International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

Effect of Addition of Nanoparticles on the Mechanical Properties of Aluminium

Adil Nazaruddin
Department of Mechanical engineering,
TKM College of Engineering, Kollam,
India.

Prof. T. S. Krishnakumar
Department of Mechanical engineering,
TKM College of Engineering, Kollam,
India.

***Abstract*- Aluminium matrix nanocomposites (AMNC) have a wider application area because of their low density and high specific stiffness. This experimental investigation was conducted to fabricate aluminium matrix nanocomposite samples using TiO_2 nanoparticles as the reinforcement by using powered stir casting method. The mechanical properties such as tensile strength and hardness are determined and compared with that of Aluminium. Microstructural characterization and X-ray diffraction studies were conducted on these prepared nanocomposite samples. The study reveals that the presence of TiO_2 nanoparticles in the aluminium matrix led to a significant improvement in the mechanical properties of the prepared nanocomposite samples when compared with that of the commercially pure aluminum. Microstructural evaluation and X-ray diffraction studies showed a positive response to the addition of TiO_2 nanoparticles into the aluminium matrix.**

Index Terms- Aluminium matrix nanocomposite, TiO_2 nanoparticles, X-ray diffraction studies.

I. INTRODUCTION

Aluminium is one of the lightest engineering metals and is the third most common element comprising 8% of the earth's crust. Low strength and hardness of aluminium, which limits its use in many engineering applications, could be increased through the addition of nanoparticles. Aluminium matrix nanocomposites (AMNC) have a wider application area because of their low density and high specific stiffness. The properties and quality of the nanocomposite material is directly influenced by achieving a uniform distribution of reinforcement within the matrix. Also, the amount, size and distribution of reinforcing particles in the aluminium matrix play an important role in enhancing or limiting the overall properties of the nano composite material.

Metal matrix composites reinforced with nanoparticles also called metal matrix nanocomposites (MMNCs) are very promising engineering materials, which is suitable for a large number of applications. These nanocomposites consist of a metal matrix filled with nanoparticles featuring physical and mechanical properties which is very different from those of the matrix. These nanoparticles can improve the base material in terms of mechanical properties. Metal matrix nanocomposites are very promising materials with high potential for use in a large number of engineering applications. The high mechanical resistance of metal matrix nanocomposites (MMNCs) is the result of several strengthening mechanisms such as load transfer effect, Hall-petch strengthening, Orowan strengthening, coefficient of thermal expansion (CTE) and elastic modulus (EM) mismatch.

Two primary factors lead to the higher cost of aluminum matrix nanocomposites. The first factor is the raw material cost for both the aluminum and the reinforcement nanoparticles. The second factor is the higher cost of the fabrication method used. If these two factors can be controlled, then a wider range of applications becomes possible. Stir casting is the most economical method for production of aluminum matrix nanocomposites.

In the stir casting method, the reinforcing particles are distributed into the molten matrix by the method of mechanical stirring. The vortex method is one of the best known approaches used to create a uniform distribution of the reinforcement particles in the matrix. In this method, after the matrix material is melted, it is stirred mechanically to form a vortex at the surface of the melt, and to this vortex, reinforcement particles are added. Then, this stirring process is continued for a few minutes before the casting process. During the process of stir casting, stirring helps in two ways such as to transfer particles into the liquid metal and to maintain the particles in a state of suspension.

The Paper has been organised as follows. Section II contains experimental procedure for the fabrication of Aluminium matrix nanocomposite. Section III contains certain characterization techniques such as microstructural characterization, mechanical characterization and x-ray diffraction studies. In Section IV the experimental results are shown with some discussions on it. Section V summarizes the conclusions deduced from the work and Section VI deals with the scope for future work.

II. EXPERIMENTAL PROCEDURE

In this study, commercially pure aluminium was used as the base material. The reinforcement was chosen as Titanium dioxide nanoparticles (TiO_2) with mean diameter of 35nm in size. With the base metal as aluminium, the nanocomposite has been fabricated with 2.5 weight % of TiO_2 nanoparticles.

