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Fabrication and Evaluation of Properties of Aluminium Alloy- Zirconium Silicate Particles Reinforced Metal Matrix Composites-A Review

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ABSTRACT: Composite materials are widely used in variety of applications such as aerospace, automotive and structural components resulting in savings of material and energy. Particulate reinforced Aluminium metal matrix composite materials which are having desirable properties such as high specific stiffness, high specific strength, high coefficient of thermal expansion, increased fatigue resistance and superior dimensional stability compared to unreinforced alloys. Among the various types of particulate reinforcements such as boron, silicon nitride, boron nitride, silicon carbide, titanium carbide and alumina, extensive research has been directed toward the development of zircon particle reinforcement. Zircon reinforced composites are preferred as these composites exhibit relatively high strength, wear resistance and chemical attack compared to composites reinforced with many other reinforcements. This review article summarizes the current development on the fabrication, microstructure, mechanical and wear properties of zircon reinforced aluminium alloy metal matrix composites. This review also summarizes the work done by various research groups on zircon reinforced Aluminium alloy MMCs in achieving higher hardness, tensile strength and wear resistance in these composites. The review also summarizes the process parameters of wear like speed, sliding distance, load and percentage of reinforcement can be optimized using Taguchi Technique.

KEYWORDS: Zircon, Stir Casting, Tensile Strength, Hardness, Wear, Taguchi

I. INTRODUCTION

Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and ductility. To overcome these shortcomings and to meet the ever increasing property demands, composites are being increasingly used as the most promising candidate materials [1].

Metal Matrix Composites (MMCs) have attractive combination of properties like high specific modulus and strength, enhanced elevated temperature properties, wear resistance, good abrasion resistance properties [1,2]. Due to these attractive properties, MMCs are being considered for a wide range of applications in space shuttles, commercial airliners, electronic substrates, bicycles, automobiles and golf clubs [3]. MMCs have been in existence for the past 30 years and a wide range of MMCs has been studied [4]. However, majority of MMCs are still in their development stage of production, and whose manufacturing processes are not well established. A major drawback of MMCs is their high cost of fabrication, which has placed limitations on their actual applications [5]. Generally, low density metals are advantageous for the fabrication of MMCs and metals like aluminium, magnesium and titanium are the popular matrix materials of current interest.

MMCs have been fabricated using a variety of methods such as stir casting [6], squeeze casting, compo casting, powder metallurgy, spray forming, liquid metal infiltration, mechanical alloying and in situ methods[2]. Ex situ fabricated

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composites exhibit isotropic properties and hence are widely preferred over in situ fabricated one due to their low cost and ease of fabrication [8].

To improve the mechanical properties of MMCs, many researchers have prepared composites by ex situ method with various particulate reinforcement such as boron, silicon nitride, silica sand, magnesium oxide, mica, glass beads, boron nitride [8], silicon carbide, titanium carbide, alumina, titanium boride and boron carbide [8,9]. Among these reinforcements, zircon has been found to be a very promising reinforcement owing to its high refractoriness and resistance to sudden volume changes at elevated temperatures. In addition to being a high melting point material, zircon also exhibits properties such as resistance to abrasion, impact and chemical attack [7]. Many researchers have fabricated zircon reinforced MMCs using different techniques and reported their microstructure and mechanical properties [6]. Though, a significant amount of work has been done on zircon composites, review articles are limited. Hence, a detailed review consolidating all the various aspects including possible fabrication methods for the production of zircon reinforced MMCs, their microstructure as well mechanical property characterization such as hardness and wear has been attempted.

Taguchi technique is a better technique to deal with responses influenced by multivariable. Researchers concentrate both on experimental and analytical portions of Al MMCs to gain better mechanical properties and excellent wear resistance. The coefficient of friction was calculated by taking the frictional force from DUCOM and the effects of the parameters like load and sliding distance on the response was studied [3]. In this study, coefficient of friction was measured based on Taguchi orthogonal design with design parameters like Weight percentage (wt. %) of Zircon, Load, Sliding distance and Speed. A multi tribotester is used to find out the coefficient of friction. Taguchi analysis was applied to find out the optimum combination of parameters that yields optimum (minimum) coefficient of friction. Analysis of variance was carried out to observe the level of significance of individual factors and their interactions. The worn surface morphology was studied using SEM to observe the wear mode [4, 5].

