INFLUENCE OF VARIOUS NANO-SIZED TIO2 PARTICLES ON THE MECHANICAL PROPERTIES OF ALUMINIUM COMPOSITES SYNTHESISED BY STIR CASTING METHOD

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Abstract - The Aluminium based metal matrix Nano composites can be used in numerous applications because of their Splendid Mechanical, Tribological Properties and Light Weight compared to Micro composites. In these work the influence of mechanical properties of two Nano sized Particles of 15 and 200 Nano meter Titanium-di-oxide (TiO_2-p) particles reinforced with LM0 aluminium metal matrix synthesized by using bottom pouring stir casting furnace and the reinforced ratios used are 0, 4, 8 and 12 wt. %. In Nano composites the ductility of matrix material will be more when compared to micro and macro sized particulate composites. Magnesium were added to the melt in order to improve the wettability of the composites. Care has to be taken while manufacturing of Nano composites because as the Particle size decreases the clustering and agglomeration is seen in the composite. The results obtained shows that the mechanical properties of composites depends on Nano Particle size of the reinforcement added and weight % of the particulates.

Keywords - Nano TiO_2 Particles, LM0 alloy, Aluminium Nano Composites, Stir Casting, Microstructure, Hardness and Tensile Properties.

I. INTRODUCTION

Nanocomposites are materials that incorporate Nano sized particles into a matrix of standard material. The result of the addition of nanoparticles is a drastic improvement in properties that can include mechanical strength, toughness and electrical or thermal conductivity. The effectiveness of the nanoparticles is such that the amount of material added is normally only between 0.5 and 15% by weight. The NMCs are one of the modern composites materials based on matrix alloy combined with Nano-scaled reinforcement due to their excellent mechanical properties at both room temperature and high temperature. These material also have many advantageous properties such as, high wear resistance, good fatigue and creep resistance. [1].

Different kinds of matrix metals have been coupled with several types of nanometric phases. Ceramic compounds (SiC, Al2O3, etc.), intermetallic materials and carbon allotropes were used to reinforce Al, Mg, Cu and other metals and alloys. Particular importance is assigned to carbon nanotubes (CNT), which are characterized by very high strength, stiffness and electrical conductivity. These properties confer higher mechanical strength while improving electrical and thermal properties of the base material [2, 3]. Moreover, MMNCs revealed to be able to improve other interesting engineering properties, such as damping capacity [4, 5], wear resistance [6] and creep behavior [7].

Titania or Titanium Di-Oxide (TiO_2) exists in a number of crystalline forms the most important of which are Anatase and Rutile. Pure titanium dioxide does not occur in nature but is derived from ilmenite or Leuxocene ores. It is also readily mined in one of the purest forms, rutile beach sand. 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 [8]. Rutile is the thermodynamically stable form of titanium dioxide; Anatase rapidly transforms to rutile above 700^o. Rutile melts between 1830^o and 1850^o [9].

Now a day's researchers all over the world are focusing mainly on aluminium because of its unique combination of good corrosion resistance, low density and excellent mechanical properties. The unique thermal properties of aluminium composites such as metallic conductivity with coefficient of expansion that can be tailored down to zero, add to their prospects in aerospace and avionics. Titanium has been used in aero engines mainly for Compressor blades and discs due to its higher elevated temperature resistance property. Magnesium is the potential material to fabricate composite for making reciprocating components in motors and for pistons, pins and spring caps. It is also used in aerospace due to its low coefficient of thermal expansion and high

stiffness properties combined with low density. The choice of Silicon Carbide as the reinforcement in aluminium composite is primarily meant to use the composite in missile guidance system replacing certain beryllium components because structural performance is better without special handling in fabrication demanded by latter's toxicity [10]. TiO2 has received attention as reinforcing phase as it is found to increase the hardness, tensile strength and wear resistance of aluminium metal matrix composites.

Zapata et al [11] explained that the preparation of nanocomposites can be done by three routes, which are "solution blending, the molten state, and in situ polymerization." They pointed out that the latter consists in placing the monomer and the catalyst between the clay layers, and polymerization takes place in the gap, so as polymerization progresses the spacing between the clay's layers increases gradually and the dispersion state of the clays changes from intercalated (the ordered of layered silicate gallery is retained) to exfoliated (delamination with destruction of the clay sheet order). The advantages of this method are 1) the one step synthesis of the metallocene polymer nanocomposites; 2) improved compatibility of the clay and the polymer matrix; and 3) enhanced clay dispersity.

