)

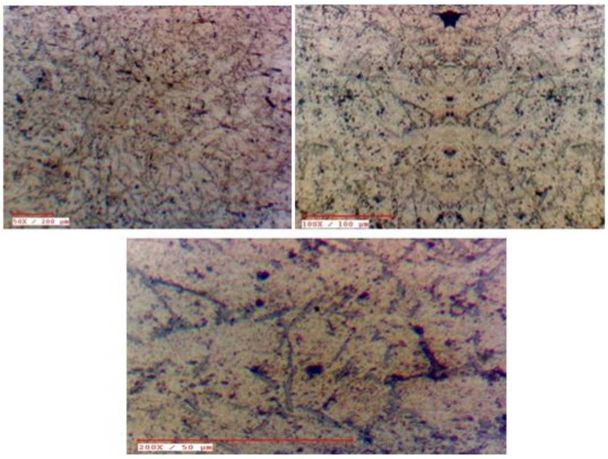

Fig. 6: Optical micrographs of Al-LM25 + 12%ZrO_2 (nano)

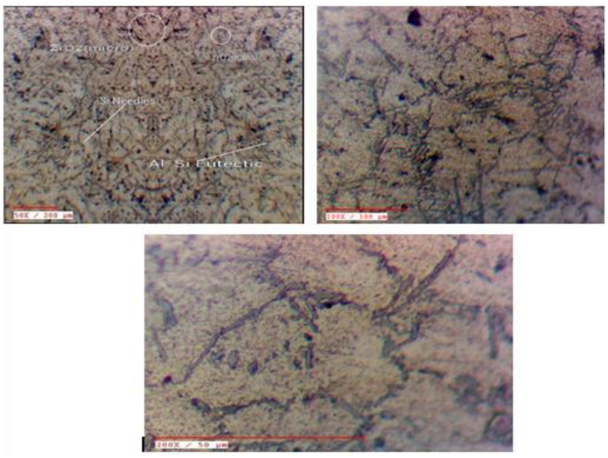

Fig. 7: Optical micrographs of Al-LM25 + 6% ZrO2 Micro + 6% ZrO2 Nano

5. Conclusion

The production and evaluation of properties of MMCs were undertaken according to the standards. For the combination of Al-LM25 with 12% ZrO2 (6% micro - 6% nano), the TS and hardness are increased and they are between micro and nano reinforced composite's strengths. The ultimate TS and hardness for all the three MMCs is higher than that of the base metal. The density of MMC cast is almost relevant to theoretical densities. The wear rate increases with increase in speed for a given constant load and time. The microstructure study reveals that Al-LM25 and ZrO2 were distributed uniformly throughout the casting with less porosity and showed fine grain microstructure.

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