RECENT STUDIES IN ALUMINIUM METAL MATRIX NANO COMPOSITES (AMMNCs) – A REVIEW

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ABSTRACT

Aluminium Metal Matrix Nano Composites (AMMNCs) are very promising materials featuring for physical and mechanical properties very different from those of the Metal Matrix Composites (MMCs). The nano particle can enhance the properties of the base material in terms of wear resistance, damping properties and mechanical strength.

This paper is focused on reviewing the processing of Nanocomposites and the effect of addition on different Nano reinforcements in aluminium alloy highlighting its merits and demerits.

Effect of different reinforcements on AMMNCs on the mechanical properties like tensile strength, hardness, wear and fatigue is also studied in detail.

Key words: Aluminium Metal Matrix Nano Composites, Nano Composites, Processing of Nano Composites, Nano Reinforcements.


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1. INTRODUCTION

To improve the ductility and fracture toughness of the traditional composites, the new class of materials known as Metal Matrix Nano composites (MMNCs) are developed by reinforcing particles in the nanometer scale [20,21]. MMNCs are the advanced materials prepared by combining two or more materials in which tailored properties are analyzed. The reinforcement of micro/ nano particles in the AMC’s has improved mechanical properties due to the reinforcement of high strength and high modulus particles like Nano sized Sic, Al₂O₃, B₄C, ZrO₂, Graphite, FeTiO₃. Aluminium Metal Matrix Nano Composites (AMNCs) are widely used for high performance applications such as automotive, military, aerospace and electrical industries.

The three production methods of these composites can be categorized into: solid state methods, semi-solid state methods and liquid state methods [17]. The solid state methods can be divided into powder metallurgy, mechanical alloying and diffusion bonding methods. It allows essentially a wide range of materials to be used as the matrix and reinforcement. Also, separation effects and intermetallic phase formations are less for these processes. However, this manufacturing route is relatively complex, lengthy,
expensive, and energy consuming. The semi-solid process (SSP), which consists of the mixing of ceramic and matrix containing both solid and liquid phases, can take the form of various routes such as compocasting and thixoforging. Semi-solid process allows very large sized components to be fabricated, and is able to sustain high productivity rates. Although, the process is restricted to longer freezing range alloys and, further, has the same limitations as in the fully liquid mixing methods. Liquid metallurgy technique is the most economical of all the available routes for metal–matrix composite production and generally can be classified into four categories: pressure infiltration, stir casting, spray deposition and in situ processing. Compared to other routes, melt stirring process has some important advantages, e.g., the wide selection of materials, better matrix–particle bonding, easier control of matrix structure, simple and inexpensive processing, flexibility and applicability to large quantity production and excellent productivity. poor wettability and heterogeneous distribution of the reinforcement material are some of the drawbacks associated with stir casting fabrication of AMCs.

Many Nano reinforcements can be added to the base metal in order to improve its mechanical properties reinforcements like Silicon Carbide, Al$_2$O$_3$, etc., for improving the base metal properties.

In this paper the following techniques and Nano reinforcements are considered for the review purpose are Stir casting, stir casting followed by squeeze casting technique, Powder metallurgy and ultrasonic based solidification process technique for comparison purpose and the reinforcements considered for this review are Sic, Al$_2$O$_3$, and Flyash.

Based on the stated potential benefits of MMNC this paper examines the various factors like (a) processing methodology and its effects. (b) effect of various reinforcement (c) mechanical behaviour like strength, wear, fatigue behaviour, etc. (d) application of the speciality AMMNC were discussed.

2. STIR CASTING

L. Rasidhar, et.al., [12] Experimentally reported on Al (99.7) matrix nano composites were fabricated and characterized with the aid of stir casting. Ilmenite(FeTiO3) nano particles synthesized by top down approach using high-energy wet ball milling process. Al (99.7) matrix reinforced with the Ilmenite (FeTiO3) nano particles at 1 to 5 weight percent were fabricated with the help of stir casting. XRD characterization is carried out on nano particles showing the least particle size. SEM images of cast composites shows the uniform distribution of nano particles in the Al matrix.

M. Karbalaei Akbari et.al., [13] Investigated on in order to avoid agglomeration of nanoparticles in matrix. Al$_2$O$_3$ nanoparticles were separately milled with aluminum and copper powders at different milling durations and incorporated into A356 alloy via stir casting method.

Hossein Abdizadeh, et.al., [9] Fabricated Al- nano MgO composites using A356 aluminum alloy and MgO nanoparticles (1.5,2.5, and 5 vol.%) using stir casting method. Distinctive preparing temperatures of 800, 850, and 950°C were considered and found that to accomplish better mechanical properties for optimum processing temperatures via stir casting is 850°C. stir casting composites have higher values of hardness and compressive strength compare to the sintered ones which is directly due to the less porosity portions, less crack formation and presence of continues. casting method represented more homogeneous data and higher values of mechanical properties compare to the powder metallurgy method.