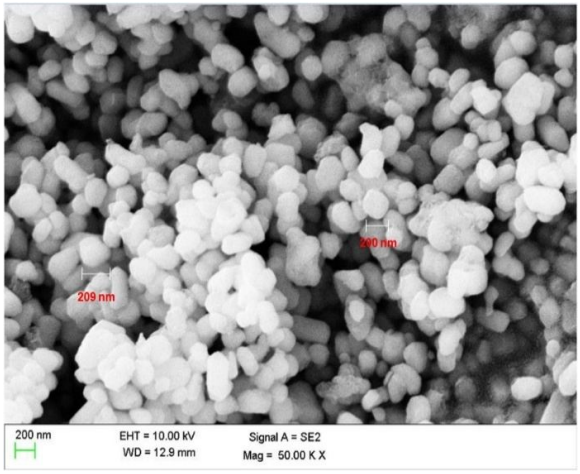
Vedani M et al [12] in their investigation proved that the Orovan equation shows that Nano size reinforcement is highly advantageous than the macro size reinforcement for mechanical and tribological applications. Only small amount of Nano size reinforcement is enough to give higher wear resistance to the matrix alloy.

Kang and Chan et al [13] showed that by increasing nanometric particulates content to 4 vol. %, the strength of Al nanocomposites increases i.e., tensile and hardness nevertheless, when the content exceeds 4 vol.%, the strength does not vary due to agglomeration of the nanoparticles.

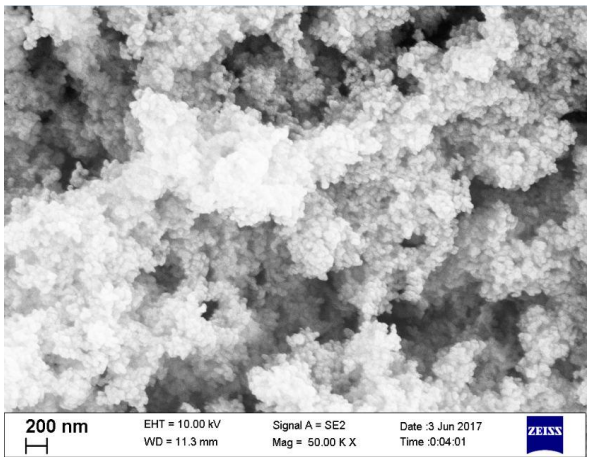
II.EXPERIMENTAL STUDIES

Al (LM0) alloy which is having 99.75% pure aluminium was chosen as matrix because it is having good castability and good resistance to corrosion [14].LM0 Alloy having density of 2.7 g/cm3, Melting Point of 650^0C, Yield Strength of 60 MPa and Thermal Conductivity 209.2 W/mK.

In the present work Rutile grade Nano-TiO_2 is used as reinforcement material having density of 3.97 g/cm3, Melting point of 1843^0C, and because of their thermodynamic properties. TiO_2 Nano particle size are conformed from the below SEM Image.



(a)



(b)

Fig 1: Scanning Electron Micrographs of (a) 200 nmTiO_2 and (b) 15nmTiO_2 Particles.

In stir casting method the reinforcements, stirrer, and permanent mould are preheated to 350^0C to eradicate moisture and gases from the surface of the reinforcements, before adding to the LM0 Alloy Matrix.

The known quantity of LM0 will be melted to 750^0C in a graphite crucible using resistance furnace. The melted liquid will be agitated with the help of stirrer having four pitched blades (45° pitch angle) to form a fine vortex and then the 5wt% of magnesium is added to minimize the coating film defects by expelling the volatile components present in the melt during casting. Then the matrix LM0 is reinforced with Nano particle size of TiO_2 particulates with different weight percentages. The Nano particle of TiO_2 were added at the temperature of 730-750^0C and a constant rigorous stirring was done for 3- 4 minutes at a speed of 500-550 rpm until a clear vortex is formed. At the pouring temperature of 730^0C the molten mixture was poured by freeing the locking nut in the bottom of the furnace to the cast iron mould and immediately after filling the mould is water quenched.