Fabrication of aluminium samples is as follows. Firstly, aluminium is cut into the required weights using Hacksaw cutting machine. Aluminium is placed in a graphite crucible inside the Pit furnace. Charcoals are burned and packed around the crucible inside the pit furnace. One side of the pit furnace is connected with an electrically operated blower which sucks the air from the atmosphere and sends to the pit furnace for the continuous generation of heat. With the help of this blower, sufficient amount of air is supplied towards the charcoal. Thus aluminium starts to melt. After the Aluminium is melted to about 700^{0}C, the crucible is lifted using crucible lifting tongs. Then the crucible is placed in the pouring shank. Then the melt was poured into the mould using the pouring shank. After pouring the molten metal into the moulds, it is kept for some time to solidify. After solidification, the specimens were prepared for hardness test and tensile test. Fig.1 shows the schematic diagram of Pit furnace set up.

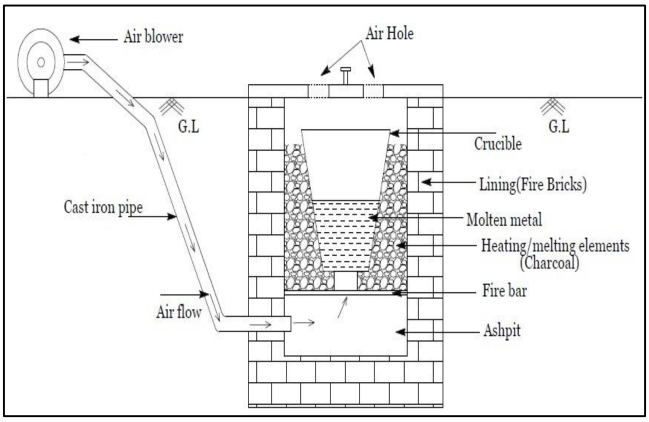

Fig.1: Schematic diagram of Pit furnace set up

Fabrication of aluminium matrix nanocomposite samples by using powered stir casting method is schematically shown in fig.2.

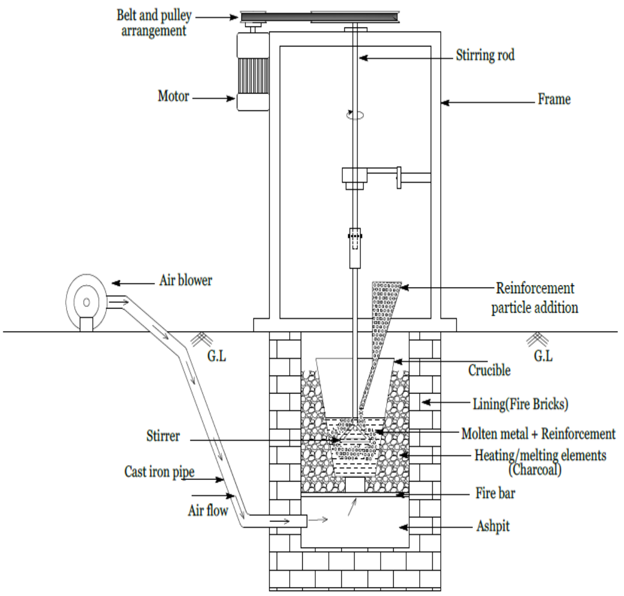

Fig.2: Schematic diagram of Powered stir casting set up

When aluminium starts to melt, powered stir casting equipment was used to stir at about 550rpm. With the help of steel tube, TiO_2 nanoparticles of size 35nm (2.5%) were added into the vortex of the aluminium matrix during stirring from the top of the crucible. Addition of TiO_2 nanoparticles was by few grams. The solution was stirred for about 5 minutes while keeping the pit furnace in working mode. Finally, it is casted into the required specimens for hardness test and tensile test.

