SYNTHESIS AND CHARACTERIZATION OF MECHANICAL PROPERTIES OF NANO TiO_2 PARTICLE REINFORCED AL-MMC

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ABSTRACT

The metal matrix Nanocomposites can be used in numerous applications. Aluminum Nano Matrix Composites (ANMC) is 25 to 30 % stronger in both mechanical and deformation behavior than micro filler Aluminum Matrix Composites (AMC). To ameliorate performance of composite matrix in aluminum alloy metal is reinforced with Nano particles in the matrix of alloy uniformly, which ameliorates composite properties without affecting limit of ductility. The paper presents the results of an experimental investigation on mechanical properties of Nanosized Titanium-di-oxide (TiO_2 -p) particle reinforced aluminum metal matrix composite. The influence of reinforced ratios of 4, 8 and 12 wt. % of TiO_2 -p on mechanical properties was examined. The reinforcement particle sizes of the TiO_2 -p were in the range of 200 to 225 Nanometer and LM0 aluminum alloy was used as matrix. The composites were synthesized by Stir Casting method by using bottom pouring muffle furnace and Magnesium was added to the melt in order to improve the wettability of the composites. It was perceived that enhancement of Nanoreinforcement element addition produced better mechanical properties such as hardness and tensile strength.

KEYWORDS: Nano TiO_2 , LM0alloy, Nano Composites & Stir Casting

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INTRODUCTION

Composites are defined as materials having two or more dissimilar materials, which when combined are stronger than the individual materials [1-3]. In recent years ceramic particle reinforced metal matrix composites (MMCs) have gained wide acceptance because of their attractive properties. MMCs offer high strength to weight ratio, high stiffness and good wear resistance resulting in an everincreasing use in the aerospace, automotive and bio-medical industries [4].

Cammarata R [5] defined “nanocomposite as a multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometers (ηm), or structures having Nano-scale repeat distances between the different phases that make up the material. The mechanical, electrical, thermal, optical, electrochemical, catalytic properties of the nanocomposite will differ markedly from that of the component materials”.

“The common idea after the addition of the nanoscale reinforcement is to generate a synergy between the

various constituents, such that novel properties capable of meeting or exceeding design expectations can be achieved. The properties of nanocomposites depend on a range of variables, particularly the matrix material, which can exhibit nanoscale dimensions, loading, a degree of dispersion, size, shape, and orientation of the nanoscale second phase and interactions between the matrix and the second phase.” Recently research work is focused on Nanometal matrix composites (NMCs) due to its unique properties such as high strength with lightweight [6].

“TiO₂ in the form of fibers or particulates has long been recognized as a high strength material. Aluminium TiO₂ particulate MMCs produced by solidification techniques represent a class of inexpensive tailor-made materials for a variety of engineering applications such as automotive components, bushes, and bearings. Use of TiO₂ reinforcement in a metal matrix has a potential to create a material with a high thermal conductivity, excellent mechanical properties and attractive damping behavior at elevated temperatures”[7].

Particulate reinforced aluminum alloy composites have shown a significant improvement in tribological properties including sliding and abrasion wear resistance, and seizure resistance [8]. Thus, much research has been conducted on particulate metal matrix composites for tribological applications due to the advantages of MMCs such as good wear resistance, high load carrying capacity and lightweight.

“Metal matrix composites (MMCs) reinforced with Nano-particles, also called Metal Matrix Nano-Composites (MMNCs), and is being examined worldwide in recent years, owing to their increased properties suitable for a large number of functional and structural applications. The reduced size of the reinforcement phase down to the Nano-scale is such that interaction of particles with dislocations becomes of significant importance and, when added to other strengthening effects typically found in conventional MMCs, results in a remarkable improvement of mechanical properties” [9].

“Al -based NMCs consist of ductile matrix alloy with Nano-sized particle /fillers. Generally they are in ceramic phase with high strength and modulus. Thus, NMCs are more suitable to use due to their high strength tensile / compression/shear processes at higher working temperature environment. Hence, they find extraordinary potential applications in lower to higher end research areas such as, automotive to aerospace structural materials” [10].

The use of Nano-TiO₂ reinforcement in a metal matrix has a capability to generate a material with a high thermal conductivity, excellent mechanical properties and attractive damping behavior at higher temperatures. TiO₂ has acknowledge consideration as reinforcing phase as it is found to increase the hardness, tensile strength and wear resistance of aluminum metal matrix composites.

Md Saiful Islam et al [11] explained that “Nano-fillers may be classified into three categories based on their sizes, morphologies, and shapes. In the first category, there are fibers that have a diameter of less than 100 nanometres and the aspect ratio from 100 to 10⁶. Some examples of this type are nanoscale graphite fibers, carbon nanotubes, and hexagonal boron/nitrogen nanotubes. In the second category, the three-dimensional nanofillers are comparatively equiaxed, and their size of the largest dimension is less than 100 nm. Some examples are silica nanoparticles, Titania nanoparticles (TiO₂), aluminum oxide nanoparticles (Al₂O₃), cerium oxide nanoparticle (CeO₂), and zinc oxide nanoparticle (ZnO). In the third category, there are platelike nanofillers, which are layered materials, with a thickness of about 1nm and an aspect ratio of at least 25 in two dimensions. Most common nanoparticles of this type are layered silicates (i.e., mica)”.