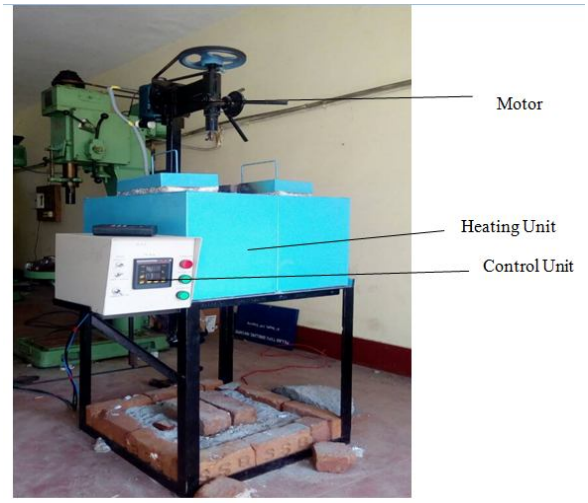


Figure 2: Bottom Pouring Muffle Furnace

The bottom portions of the casting were taken for Microstructural characterization to check the distribution of second phase particulates and the mechanical Properties will mainly depends upon the uniform distribution of the Particulates in the Matrix of the Composites.

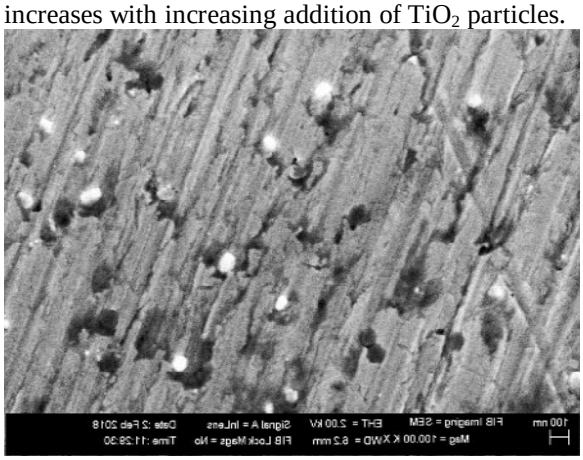
The Brinell hardness testing is carried out to determine Brinell hardness number of the composite as per ASTM E10 standards. The Brinell hardness test is a simple indentation test for determining the particle reinforced composites as it could provide a better average hardness over a larger area containing several fine particles in the matrix. The testing was carried out at a load of 500 Kg by using a steel ball indentor 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 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 (30-36) indentations for hardness measurement were made at different locations and the average of these readings is reported as the hardness value of the material.

Tensile testing is carried out to determine the tensile properties of the prepared composites. Many parameters can be derived from the complete tensile test record. The materials elastic properties, the character and extant of plastic deformation, yield strength, tensile strength and toughness and ductility of the composites can be evaluated. Testing specimen was prepared according to the American Standard Testing Materials ((ASTM) E8-M88 standard) [15].

