



**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH
TECHNOLOGY**

**Wear Performance and Hardness Property Of A356.1 Aluminium Alloy Reinforced with
Zirconium Oxide Nano Particle**

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Abstract

Aluminium alloy reinforced with Nano-sized ZrO₂ particles are widely used for high performance applications such as automotive, military, aerospace, and electricity industries because of their improved physical and mechanical properties. In this research, Zirconium Oxide (ZrO₂) Nano particles were synthesized by Solution Combustion Synthesis process. The Nano particles were characterized by Powder X-ray diffraction (PXRD) and TEM. A356.1 Aluminium alloy was reinforced with 0.5, 1.0, 1.5 and 2.0 Wt.% of the Synthesized Zirconium Oxide Nanoparticle via stir casting Technique. The composites were then characterized by scanning electron microscopy (SEM). Hardness and Wear tests were carried out at Varying Wt. % ratios with varying Conditions of Speed, Load and Time. The results reveal that the Nano Metal Matrix Composite (NMMC)'s containing 2.0 Wt.% reinforcement particle has improved mechanical properties.

Keywords: Nano Metal Matrix Composite, ZrO₂ /A356.1 Composite, SEM, TEM

Introduction

The attention of material scientists and engineers has shifted from monolithic materials to composite materials for the development of light weight, environment friendly and high performance appliances. As aerospace technology continues to advance, there is a rapidly increasing demand for advanced materials with high mechanical and thermal capabilities for such ultra high applications [1]. Its application also stretched to automobile, electronic and computer industries to replace the existing materials including plastics [2]. The early 1990s are considered to be the renaissance for Aluminium as structural material due to environmental concerns, increasing safety and comfort levels. A significant improvement in the properties of Aluminium alloys, reduced fuel consumption because of light weight has made huge demand from automobile industry [3,4]. This growing requirements of materials with high specific mechanical properties with weight savings has fueled significant research activities in recent times targeted primarily for further development of Aluminium based composites [5-7]. A recent industrial review revealed that there are hundreds of components from structural to engine in which

Aluminum alloy is being developed for variety of applications [8]. It is also predicted that for Aluminium alloys demand increased globally attain average rate of 20% every year [9]. It is noticed that the limited mechanical properties (strength and hardness) of Aluminium and its alloys adversely affect its applications in automobile and aerospace industries [10,11]. This remains one of the major concerns in its fabrication to suit its application in recent days. Search of open literature indicates that for number of Aluminium based MMCs (Metal Matrix Composites) including chilled MMCs [12-15] are being developed but no work has been done in this field. Hence the present research is undertaken to fill the void and to investigate the integrated properties of A356.1 alloy/ZrO₂ NMMCs (Nano Metal Matrix Composite). Among all the reinforcements used in Aluminium based composites only Nano-size particulates has shown their potential superiority in improving mechanical properties, such as wear, hardness and microstructure with noticeable weight savings [16].

Liquid metallurgy technique is one of the most economical of all the available routes for Nano metal–matrix composite production and generally can be classified into four categories: pressure infiltration, stir casting, spray deposition and in situ processing [17]. Compared to other routes, melt stirring process has some important advantages ,e.g., the wide selection of materials, better matrix–reinforcement bonding, easier control of matrix structure, simple and inexpensive processing, flexibility and applicability to large quantity production and excellent productivity for near-net shaped components[18]. However, there are some problems associated with stir casting of AMCs such as: poor wettability and heterogeneous distribution of the reinforcement material. Poor wettability of reinforcement in the melt means that the molten matrix cannot wet the surface of reinforcement particles. Therefore, when the reinforcement particles are added into the molten matrix, they float on the melt surface. This is due to the surface tension, very large specific surface area and high interfacial energy of reinforcement particles, presence of oxide films on the melt surface and presence of a gas layer on the ceramic particle surface. Mechanical stirring can usually be applied in order to mix the particles into the melt, but when stirring stops, the particles tend to return to the surface. There are some methods to improve the wettability of the reinforcement particles within the molten matrix alloy, for example heat treatment of the particles before dispersion into the melt caused removal of the adsorbed gases from the particle surface [19]. Another problem is distributing of reinforcement particles uniformly in molten matrix.