III. CHARACTERIZATION TECHNIQUES

Microstructural characterization of the nanocomposites produced was performed using an optical microscope with accessories for image analysis. Standard polishing and etching techniques were used in this research. A specimen of size nearly 15mm x 15mm were cut from different positions of the final castings by using Wire EDM System (Electrical Discharge Machining). Then this specimen is polished on a series of emery papers of grit sizes 200, 400, 600, 800, and 1000 in five steps. After the grinding operation, the specimens were polished by brushing the specimen surface against the emery papers 1/0, 2/0, 3/0, 4/0. The final flat scratch-free surface was obtained by using a wet rotating wheel covered with a cloth. The abrasive used was diamond paste. Double disk polishing machine was used for this operation. The polished specimen obtained was then etched with Kellers reagent (190 ml Distilled water + 5 ml HNO3 + 3 ml HCl + 2 ml HF). Finally under optical microscope containing accessories for image analysis, microstructures of the samples were observed and characterization was done.

X-ray diffraction test for all the nanocomposite samples were carried out by using X-PERT PRO diffractometer system. The hardness testing for all the nanocomposite specimens were determined by using Brinell hardness testing machine with 500 kg load and 10 mm diameter steel ball indenter. The detention time for the hardness measurement was 1 minute.

The tensile properties namely nominal breaking stress, actual breaking stress and ultimate stress were investigated in the Universal Testing Machine (UTM).

IV. RESULTS AND DISCUSSION

The microstructural images of aluminium and aluminium matrix nanocomposite (AMNC) samples as obtained from optical microscopy taken at 50X magnification is shown in fig.3 and fig.4 respectively. It is very clear from the microscopic images that with the addition of different sized TiO_2 nanoparticles into the aluminium matrix, the grain size gets refined. So, with the formation of aluminium matrix nanocomposite samples the aluminium grain size gets refined and thus shows the fine distribution of grains. Smaller grains have greater surface area to volume ratio, which means there exists a greater grain boundary to dislocation ratio. The more the grain boundaries, the strength will be higher.

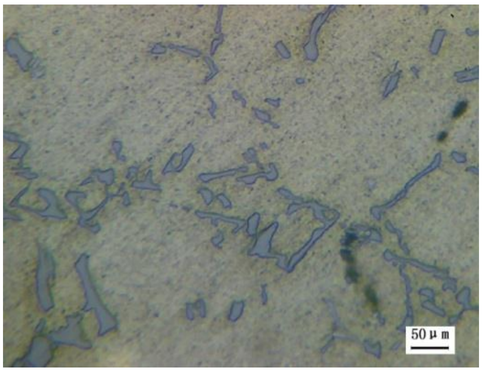

Fig.3: Optical microscopic image of pure aluminium

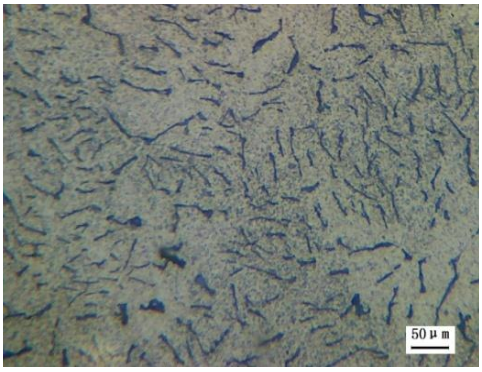

Fig.4: Optical microscopic image of aluminium reinforced with 35nm sized TiO_2 particles

Aluminium grain size refinement has a direct influence on mechanical properties of the nanocomposites fabricated. The refinement of aluminium grain size with TiO_2 nanoparticle addition can be explained based on two different mechanisms: First one is the pinning of the previous grain boundary by the second phase particles and second is the increase of nucleation sites for transformation.

Grain size variation is the result for the change in mechanical properties of all the samples fabricated. Grain size value for all the samples was obtained from the Dewinter material plus software interfaced with optical microscope. Comparison of grain size variation of aluminium with aluminium matrix nanocomposite samples is shown in fig.5.