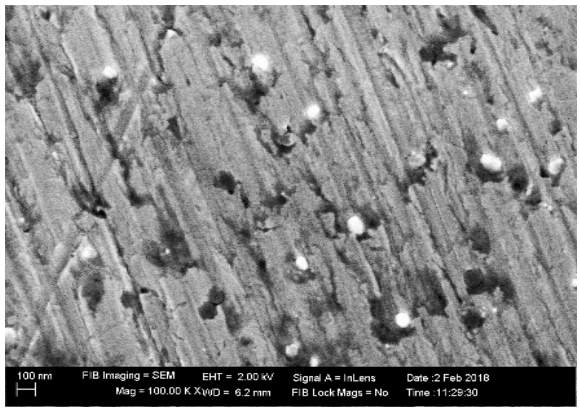
III. RESULTS AND DISCUSSION

A. Microstructure

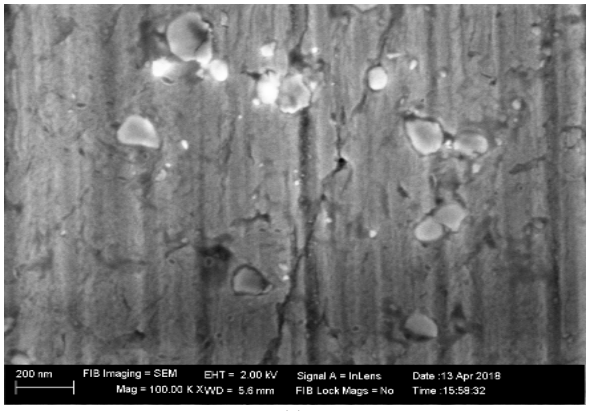
Fig. 3 (a),(b) and (c) shows the SEM micrographs of LM0 reinforced with15 nm TiO_2 particles with 4, 8 and 12 wt.%, and Fig. 3 (d),(e) and (f) shows the SEM micrographs of LM0 reinforced with 200 nm TiO_2 particles with 4, 8 and 12 wt.%. SEM of the prepared specimen has taken at a magnification range of 200nm and the magnification used was 1,00,000. From the SEM Micrographs it can be seen the differences of particles and as the particle size decreases the agglomeration and clustering of the particles will be more in composites. The agglomeration is more in higher weight percentage of TiO_2 (12 wt.%), but agglomeration is more in composites prepared with 15 nm particles of TiO_2 compared to composites of 200 nm TiO_2 particles. The microstructure of these aluminium based composites contains intermetallic Al_3Ti and oxide Al_2O_3 particles and their amount increases with increasing addition of TiO_2 particles.



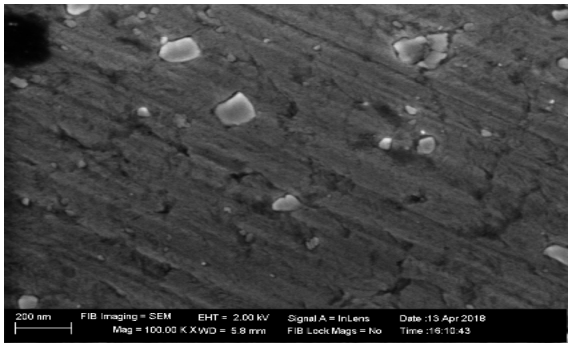
(a)



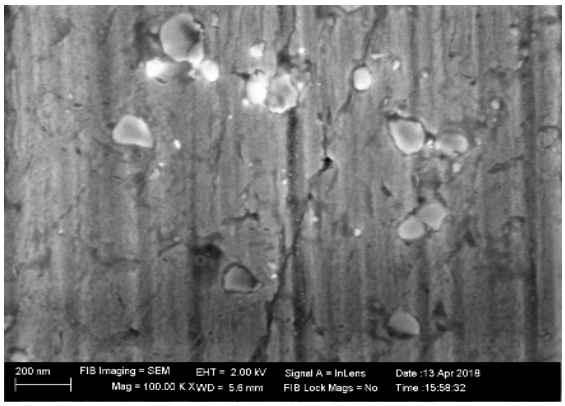
(b)



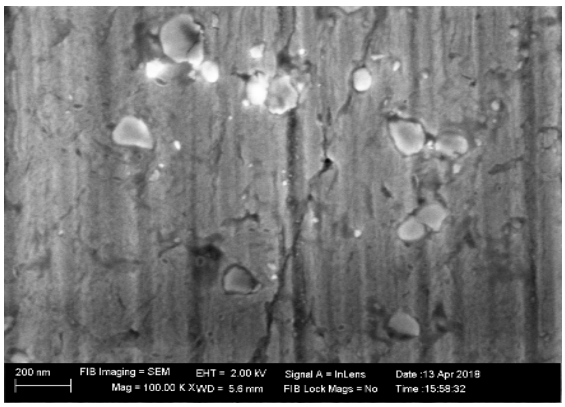
(c)



(d)



(e)



(f)

Fig. 3: Scanning Electron Micrographs of (a) LM0-4 % 25 nmTiO_2 and (b) LM0-8 % 25nmTiO_2 (c) LM0-12% 25nmTiO_2, (d) LM0-4 % 60 nmTiO_2 (e) LM0-8 % 60nmTiO_2 and (f) LM0-12 % 60nmTiO_2 composites.

B. Hardness Measurements

The hardness of composite depends on the hardness of the reinforcement and the matrix used. The hardness of composites synthesized with 200 and 15 nm particle size of TiO_2 with various weight percentage of 0, 4, 8 and 12wt. % are evaluated using ball indenter of diameter 10mm at an applied load of 500kg for each sample at different locations. Variation of Hardness of Aluminium alloy 200nm TiO_2 composites and 15nm TiO_2 composites are shown in figure 4 respectively. The hardness has increased with increasing particle content in the composite and as the particle size decreases the hardness will increase mainly due to the coefficient of thermal expansion (CTE) of ceramic particles is less than that of aluminium alloy and because of sudden water quenching. The 15nm TiO_2 particle composites shows higher hardness compare to 200nm TiO_2 particulate composites. From the experiment it is observed that with increase in weight % of TiO_2 particle and decrease in particles size, the hardness of composites increases because the reinforcement particles act as obstacles to plastic deformation and cause a reduction in grain size of the matrix, which is one reason of increase in hardness.. The BHN of the composites is approximately 31.5% for 200 nm TiO_2 particle and 49.3% for 15nm TiO_2 particle of 4 Wt. %. Which is higher than that of the un-reinforced alloy.