When the particles were wetted in the metal melt, the particles will tend to sink or float to the molten melt due to the density differences between the reinforcement particles and the matrix alloy melt, so that the dispersion of the Zirconium Nano particles is not uniform and the particles have high tendency for agglomeration and clustering. Mechanical Stirring is preferred. In addition to mechanical stirring, there are some other techniques for introducing particles into the matrix. One of them is injection of the particles with an inert carrier gas into the melt. It has been reported that the technique is helpful in improving the distribution of the reinforcement particles within the melt [20]. Wettability and distribution of reinforcement particles becomes more difficult when the particle size decreases to the Nano scales. This is due to the increasing surface area and surface energy of Nano particles which cause an increasing tendency for agglomeration of

reinforcement particles. Moreover, several structural defects such as porosity, particle clusters, oxide inclusions and interfacial reactions arise from the unsatisfactory casting technology [21].

In this study zirconium oxide Nano particles were prepared using combustion synthesis method at a temperature of $850 \pm 5^\circ \text{C}$ using stir casting technique at a speed of 100 rpm, the Nano metal matrix composites thus obtained were casted using Die cast technique and characterized for their micro structure, hardness and wear properties and the Nano particles is characterized by PXRD,SEM and TEM. Zirconium Nano material is reinforced with A356.1 Aluminium alloy in the ratio of 0.5,1.0,1.5 and 2.0 wt% .

Experimental procedure

Synthesis of ZrO_2 powder:

The ZrO_2 Nano powder was prepared by dissolving zirconyle nitrate ($\text{ZrO}(\text{NO}_3)_2$) and Crystal sugar ($\text{C}_6\text{H}_{12}\text{O}_6$) as fuel in a minimum quantity of double distilled water is taken in a ceramic crucible. The crucible containing the solution was placed in a preheated muffle furnace maintained at $850 \pm 5^\circ \text{C}$. The solution initially boils and undergoes dehydration followed by decomposition with the evolution of large amount of gases resulting in a transparent gel. The gel then formed in to white foam, which expanded to fill the vessel. Shortly thereafter, the reaction was initiated somewhere in the interior and a flame appeared on the surface of the foam and proceeded rapidly throughout the entire volume, leaving a white powder with an extremely porous structure. The entire combustion process for producing ZrO_2 powder takes place. The reaction for combustion synthesis in the present case can be written in equation (1)



Table 1. Chemical composition of Aluminium alloy A356.1

Elements	Al	Si	Fe	Cu	Mg	Mn	Zn	Ni
Wt.%	91.7	7.2	0.32	0.18	0.38	0.02	0.05	0.05

Preparation of(A356.1) ZrO_2 Nano composites

Aluminium alloy (A356.1) and Nano sized ZrO_2 were used to fabrication of composites. The composition of A356.1 is shown in Table1 [1]

The samples were prepared using a resistance furnace, equipped with a stirring system. After smelting of aluminum ingots, ZrO_2 Nano powder was added to the molten metal and stirring

was carried out at constant rate of 150 rpm for 20 min.

According to the results of literature and previous works [31, 32]. Nano-powder ZrO_2 (0.5, 1.0, 1.5, and 2.0 wt %) added to the molten metal during stirring. The casting was performed at $850^\circ C$. Steel circular die was used for casting of specimens. Finally, specimens fabricated in five various conditions were prepared for subsequent Microstructural and mechanical analyses.