This paper represents a literature review on Zircon particulate reinforced Aluminium alloy metal matrix composites. The paper describes the synthesis of Zircon-Aluminium alloy metal matrix composites and their mechanical and wear and properties and optimization of wear processing parameters using Taguchi Method.

II. RELATED WORK

K S Sucitharan et.al., conducted experiment on “Wear behaviour of Al6063-Zircon sand MMC’s by pin-on disc method” and they found that with increase in the percentage of zircon sand particles will reduce the wear rate. **J.Jenix Rino et.al.**, conducted experiment on “Properties of Al6063 MMC Reinforced With Zircon Sand and Alumina” From the experiment they found that, Al 6063 alloy matrix hybrid composites reinforced with Zircon Sand particles and Alumina particles has been successfully synthesized by the stir casting method. They revealed that hybrid reinforced composites have the property improvement better than Zircon sand and Alumina particles alone reinforced composites, the hardness and the tensile strength of the composite have increased with the increase in the percentage of Zircon and alumina.

Sanjeev Kumar Yadav et.al., studied the Microstructure, Micro hardness and compressive behaviour of dual reinforced particles Aluminium alloy composites and found that the microstructure and micro hardness of the micro size particle reinforced composites, which have positively affected the micro hardness and compressive strength behaviour that as the size of the reinforcement increases the microstructure heterogeneity increases. The combination of reinforcement in ADC-12 alloy composites 50 % TiC and 50 % zircon sand particles reinforced composite (Composite B) yields better compressive strength as compared to other combination. The reinforcement up to 12Wt% yields better mechanical properties as compared to other combination. **S Johnnyjames et.al.**, worked on the Fabrication of Aluminium Metal Matrix Composite and Testing of Its Property and found that microstructure analysis proves the existence and distribution of $ZrSiO_4$ in the metal matrix. Hardness test proves improvement of hardness value up to 40% due to the good cohesion between metal matrix and reinforcement phase. Tensile test result proves elevation in mechanical property and it is minimum level due to the agglomeration of reinforcement particles and poor bonding. Optical micro graphs strengthen this fact. Wear resistant property which is one of the peculiar properties of Composite

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has been achieved due to reinforcement of $ZrSiO_4$ in metal matrix Al 6061. The wear is measured in microns and its value is 104.206 μm . Altogether above fabrication and tests concludes successful fabrication of aluminium metal matrix composite with elevated metallurgical mechanical and tribological properties.

Balaje Krishnay et.al., worked on the Synthesis and Characterization of Zircon/Graphite and Flyash/Graphite Reinforced Aluminium 7075 Alloy and observed that reinforcing Flyash and Graphite into Al 7075 produces more strength compared to Zircon and Graphite reinforcement. Incorporating Zircon and Graphite results in increasing hardness of the parent alloy, despite having weaker interfacial strength than Flyash reinforced hybrid composite. Adding fine Zircon particles to the matrix would increase the density of the alloy without decreasing the hardness. The density of Al 7075/Flyash/Graphite composite is found to be lower than the density of monolithic Al 7075. Porosity and non-wettability is witnessed in Al 7075/Zircon/Graphite composite whereas Flyash/Graphite particles are uniformly distributed along the matrix. **Shivanna et.al.**, studied the Microstructure and Wear Characterization of A356-ZrSiO₄ Particulate Metal Matrix Composite and found that Wear increases as the % of Zirconium Silicate increases. Wear rate decreases as sliding distance and load increases. The hardness of the composite found to be higher than the base matrix this is mainly due to the influence of $ZrSiO_4$. The microstructure of the cast composite shows uniform particle distribution with less priority. **M.A. Baghchesara et.al.**, worked on the Hardness and Tensile Strength behavior of Zircon Particles and TiB_2 Reinforced Al-A356. 1 Alloy Matrix Composites and found that For Al/zircon composites, the sample containing 5vol. % zircon particles, the best results is achieved. The hardness and the tensile strength values are maximum compare to matrix aluminium and the composites containing 10 and 15 vol.% zircon. This can be related to poor wettability of zircon by aluminium. The Al/ TiB_2 composites have much more values of hardness that increase with increasing of reinforcement volume. The high hardness of these particles and their suitable incorporation are the reasons of this phenomenon. All composite samples show the hardness and tensile strength values more than those of monolithic matrix aluminium. This is due to produce a lot of mismatches into the boundary of particle/matrix. By adding 5vol.% zircon into aluminium, 65.9% and 52% increase are achieved for hardness and tensile strength respectively. This could be interesting in the economic view.