From the graph it is observed that for 4% the BHN of 15 nm TiO_2p is 26.12% more when compared with 200 nm TiO_2p composites. Similarly for 8% and 12% the BHN of 15 nm TiO_2p is 20.73% and 18.18% more than 200 nm TiO_2p composites respectively. From the result we can observe that as the Wt. %.of the reinforcement increases the hardness will decrease because of clustering and agglomeration is more as the percentage of reinforcement increases.

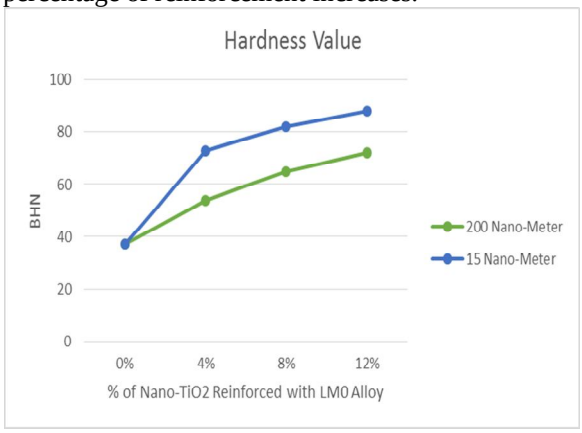


Fig.4. Comparison of hardness of LM0-200 nm and 15 nm $TiO_2$with different wt. % of reinforcement.

C. Tensile Properties

Figure 5 shows the effect of particle sizes of Nano TiO_2 particulates on the tensile behavior of LM0 alloy. From the graphs, it is noted that the ductility of the Nano composites will be more when compared with micro and macro composites. The ductility of the MMCs deteriorates significantly with high ceramic particle concentration in the case of composites with micron size particle. It is of interest to use Nano-sized ceramic particles to strengthen the metal matrix while maintaining good ductility.

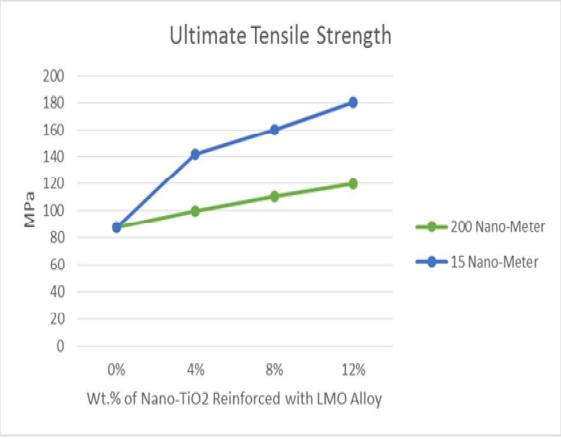
Composites prepared with 15nm TiO_2 particles shows higher ultimate tensile strength, yield strength and ductility as compared to 200nm TiO_2 reinforced composites. The increase in tensile strength is higher in case of 12% Nano TiO_2 composites compared to un-reinforced alloy. It may be due to the presence of more Al_3Ti and Al_2O_3 particles present in the composites.

As the particle size decrease, the interfacial area between the matrix and the particles also increase, and more load can be transferred from the matrix to the particles. It should be noted that a large interfacial area can also facilitate the generation of more dislocations in the matrix, thereby improving the mechanical properties of the composites. On the other hand, the larger-sized particles fracture more easily than the smaller ones during tensile testing.