Results and discussion

X-ray Diffractometer (XRD) Studies

The powder X-ray diffraction studies were carried out using Phillips X-ray diffractometer (model PW 3710) with $Cu K\lambda$ radiation ($\lambda = 1.5405 \text{ \AA}$) The X-ray diffraction pattern of Nano- ZrO_2 powder confirms the crystalline phase and mean crystal size determined was around 40 nm. In the XRD observations three Strongest peaks shown in Fig. 2 were detected with Miller indices (223), (054), (126), and (082) corresponding to Bragg angles 30° , 36° , 51° and 59° respectively. The characteristic peaks are higher in intensity which indicates that the products are of good crystalline nature. No peaks corresponding to impurities are detected, showing that the final product is purely ZrO_2 Nano powder. It is observed that intensity of the peaks increases with thermal treatment due to Agglomeration, which means that the crystalline has been improved. The full width at half maxima of major peaks decrease and confirms the grain size growth.

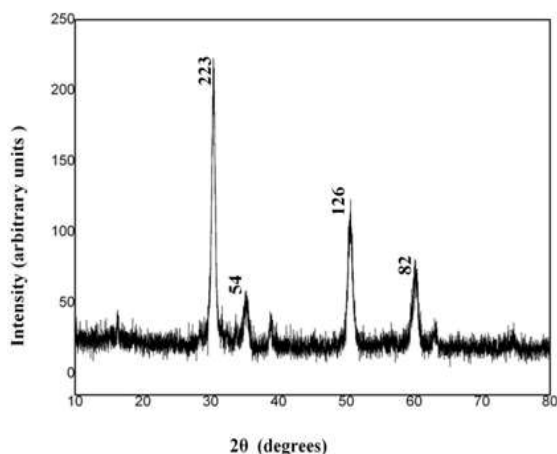


Fig.2:XRD pattern of Nano particles fabricated at $850^\circ C$

SEM analysis:

The size and morphology of the ZrO_2 Nanoparticles have been determined using scanning electron microscopy. Fig.3 shows the image random distribution of the ZrO_2 Nanoparticles having non-spherical shape and diameter in the range of Nanometer.

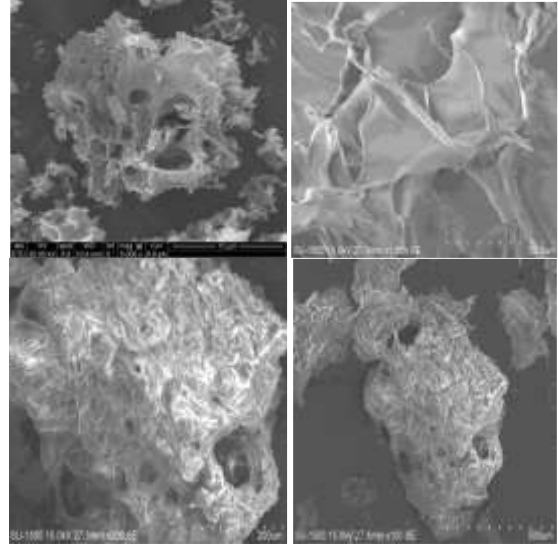
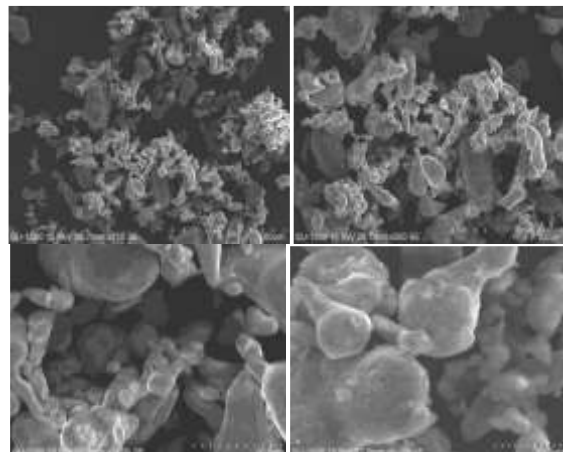


Fig.3:SEM Micrographs of ZrO_2 Nanoparticles

The Nano composites were found to be agglomerated when analyzed by scanning electron microscopy (SEM: JEOL, Japan, JSM 840A) studies shown in Fig.3. It can be observed that the ZrO_2 crystallites have no uniform shape. This believed to be related to the non-uniform distribution of temperature and mass flow in the combustion flame, due to the high surface energy of the particles and from the SEM there is such difference was observed for different wt % of ZrO_2 dispersed aluminum powder. In micrographs also observing that the big particles are aluminum powder and the very small particles surrounded by that are ZrO_2 .