Zamanian et al. [12] “observed additional improvement in Young’s modulus of nanocomposites at higher weight

fractions of nanoparticles. The improvement was higher when reduced sized nanoparticles were used. Yang et al [16] reported that mechanical properties (UTS & E) of Al matrix alloy and Al MMCs rapidly dropped at a higher temperature but with different magnitude. The strength of Al matrix alloy decreases 80 % but 50 % for its composites at 400 °C. These results show that composites at the higher temperature will have better properties than the matrix alloy.

Iman S. El-Mahallawi et al. [13] “Observed the properties of cast aluminum alloys by adding nanoparticles. In his work, the effect of adding alumina (Al₂O₃), titanium dioxide (TiO₂) and zirconia (ZrO₂) Nano-particles (40 nanometres) to the aluminum cast alloy A356 as a base metal matrix was investigated. Alumina, titanium dioxide and zirconia Nano-powders were stirred in the A356 matrix with different fraction ratios ranging from (0%–5%) by weight at variable stirring speeds ranging from (270, 800, 1500, 2150 rpm) in both the semisolid (600 °C) and liquid (700 °C) state using a constant stirring time of one minute. The cast microstructure exhibited a change of grains from dendritic to spherical shape with increasing stirring speed. The fracture surface showed the presence of nanoparticles at the interdendritic spacing of the fracture surface and was confirmed with EDX analysis of these particles. The results of the study showed that the mechanical properties (strength, elongation, and hardness) for the Nano-reinforced castings using Al₂O₃, TiO₂ and ZrO₂ were enhanced for the castings made in the semi-solid state (600 °C) with 2 weight% Al₂O₃ and 3 weight% TiO₂ or ZrO₂ at 1500 rpm stirring speed”.

Ganesh Khandoori et. al [14] studied aluminum reinforced with 5%, 10%, 15% TiO₂ particulate fabricated by stir casting process and properties are investigated. Addition of Mg improves the wettability in aluminum melt and thus increases the amount of reinforcing phase in the composite. The wear resistance and frictional properties of Aluminium composite are studied by performing dry sliding wear test using a pin on disc wear tester. The wear rate decreases with increasing TiO₂ volume content of the reinforcement.

EXPERIMENTAL STUDIES

Al (LM0) alloy was chosen as a matrix because it is having good castability and good resistance to corrosion.

Table 1: Chemical composition of LM0 alloy

Element	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
Wt. (%)	0.3	0.03	0.03	0.03	0.4	0.07	0.03	0.03	Balance

Table 2: Physical Property of LM0 alloy and Nano-TiO₂

Material	Density(g/c m ³)	Melting Point °C.	Yield Strength (Mpa)	Thermal Conductivity (W/mK)
LM0 Alloy	2.7	650	60	209.2
Nano TiO ₂	3.97	1843	2000C	11.8

“Titania or Titanium Di-Oxide (TiO₂) exists in a number of crystal-like forms and the most important of which are anatase and rutile. Pure titanium dioxide does not occur in nature but is derived from ilmenite or leucocene ores. Titanium dioxide is produced either in the Anatase or Rutile crystal form. Most titanium dioxide in the Anatase form is produced as a white powder, whereas various Rutile grades are often off-white and can even exhibit a slight color, depending on the physical form, which affects light reflectance. Titanium dioxide may be coated with small amounts of alumina and silica to improve technological properties” [15]. In the present work Anatase grade Nano-TiO₂ is used as reinforcement.

In stir casting method the reinforcements, stirrer, and permanent mold are preheated to 300°C to eliminate moisture and gases from the surface of the reinforcements, and equipment before the casting. Now the required amount of LM0 is weighed and placed in the graphite crucible and heated to 730°C using bottom pouring muffle furnace then the magnesium is added to reduce the coating film defects by ejecting the volatile components present in the melt during casting. The magnesium helps in the elimination of entrapped air in the melt and thus prevents casting defects like porosity and blowholes. Then the matrix LM0 is reinforced with Nanoparticle size of TiO₂ particulates with different weight percentages. The Nanoparticle of TiO₂ was added at the temperature of 730°C and a constant vigorous stirring was done for 3- 4 minutes at a speed of 500 rpm until a clear vortex is formed. At the pouring temperature of 730°C, the molten mixture was poured by releasing the locking nut in the bottom of the furnace to the cast iron mold and immediately after filling the mold is water quenched.

Figure 1: Bottom Pouring Muffle Furnace

The bottom portion of the casting was taken for Microstructural characterization to note the distribution of second phase particulates. Metallography is the study of a material's microstructure. Analysis of a materials microstructure aids in determining whether the material has been processed correctly and is, therefore, a critical step for determining product reliability and for determining why a material failed.