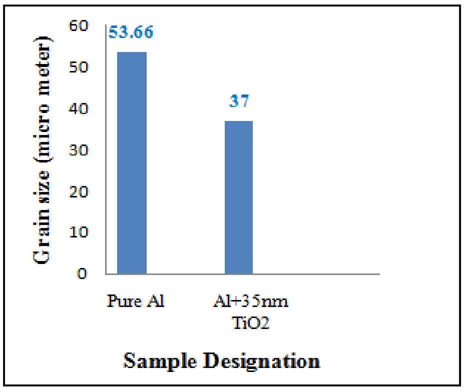

Fig.5: Grain size variation

From the above result, it is very clear that the grain refinement occurs with the addition of TiO_2 nanoparticles in the aluminium matrix because of the reduction in grain size from 53.66 microns to the lower level. By adding the TiO_2 nanoparticle reinforcement into the aluminium matrix, surface area of the reinforcement gets increased and grain sizes of the matrix get decreased. Hence the strength of aluminium is increased with the TiO_2 nanoparticle addition.

Variation of Brinell hardness number for aluminium and aluminium matrix nanocomposite is shown in fig.6. From the graphs, it is clear that the brinell hardness number were improved with the addition of titanium dioxide nanoparticles into the aluminium matrix. The hardness of nanocomposite is higher than that of the aluminium matrix. This is because of the presence of hard TiO_2 nanoparticles. This is to be expected since aluminium is a soft material and the TiO_2 nanoparticles being hard, contribute positively to the hardness of the nanocomposite.

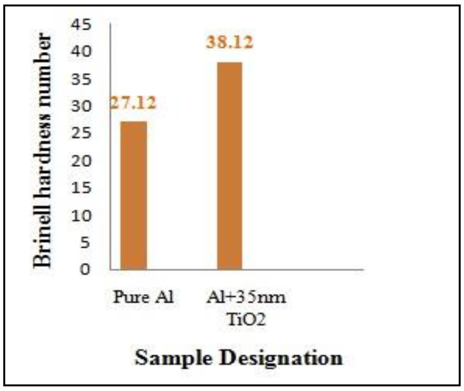

Fig.6: Variation of Brinell hardness number

The tangible enhancement in hardness value of the aluminium matrix nanocomposite compared with that of the pure aluminium indicates that nano-TiO_2 particles have a great effect on the strengthening of aluminium matrix. This improvement in hardness value is due to the grain refinement of aluminium matrix which was already confirmed in the microstructure study, and the role of uniformly distributed nanoparticles which act as obstacles to the motion of dislocations according to the Orowan mechanism.

Variation of nominal breaking stress, actual breaking stress and ultimate stress for aluminium and aluminium matrix nanocomposite is shown in fig.7, 8 and 9 respectively.