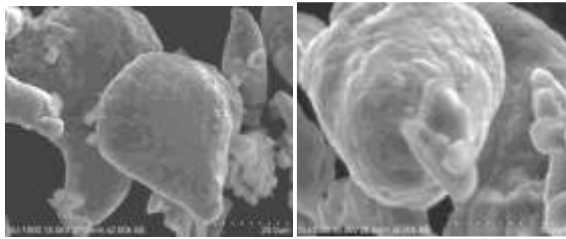


Fig.4: SEM micrographs of A356.1 Aluminium alloy reinforced with ZrO₂ Nano particle

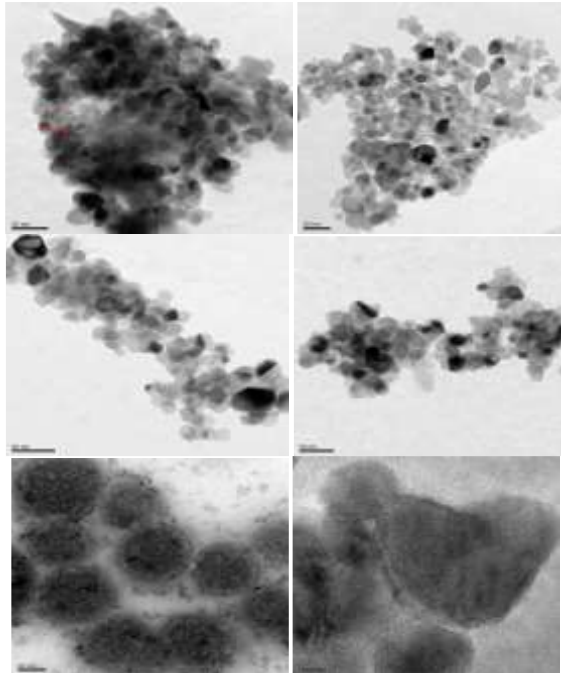


Fig.5: TEM micrographs ZrO₂ Nano particle

Fig.5 shows the transmission electron micrographs of the ZrO₂ samples. The TEM images show evidence of a porous frame, which is consistent with the SEM micrographs.

Wear properties

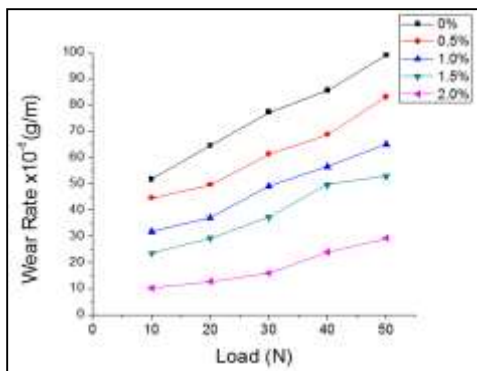


Fig.6: Wear Rate Vs Load

Wear test were performed, ZrO₂ Nano made up of Al A356.1 alloy incorporating 0.5, 1.0, 1.5, 2.0 Wt% respectively. Test were performed using Pin on Disc machine using samples in the form of 28 X 8 mm cylindrical block. One side of sample were put in contact with rotating disc at different loading conditions. The Fig.6 depicts of as cast and different varying Wt % of ZrO₂ Nano metal matrix composites(NMMC) .The wear rate of 2 Wt% of ZrO₂ Nano particles shows better wear rate compared to as cast and other Wt % NMMC's . The graph shows when load at 10N the wear rate is 10.875X10⁻⁶ g/m for as cast A356.1 alloy, for the same load 2.0Wt% of ZrO₂ Nano particle added to alloy shows a decrease of wear rate consistently by adding different percentages of Nano particles. The Fig.6 reveals that when a varying % of ZrO₂ Nano particle is added, it increases wear rate with increase of loads.