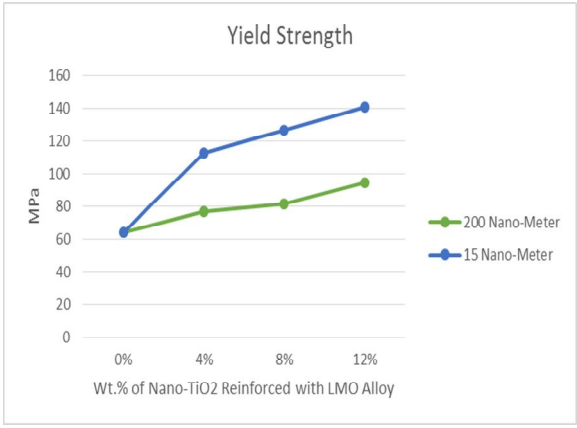
For the 4wt. % weight % of Nano TiO_2 particles the ultimate tensile strength of 15 nm and 200nm composite are 99.93 MPa and 142.2MPa respectively i.e. 25 nm TiO_2p approximately 29.7% more when compared to 200 nm TiO_2p Composites. Similarly for 8 and 12% ultimate tensile strength of 15 nm and 200nm composite are 110.46 Mpa, 160.5 MPa and 120.1 Mpa, 180.4 Mpa respectively i.e. 15 nm TiO_2P approximately 31.1 % and 33.4% more when compared to 200 nm TiO_2P Composites.

For the 4wt. % of Nano TiO_2 particles the yield strength of 15 nm and 200nm composite are 76.6MPa and 112.6MPa respectively i.e. 15 nm TiO_2P approximately 31.9 % more when compared to 200 nm TiO_2P Composites. Similarly for 8 and 12% yield strength of 15 nm and 200nm composite are 81.5 Mpa, 126.4MPa and 94.4 Mpa, 140.6 Mpa respectively i.e. 15 nm TiO_2P approximately 35.5% and 32.8% more when compared to 200 nm TiO_2P Composites.

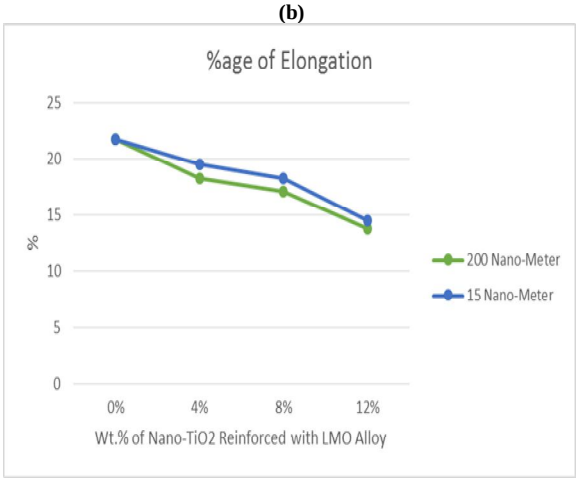
Since the fractured particles cannot withstand any load, but act as privileged failure sites, the composites with larger TiO_2 Nano particle size show lower mechanical properties as compared to that with smaller Nano particle size. This increase in UTS and YS is mainly due to the presence of Al_3Ti and Al_2O_3 particles present in composites. These particulates act as the barrier for dislocations. The ductility decreases with increasing in wt. % percentage of Nano TiO_2 particles in the composites but interestingly, the ductility of all the 15nm composites with different weight % shows higher than that of respective weight % of 200nm composites.



(a)



(b)



(c)

Fig 5: Comparison of LM0-200 and 15 Nano-TiO_2 composites (a) Ultimate Tensile Strength, (b) Yield Strength, c) %age of Elongation.

CONCLUSION

Nano Composites were successfully fabricated by Bottom Pouring Stir Casting Method and Effect of various Nano Particle Sizes of TiO_2 was evaluated. The following conclusion ware made after testing and characterization.

1. The SEM shows the uniform distribution of particles with low amalgamation but care has to be taken at higher weight % of TiO_2 addition in composites because clustering is more in Nano size composites of 15nm particles when compared with 200nm Particles.
2. The Brinell hardness of the Nano-composites shows increases in hardness value which is more with 15nm TiO_2 particles when compared with 200nm TiO_2 Particles.
3. The UTS and YS of the Nano-composites shows that as the particle size decreases the UTS and YS of the composites increases.
4. The percentage of elongation decreases with increase in Nano TiO_2 particles content, but remarkably 15nm size particles composites shows higher ductility than 200nm size particles composites.

5. From the results obtained it can be seen that as the particle size decreases the mechanical properties will enhance i.e. mechanical properties of composites depends on Particle size and weight % of the particulates.

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