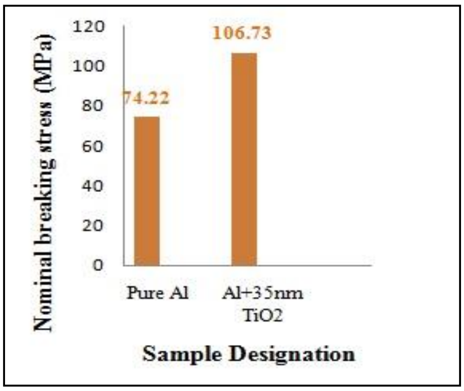

Fig.7: Variation of Nominal breaking stress

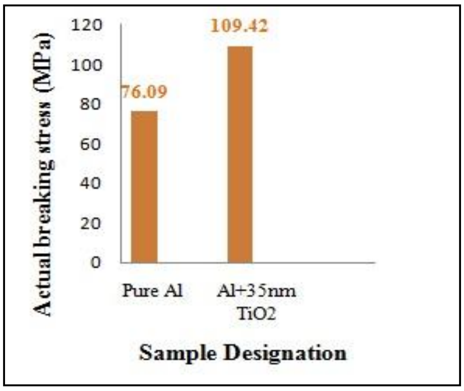

Fig.8: Variation of Actual breaking stress

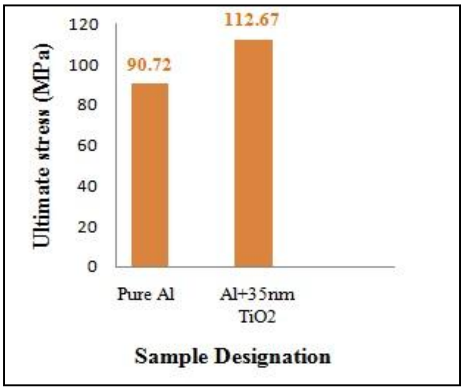

Fig.9: Variation of Ultimate stress

From the above graph, it is clear that the nominal breaking stress, actual breaking stress, and ultimate stress were improved with the addition of titanium dioxide nanoparticles into the pure aluminium matrix. By adding the TiO_2 reinforcement nanoparticles into the aluminium matrix, surface area of the reinforcement gets increased and grain sizes of the matrix get decreased. Hence the strength of aluminium is increased with the TiO_2 nanoparticle addition.

Aluminium grain size refinement has a direct influence on tensile strength of the nanocomposites fabricated. This improvement in tensile strength of aluminium with the addition of TiO_2 nanoparticles is due to the grain refinement of aluminium matrix which was already confirmed in the microstructure study. It can be seen that the nominal breaking stress, actual breaking stress and ultimate stress of the nanocomposite is enhanced because of the coupled effects of increase in grain boundary area due to grain refinement and due to the effective transfer of tensile load to the uniform distribution of TiO_2 nanosized particles in the aluminium matrix. The nanoparticle reinforced aluminium has shown higher ultimate tensile strength, which indicates the presence of different dislocation densities.

The X-Ray diffraction (XRD) studies were conducted for the phase identification of all the samples by using X-PERT PRO diffractometer system. Fig.10 and fig.11 shows the XRD pattern of aluminium and aluminium matrix nanocomposite samples respectively.