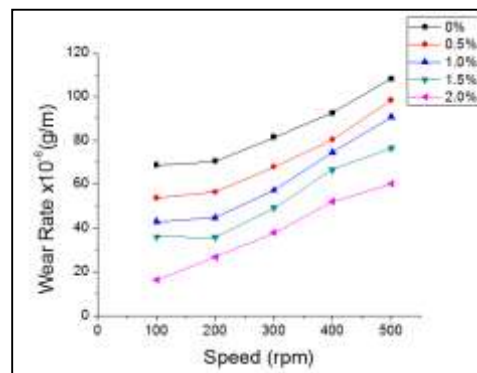


Fig.7: Wear Rate Vs Load

To investigate the speed effect of reinforcing particulates with ZrO₂ Nano is added to the A356.1 alloy at varying percentages, at different speed rates. It is generally believed contribution of Nano particles to A356.1 alloy results in improvement of base alloy to great extent[33,34]. Based on the results from Fig.7, when speed increases ,wear rate increases as cast to Wt 2% added. For as cast alloy wear rate is 71.23X10⁻⁶g/m at 100rpm and for Wt.2% wear rate is 14.62X10⁻⁶g/m at 100rpm.And for as cast alloy wear rate is 110X10⁻⁶g/m at 500rpm and for Wt.2% wear rate is 46.77X10⁻⁶g/m at 500rpm.

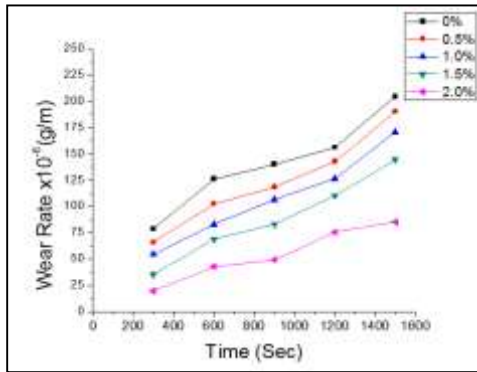


Fig.8: Wear rate Vs Time

Operating Time is proportional to Wear rate, as shown in the Fig.8. Based on this graph, for As Cast alloy at the Operating time of 300sec, Wear rate is $81.70 \times 10^{-6} \text{g/m}$ and for the same time with 2.0 Wt. % reinforcements of Nano particle to base alloy the wear rate decreases to $22.50 \times 10^{-6} \text{g/m}$. For As Cast alloy at Operating time of 1500 Sec, Wear rate is $207.96 \times 10^{-6} \text{g/m}$ and for the same operating time with 2 Wt. % reinforcements of Nano particle to base alloy, the wear rate considerably decreases to $75.35 \times 10^{-6} \text{g/m}$.

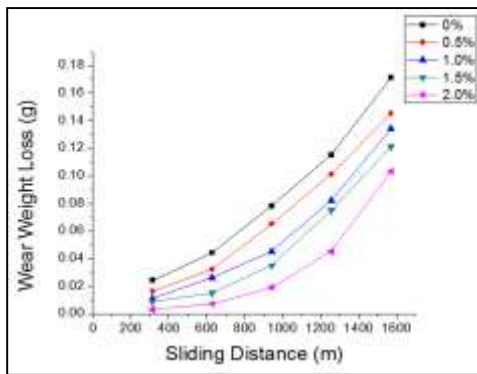


Fig.9: Wear Rate Vs Sliding Distance

Based on the results reinforcement of Nano particle into the base alloy, Wear rate gradually decreases with increasing reinforcement content (0.5,1.0,1.5,2.0%), as seen from the Fig.9 the wear loss for As cast A356.1 Aluminium alloy at a sliding distance of 314.15m and at a speed of 100rpm is 0.024g. By increasing the reinforcement to 2.0 Wt.% of Nano particles wear loss decreases to 0.003g for same speed and sliding distance. Similarly, for As cast A356.1 Aluminium Alloy for a sliding distance of 1570.79 m and at a speed of 500 rpm and load of 30N wear loss is 0.177 g and for same load and speed

condition wear loss value decreases with the reinforcement of Nano particles to 0.103g.