M. Karbalaei Akbari, et.al., [14] Focused on particle distribution in metal matrix. Al and Cu powders were separately milled with nano- Al$_2$O$_3$ particles and incorporated into A356 alloy via vortex method to produce cylindrical A356/nano- Al$_2$O$_3$ composites. The stirring was carried out in various durations. The evaluation of mechanical properties and microstructural studies showed that an increase in stirring time led to a more uniform dispersion of particles in the matrix and also led to a decrease in mechanical properties due to an increase in porosity content of the composites compared with those of the samples stirred for shorter durations.

S.A. Sajjadi, et.al., [17] Studied in order to enhance the wettability and distribution of reinforcement particles within the matrix, a novel three step mixing method was used. The process included heat treatment of micro and nano Al$_2$O$_3$ particles, injection of heat-treated particles within the molten A356
aluminum alloy by inert argon gas and stirring the melt at different speeds. As compared to the common method, this method improved the wettability and distribution of the nano particles within the aluminum melt by the use of heat-treated particles, injection of particles and the stirring system improved.

H.R. Ezatpour, et.al., [10] Experimentally investigated on Al6061/ Al2O3 nanocomposites with different Al2O3 weight percentage 0.5, 1 and 1.5 wt% were fabricated by the developed stir-casting process. The nanocomposites were then extruded at 550°C. Mechanical test results indicated that in as-cast state, tensile and compression strength increased while ductility decreased with increasing particle content. The extrusion process effectively caused the improvement of mechanical properties and ductility especially in the nanocomposites with high percentage of reinforcement.

A. Ansary Yar, et.al., [1] Experimentally investigated on the aluminum alloy (A356.1) matrix composites reinforced with 1.5, 2.5 and 5 vol% nanoparticle MgO were fabricated via stir casting method. Fabrication was performed at various casting temperatures, viz. 800, 850 and 950°C. Optimum amount of reinforcement and casting temperature were determined by evaluating the density, microstructure and mechanical properties of composites. The results reveal that the composites containing 1.5 vol% reinforcement particle fabricated at 850 °C have homogenous microstructure as well as improved mechanical properties.

Sankara Narayanan.S [18] experimentally investigated on the Aluminium alloy with MWCNT Composite to increase the Mechanical Properties by Stir Casting Method and found that Al6061 -MWCNT composite showed better ductile property, its Young’s Modulus increases remarkably with the increase in Reinforced particulate (MWCNT), the Tensile strength increases with the addition of MWCNT but compressive strength decreases with the addition of MWCNT.

3. POWDER METALLURGY
Hossein Abdizadeh, et.al., [9] Fabricated Al- nano MgO composites using A356 aluminum alloy and MgO nanoparticles (1.5,2.5, and 5 vol.%) using powder metallurgy (PM) methods. Different processing temperatures of 575, 600, and 625°C were considered and results showed that to achieve better mechanical properties for optimum processing temperatures via stir casting is 625°C.

Amal E. Nassar, et.al.,[2] fabricated Pure aluminum Nano composite reinforced with Nano titanium dioxide was produced by powder metallurgy route. Measurements of tensile strength, hardness, and density showed that the porosity and the tensile strength of composites increased with an increase in volume fraction of nanoparticles; however ductility of aluminum was decreased. Wear test revealed that composites offer superior wear resistance compared to alloy.

M. Ramachandra, et.al., [15] found experimentally that the Incorporation of n-ZrO2 particles in aluminium matrix can lead to the production of aluminium composites with improved hardness and wear resistance.

A.J. Knowles, et.al., [3] used a powder metallurgy route consisting of high energy ball milling, hot isostatic pressing (HIP) and extrusion has proved a highly effective process for achieving a homogeneous distribution of particles, with minimal clustering of the nanoparticles, at an industrially relevant scale.

Umma A, et.al., [19] Concentrated on some important areas of CNT-Al nano-composite fabrication. In the area of fabrication of CNT-Al nano-composite they found that Powder Metallurgy is the most cost effective and captive process. Therefore, this Powder Metallurgy process route with appropriate processing technique factors can help to develop a new nano-composite material without sacrificing any functional properties and hence, the lightweight industries, such as aerospace, automotive, sports and other industries will be attracted to use this material for many structural and tribological applications.
4. ULTRASONIC BASED SOLIDIFICATION PROCESS

L. Poovazhagan, et.al., [11] Hybrid nanocomposites based on aluminum alloy 6061 reinforced with different hybrid ratios of SiC (0.5, 1.0 and 1.5 vol. %) and B_N (fixed 0.5 vol. %) nanoparticles were successfully fabricated using ultrasonic cavitation based solidification process. Compared to the unreinforced alloy, the room temperature hardness and tensile strength of the hybrid composites increased quite significantly while the ductility and impact strength reduced marginally. The combination of 1.0 volume percentage SiC and 0.5 volume percentage B_N gives the superior tensile strength.