The Brinell hardness testing method is used to determine Brinell hardness, is defined in ASTM E10. The Brinell hardness test is a simple indentation test for determining the hardness of a wide variety of materials and it is particularly preferred for particle reinforced composites as it could provide a better average hardness over a larger area containing several fine particles in the matrix. The Brinell hardness of the cast composites was studied on the samples. The testing was carried out at a load of 500 Kg by using a steel ball indenter of diameter 10 mm, the load was applied for about 180 seconds on a sample and then the diameter of indentation was measured with the help of a travelling microscope. For each indentation, an average of two diameters measured perpendicular to each other was used to find the corresponding hardness. On each sample, at least thirty (30) indentations for hardness measurement were made at different locations and the average of these readings is reported as the hardness value of the material.

Among the various mechanical testing, tensile testing is most important and widely used one. Many parameters can be derived from the complete tensile test record. One can obtain important information concerning the materials elastic properties, the character and extent of plastic deformation, yield strength, tensile strength and toughness [16]. The response of materials to other types of loading can sometimes be explained or predicted on the basis of their behavior under simple tension.

Figure 2: Dimensions of ASTM E8-M88 Standard for Tensile Strength

The testing specimen was prepared according to the American Standard Testing Materials ((ASTM) E8-M88 standard) [16] as shown in figure 2.

RESULTS AND DISCUSSIONS

Microstructure

Figure 3 (a) – (c) shows the SEM micrographs of LM0 reinforced with 200 nm TiO₂ particle of 4, 8 and 12 wt. %. This reveals the uniform distribution of TiO₂ particles in LM0 base matrix and very low agglomeration and segregation of particles were seen. The vortex generated in the stirring process breaks solid dendrites due to higher friction between particles and LM0 matrix alloy, which further induces a uniform distribution of particles.

Figure 3: Scanning Electron Micrographs of
(a) LM0-4 %TiO₂ and
(b) LM0-8 %TiO₂
(c) LM0-12 %TiO₂ Composites

Figure 4 shows energy dispersive X-Ray spectrographs of LM0 with 8 wt. % of Nano TiO₂ composites respectively. The EDS analysis confirmed the presence of Al, Ti, O, and Mg in the Al matrix alloy. Ti, O, and Mg are the major elements, which are confirmed.

Figure 4: Showing the Energy Dispersive Spectrographs
of LM0-5% TiO₂ Composites

Hardness Measurements

The hardness of as -cast LM0 with 200 nm particle size of TiO₂ for 0, 4, 8 and 12wt. % composites are evaluated using ball indenter of diameter 10mm at an applied load of 500kg for each sample at different locations. The hardness variation of samples for as -cast LM0 with 200 nm particle size of TiO₂ for 0, 4, 8 and 12wt. % is illustrated in Figure.5. The hardness of LM0 for 12% of TiO₂ composites is higher than the LM0 alloy (37 BHN), due to the presence of Nano Ti particles. Also, it can be attributed to the higher hardness of TiO₂ particles compared to aluminum alloy. In fact, the hardness of composite depends on the hardness of the reinforcement and the matrix. The increase in hardness is mainly due to the coefficient of thermal expansion (CTE) of ceramic particles is less than that of aluminum alloy and because of sudden water quenching [17]. So, an enormous amount of dislocations are generated at the particle-matrix interface during solidification process, which further increases the matrix hardness. The higher the amount of particle-matrix interface, the more is the hardening due to dislocations [18].

Figure 5: (a) Indentations on the Composites, (b) Comparison of Hardness of LMO-200nm TiO₂ with Different Percentage of Reinforcement

Figure 6 showing the effect of Nano TiO₂ particulates on the tensile behavior of LM0 alloy. From the graphs, it is noted that Nano TiO₂ reinforced composites showed more ultimate and yield strength as compared to the LM0 base matrix. Further, as a weight percentage of Nano TiO₂ increases from 4 to 8 and 12 %, in LM0-TiO₂ composites, it is observed that UTS increased from 97 MPa to 110 MPa, to 119 MPa for base alloy it is found that 88 MPa. This increase in UTS and YS is mainly due to the presence of Nano TiO₂ particulates in the matrix. These particulates act as the barrier for dislocations. When compared to particles sizes in microns 12% has been increased when the particles in Nano size. As seen from the graph the percentage of elongation decreases with increase in the percentage of nano TiO₂ and the ductility also decreases.

Figure 6(a): UTS of LMO-200 Nano TiO₂ Composites
b) % age Elongation of LMO-200 Nano TiO₂ Composites

CONCLUSIONS

NanoComposites are successfully fabricated by Bottom Pouring Stir Casting Method. The following conclusion were made after testing and characterization.

- The micrographs showed the uniform distribution of Nano TiO₂ reinforcement without amalgamation and clustering.
- The XRD results show the presence of nano TiO₂ and Magnesium phases.
- The hardness and UTS of the nanocomposites increase with an increase of weight % of Nano TiO₂ reinforcements particles.
- The percentage of elongation and ductility decreases with an increase of weight % of Nano TiO₂ reinforcement particles.

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