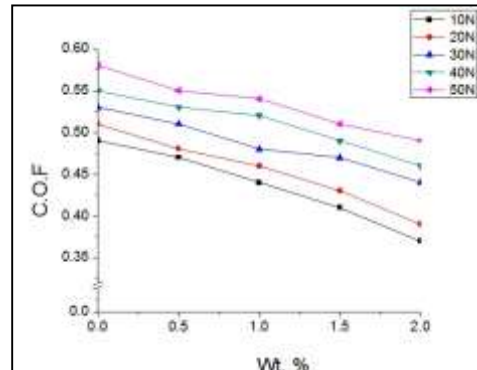


Fig.10: COF Vs Wt %

As the wt % of ZrO₂ reinforcement increase in A356.1 aluminum alloy the coefficient of friction (cof) decreases. As, seen in Fig.10, For as cast the COF is 0.49 for 10N and it gradually decreases 0.39 for Wt 2% at 10N. For the same as cast 0.56 for 50N and it gradually decreases 0.52 for Wt 2% at load of 50N.

Hardness Test:

The results of micro hardness test conducted on NMMCs samples revealed an increasing trend in matrix hardness with increase reinforcement content of 2.0%. Results of hardness measurements revealed that an increase in the reinforcement content leads to a significant increase in the hardness and can be attributed primarily to the presence of harder ZrO₂ Nano materials a higher constraint to the localized deformation during indentation due to their presence and reduced grain size. Results shows that for 2.0 wt% of reinforcement increases the mechanical properties as shown in Fig.11 and Fig.12

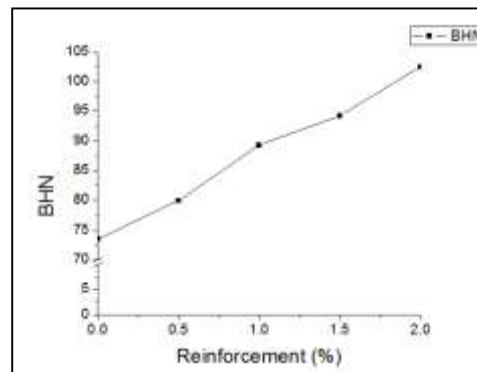


Fig 11: BHN Vs Wt% Reinforcement

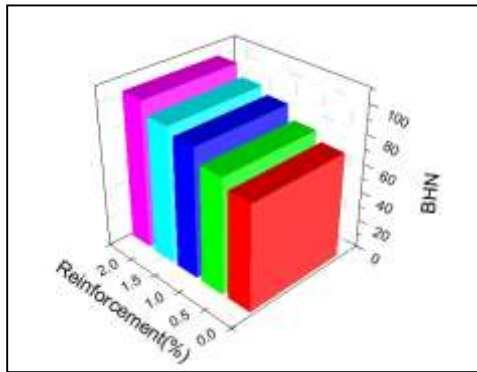


Fig 12: Bar chart and line graph shows the BHN for A356.1 reinforced with different Wt. % of ZrO₂ Nano particle.

Conclusion

A356.1 Aluminium alloy reinforced with Nano sized ZrO₂ was successfully fabricated via stir casting method. Reinforcement particles were well distributed in the matrix of composites. However, particle agglomeration was observed in composites with high content of ZrO₂. Therefore stir casting was found as suitable method for fabrication of this kind of composites. Mechanical characterization revealed that the presence of Nano-ZrO₂ particulates in Al matrix significantly improved hardness and wear properties of A356.1 Aluminium alloy reinforced with (0.5%, 1.0%, 1.5%, and 2.0%) 2.0% of Zirconium Nano material. The result has revealed that the wear properties, Hardness of the reinforced composite is enhanced compared to the base metal.

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