G. Cao, et.al., [4] fabricated Mg–6Zn/1.5%SiC nanocomposites by ultrasonic cavitation-based dispersion of SiC nanoparticles in Mg–6Zn alloy melt. As compared to un-reinforced Mg–6Zn alloy matrix, the mechanical properties of the nanocomposites including the tensile strength and yield strength of the Mg–6Zn/1.5%SiC nanocomposites were significantly higher; the good ductility of Mg–6Zn alloy matrix was retained.

J. KOBLISKA, et.al., [5] Fabricated Mg-4Zn/1.5 pct SiC nanocomposites by ultrasonic cavitation–based dispersion of SiC nanoparticles in Mg-4Zn alloy melt. As compared to the Mg-4Zn magnesium alloy matrix, the tensile properties including tensile strength, yield strength, and ductility of the Mg-4Zn/1.5 pct SiC nanocomposites were improved significantly.

H. Konishi, et.al., [6] SiC nanoparticles reinforced magnesium and magnesium alloys including pure magnesium, and Mg-(2, 4) Al-1Si and Mg-4Zn were successfully fabricated by ultrasonic cavitation based dispersion of SiC nanoparticles in magnesium melt. As compared to un-reinforced magnesium alloy matrix, the mechanical properties including tensile strength and yield strength were improved significantly while the ductility was retained or even improved.

R. Harichandran, et.al., [16] Investigated the effect of the addition of micro- and nano-boron carbide particles to aluminum on the mechanical properties of the composites. Various tests were carried on the speicemen. The tensile test results showed that the properties of the samples containing up to 6% nano B_4C-reinforced composites were better than the micro B4C-reinforced composites. The wear resistance of the nanocomposite significantly increased.

Guoping Cao, et.al., [7] Investigated on Mg/SiC nanocomposites were successfully fabricated by ultrasonic cavitation based dispersion of SiC nanoparticles in Mg melts. As compared to pure magnesium, the mechanical properties including tensile strength and yield strength of the Mg/SiC nanocomposites were improved significantly, while the good ductility of pure Mg was retained.

Hai Su, et.al., [8] Investigated on nano- Al_2O_3/2024 composites were prepared by solid–liquid mixed casting combined with ultrasonic treatment. The obtained composite exhibited fine grain microstructure, reasonable Al_2O_3 nanoparticles distribution in the matrix, and low porosity. The application of ultrasonic vibration on the composite melt during the solidification not only refined the grain microstructure of the matrix, but also improved the distribution of nano-sized reinforcement. Compared with the matrix, the ultimate tensile strength and yield strength of 1 wt.% nano- Al_2O_3/2024 composite were enhanced by 37% and 81%, respectively. The better tensile properties were attributed to the uniform distribution of reinforcement and grain refinement of aluminum matrix.

5. SUMMARY

• The optimum condition for fabricating the composites reinforced with 5 wt percent nano particles cast at 850°C have homogeneity in micro structures and exhibit’s increased mechanical properties like hardness and tensile strength
• Nano particles addition results in a significant improvement in, ultimate tensile and yield strength of composites. It was also found that the addition of nanoparticles to the matrix alloy increases the hardness
• ZrO_2 Nano Particle Reinforced Al Nan composites can find applications in automotive components like pistons, cylinder liners and connecting rods.
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- Powder metallurgy route used, consisting of high energy ball milling, HIP and then extrusion, was found to be an effective method of producing composites with a homogeneous distribution of particles. SiC particles of size < 500 nm and low ageing temperature, display high strength and hardness while maintaining remarkable ductility.
- The optimum processing temperatures to achieve better mechanical properties were 625°C and 850°C for powder metallurgy and stir-casting respectively.
- Ultrasonic based solidification of the AMMNCs found efficient in dispersing nanoparticles in metal melts for improved properties in AMMNCs.

**Table 1** Comparative evaluation for different techniques used in fabrication of AMMNCs

<table>
<thead>
<tr>
<th>S.no</th>
<th>Method</th>
<th>Range of shape and size</th>
<th>Metal yield</th>
<th>Damage to reinforcement</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stir casting</td>
<td>Wide range of shapes</td>
<td>Very high; &gt;90%</td>
<td>No damage</td>
<td>Least expensive</td>
</tr>
<tr>
<td>2</td>
<td>Powder metallurgy</td>
<td>Wide range, but restricted in size</td>
<td>high</td>
<td>Reinforcement fracture</td>
<td>expensive</td>
</tr>
<tr>
<td>3</td>
<td>Ultrasonic based solidification process</td>
<td>Wide range of shapes</td>
<td>Very high</td>
<td>No damage</td>
<td>Very expensive</td>
</tr>
</tbody>
</table>

**REFERENCES**


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