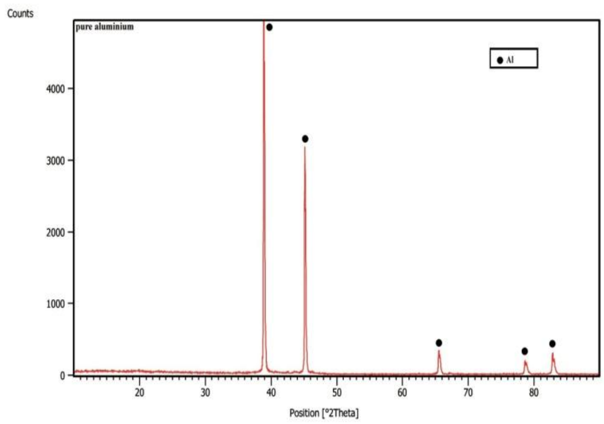

Fig.10: XRD pattern of pure aluminium

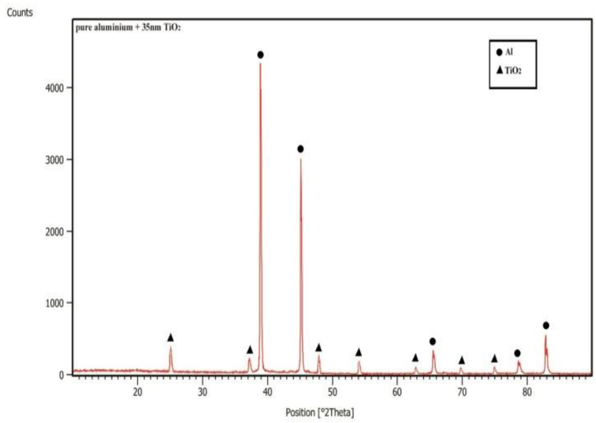

Fig.11: XRD pattern of aluminium reinforced with 35nm sized TiO_2 particles

In fig.19, the diffraction peaks at 2θ values are the characteristic pattern of pure aluminium and are identified by matching the peak positions and intensities in XRD patterns to those patterns in the JCPDS (Joint Committee on Powder Diffraction Standards) database. Hence the experimental XRD pattern of pure aluminium agrees with the JCPDS card no. [89-4037] which indicates the presence of aluminium. In fig.20, the diffraction peaks at 2θ values indicates the XRD pattern of TiO_2 nanoparticles along with the XRD pattern of pure aluminium and are identified by comparing with those in the JCPDS database. Hence the experimental XRD pattern of TiO_2 nanoparticles agrees with the JCPDS card no. [21-1272] which signified the presence of the nanoparticles of TiO_2 within the aluminium matrix.

V. CONCLUSIONS

A brief glance on the results obtained from this work showed a positive response to the addition of TiO_2 nanoparticles into the aluminium matrix. Aluminium matrix nanocomposite samples have been successfully fabricated through powered stir casting technique with fair uniform distribution of TiO_2 nanoparticles. The hardness, nominal breaking stress, actual breaking stress and ultimate stress were improved with the addition of titanium dioxide nanoparticles into the pure aluminium matrix. Microstructural evaluation revealed that the aluminium grain size refinement is the major factor leading to the improvement of mechanical properties of the aluminium matrix nanocomposite samples fabricated. X-Ray Diffraction (XRD) results revealed the presence of TiO_2 nanoparticles within the aluminium matrix.

VI. SCOPE FOR FUTURE WORK

The present research work leaves a wider scope for the future investigators to explore many other aspects of metal matrix nanocomposites. Study of properties of nanocomposites on the basis of different fabrication techniques other than powered stir casting method can be performed. Other mechanical properties like compression strength, impact strength and wear test can also be investigated. Cost analysis of these nanocomposites can be evaluated in order to assess their economic viability in various engineering applications.

REFERENCES

[1] M. Ravichandran and S. Dineshkumar, "Synthesis of Al-TiO_2 Composites through Liquid Powder Metallurgy Route," SSRG-IJME volume 1 Issue 1, (2014) 12-17.

[2] M. Karbalaei Akbari, O. Mirzaee and H.R. Baharvandi, "Fabrication and study on mechanical properties and fracture behavior of nanometric Al_2O_3 particle-reinforced A356 composites focusing on the parameters of vortex method," Materials and Design 46 (2013) 199–205.

[3] Gwang-Ho Kim, Sung-Mo Hong, Min-Ku Lee, Soon-Ho Kim, Ikuo Ioka, Byoung-Suhk Kim and Ick-Soo Kim, "Effect of Oxide Dispersion on Dendritic Grain Growth Characteristics of Cast Aluminum Alloy," Materials Transactions, Vol. 51, No. 10 (2010) pp. 1951 to 1957.

[4] Mitsuaki Matsumuro and Tadashi Kitsudo, "Fabrication of In-Situ Intermetallic Compound Dispersed Aluminum Matrix Composites by Addition of Metal Powders," Materials Transactions, Vol. 47, No. 12 (2006) pp. 2972 to 2979.

[5] A. Dehghan Hamedan and M. Shahmiri, "Production of A356–1 wt% SiC nanocomposite by the modified stir casting method," Materials Science & Engineering A 556 (2012) 921–926.

[6] Riccardo Casati and Maurizio Vedani, "Metal Matrix Composites Reinforced by Nano-Particles—A Review," Metals 2014, 4, 65-83; doi:10.3390/met4010065

[7] Hai Su, Wenli Gao, Zhaohui Feng and Zheng Lu, "Processing, microstructure and tensile properties of nano-sized Al_2O_3 particle reinforced aluminum matrix composites," Materials and Design 36 (2012) 590–596.