Ramesha V et.al., studied the Mechanical and Wear Characteristics of $ZrSiO_4$ Reinforced Aluminium Metal Matrix Composite and observed that as the percentage of reinforcement increases wear rate decreases at all load conditions when compared to the base material. From the result it can be seen that 12% of reinforcement will have better wear resistance properties compared to all other percentage of reinforcement. As the speed increases it is found that wear resistance also increases and 12% reinforcement shown better wear properties. Brinell hardness result shown that 3% reinforcement will give the better hardness property when compared to other percentage of reinforcement. **E. G. Okafor et.al.**, studied the Effect of Zircon Silicate Reinforcements on the Microstructure and Properties of as Cast Al-4.5Cu Matrix Particulate Composites Synthesized via Squeeze Cast Route and concluded that addition of $ZrSiO_4$ particles using Al-4.5%Cu alloy increased both the strength and hardness and an overall reduction in toughness and density. Also, little increase in the apparent porosity of the composite with percentage increase in $ZrSiO_4$ addition was observed. From the result, maximum service performance of the Al4.5Cu/ $ZrSiO_4$ particulate composite synthesis via squeeze casting should not exceed 15% in order to develop balance in the necessary properties. Pronounce increase in hardness value was observed by reinforcing the matrix alloy with 5-25% zircon sand. Al4.5Cu/15% $ZrSiO_4$ particulate composite could be appreciable in automobile industries (brake drum, crankshafts, valves and suspension arms), recreational products (golf club shaft and head, skating shoe, bicycle frames and base ball shaft) and in construction company (truss structure).

Mr. Balu Mahandiran et.al., studied the dry sliding wear behaviour of Al-SiC composites using Design of Experiments and showed that sliding distance has the highest influence on wear rate followed by sliding speed and applied load. The sliding distance and applied load have the highest influence on wear rate. They also showed that the error associated with dry sliding wear varied from 11.42% to 12.01%. **Ajay Singh Verma et.al.**, worked on "Aluminium 6063 based Flyash composites and studied the effect of process parameters using Taguchi method and showed that the value of hardness was found to be maximum for 9% flyash composition at 720^oc at 400 rpm.

V.C. Uvaraja et.al., worked on the "Optimization of Friction and Wear Behaviour in Al-7075-SiC-B₄C Hybrid Metal Matrix Composites Using Taguchi Technique" and showed that 4,5 m/s sliding speed, 10N applied load, 5 min sliding time and 15% of reinforcement are the optimum conditions for both wear rate and the coefficient of friction. They also showed that the percentage of reinforcement is the wear factor that has the highest physical properties as well as

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statistical influence on the dry sliding wear rate of the composites among the other factors such as applied load and sliding speed. **Ashok Kr. Mishra et.al.**, studied the tribological behaviour of Al6061/SiC Metal Matrix Composite by Taguchi's Techniques and showed that sliding distance has the highest influence followed by load and sliding speed. They also conducted the confirmation test and verified the experimental results. **Dr. Osama S. Nuhammed et.al.**, worked on "The use of Taguchi Method to optimize the Casting of Al-Si/Al₂O₃ Composites" and showed that the volume fraction is a major contributing factor for improving tensile strength and hardness.

III. METAL MATRIX COMPOSITES (MMCs)

Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing high strength, high wear resistance and high temperature resistance reinforcements. Among various discontinuous dispersions used, Zircon is one of the most easily available and economical reinforcement. Hence, composites with Zircon as reinforcement are likely to possess excellent mechanical and wear properties for wide spread applications in automotive and small engine applications.

IV. ALUMINIUM MATRIX COMPOSITE (AMCs)

The low density and high specific mechanical properties of aluminium metal matrix composites (MMC) make these alloys one of the most interesting material alternatives for the manufacture of lightweight parts for many types of vehicles. With wear resistance and strength equal to cast iron, 67% lower density and three times the thermal conductivity, aluminium MMC alloys are ideal materials for the manufacture of lightweight automotive and other commercial parts. The automotive industry recognizes that weight reduction and improved engine efficiency will make the greatest contribution to improved fuel economy with current power trains. This is evidenced by the increased use of aluminum alloys in engine and chassis components. Aluminium and magnesium castings in this sector have grown in leaps and bounds over the past five years to help engineers design and manufacture more fuel efficient cars.

V. MATRIX

The matrix is the monolithic into which the reinforcements embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt-nickel alloy matrices are common.

VI. REINFORCEMENT

The reinforcement material is embedded into a matrix. The reinforcement does not always serve purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metal working techniques, such as extrusion, forging, or rolling.

VII. PROCESSING ROUTES OF MMCS

MMCs have been fabricated using a variety of methods such as stir casting [6], squeeze casting, compo casting, powder metallurgy, spray forming, liquid metal infiltration, mechanical alloying and in situ methods [2]. Composites fabricated by ex situ method suffer from limitations such as poor wettability and subsequent interfacial reactions between matrix and reinforcement in comparison to in situ composites [1]. In spite of the above drawbacks, ex situ fabricated composites exhibit isotropic properties and hence are widely preferred over in situ fabricated one due to their low cost

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and ease of fabrication [8]. In ex situ processes, reinforcement size ranges from few microns to nano sizes and the resultant properties greatly depend on the volume fraction of the reinforcement [1].

VIII. TAGUCHI TECHNIQUE

Taguchi technique is an extraordinary tool for designing high-quality system based on Orthogonal Array (OA), which is a reliable and systematic approach to optimizing designs for performance, quality, and cost [12]. An orthogonal array represents the requisite number of experiments. There are five basic phases applied in Taguchi experimental design technique. Phase 1- Experimental Planning, Phase 2- Design of Experiments, Phase 3- Conducting Experiments, Phase 4- Analyzing Results, and Phase 5- Confirming Prediction. Orthogonal array provides a best set of well balanced (minimum) experiments. There are several orthogonal arrays based on the process parameters and their levels in which suitable OA is selected and the experiments are carried out as per the OA specifies. The experimental results are analyzed by signal to noise ratio (S/N) values that are categorized into three types of quality characteristics such as lower the better (LB), higher the better (HB) and nominal the best (NB). This will be selected based on the response of the process, since here the response is wear and we have to minimize the value of response so LB characteristics need to be applied here. The Mathematical equation for smaller the better S/N ratio is represented in equation 1. Furthermore, Analysis of Variance (ANOVA) has been performed to find out the influencing parameter over the other and to find the percentage of contribution of each parameter on wear. With the help of S/N ratio and ANOVA analysis, optimal combinations of process parameters are obtained and confirmation test was performed to verify optimum process parameters.

$$S/N = - 10 \log_{10} (y_1^2 + y_2^2 + y_3^2 + \dots + y_n^2) \quad (1)$$

Where $y_1, y_2, y_3 \dots y_n$ are the response of sliding wear, n is the number of observations

IX. CONCLUSIONS

These review paper represents the mechanical and wear properties for the metal matrix composites. The conclusions of the aluminum graphite composite material are as follows. The zircon particulates distribute uniformly in the aluminium matrix. Aluminium-Zircon composite possess very good mechanical properties like ultimate tensile strength, compression strength and impact strength. These properties increase as the percentage of zircon increases. The Aluminium-Zircon composite possess very good wear resistance properties. The Aluminium-Zircon composite possess very good hardness properties. Taguchi technique can be used to optimize the wear processing parameters.

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