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Evaluation of Mechanical and Tribological Characteristics of Al4032 - A Review

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ABSTRACT: Aluminum MMC's are widely used in various applications because of their higher mechanical and physical properties when compared with their base Al alloy. This review paper focuses on the change in mechanical properties of various composites fabricated by using stir casting method. Effect of various reinforcement in different alloys on mechanical properties like hardness, tensile strength, wear test, percentage elongation, residual stress measurements are discussed in detail. For this purpose, various reinforcement with different weight percentage and different particle sizes are considered along with alloys. Variations in process parameters of stir casting are also made and taken into consideration.

I. INTRODUCTION

Material scientists have been working for development of advanced materials for satisfying the need of the engineering sector to improve efficiency, and reducing costs of the industrial sector, for decades. Aluminum and its alloy-based composites (AMCs) are the most demanding material in various industrial sectors (aeronautical, automobile, sports etc.) for having substantially superior properties involving high specific strength, specific modulus, and damping capacity than conventional Al-alloys. [1]

The AMCs are used extensively in various fields due to their low density, high strength-to-weight ratio, good damping properties and better chemical properties. The hybrid metal matrix composite, having two or more reinforcement materials simultaneously in equal or different proportions, is the new concept in this field for the research. [1,2]

The properties of aluminum matrix composites depend on the type, size, shape, mass fraction, and spatial dispersion of the ceramic particles. In recent decades, most of the researchers have been using a wide variety of ceramic materials such as SiC[1], Al₂O₃[5], TiB[2], AlN[6,38], ZrB₂[7], ZrO₂[8], Si₃N₄[32], TiC[9], and also use industrial and agro wastes such as granite powder[3], red mud[10], bagasse ash[12], maize stalk waste[18,31], rice husk ash[19], baboo leaf ash[20], palm kernel shell[21], marble waste[22], they have been significantly used as reinforcement materials in AMCs. The role of reinforcement in a composite material is to improve the mechanical and tribological properties of the base metal. The properties of the hybrid ceramic reinforcements (different material) can be merged/combined to attain improved material properties than single reinforced composites. [2,3]

II. METHODOLOGY

2.1 Material:

The base material selected for this investigation is Aluminum 4032, The research on Al-4032 alloy matrix-based composites is going on to reduce weight and improve the mechanical, chemical & tribological properties of components used in industrial machinery.[2] The aluminum alloy (Al-4032) matrix-based composites (AMCs) have wide significance in both, research as well as industrial applications. There are strong and light weight composite material being used in industry.[3] Al4032 is widely used In the automotive sector and industries because it has a

striking advantages, it is used for several engine components such as pistons, transmission valves, master brake cylinders, bushings for rack and pinion steering systems, hydraulic applications, and many more. [4]

Chemical composition (Wt%) of Al4032 alloy

Si	Mg	Ni	Cu	Fe	Mn	Zn	Ti	Al
11.77	1.47	1.19	0.98	0.88	0.415	0.0895	0.017	Remaining

The reinforcement materials are red mud and bagasse ash which abundantly available and low-cost materials. Red mud basically an industrial waste which is a byproduct obtained during extraction of alumina by Bayer's process [11]. The use of red mud as a reinforcement material will consume a waste product which otherwise can cause disposal problem and environmental hazards. It possesses high abrasive resistance due to its hardness it is most commonly used in tool cutting, wear components and metal matrix composition. It is mainly preferred in preparing of armours in defense and engine blocks pistons and break components [13]. Bagasse ash nano powder is a super fine powder made from left over sugarcane fibers. It can be mixed with metals like aluminum to make them stronger and lighter [14]. using this powder is good for the environment because it recycles waste from sugarcane production. Bagasse fly-ash was chosen due to low weight, density and increase in the strength [17].

Al4032 fabricate with rice husk ash

This study was aimed at developing low-cost composites with high specific strength and better performance by incorporating agro-waste as reinforcements[19]. The stir-casting technique was adopted for fabricating composites with aluminum (Al) 4032 as matrix material and different weight ratios of rice husk ash (RHA) as reinforcements[20]. Better results were obtained for composites with 6 wt.% RHA with 84 HRB, 92.30 HV, ultimate tensile strength of 383.73 MPa and ultimate compressive strength of 571.6 MPa. Minimum wear rate was obtained for composites with 6 wt.% RHA at 100 rpm and 10 N. Speed was found to be the most contributing factor, with 72.94%, followed by load, with 13.34%, and weight percentage of reinforcements, with 11.88%.[23]

Bagasse ash Reinforcement with Al6061

The Tensile Strength of the composite increases with increase in volume fraction of bagasse ash reinforcement up to 5%, for composites with more than 8% weight fraction of Sugarcane Bagasse ash particles the tensile strength was seen to be decreasing [41]. Wear depth decreases as the amount of SCBA particles reinforcement increases in the alloy [42]. Brinell hardness values increased linearly with increase in wt % bagasse ash particles and composite containing 5wt % of bagasse ash particles was observed to have a maximum value [43]. Compressive strength and tensile strength increased with increase in wt % of bagasse ash particles. Increase in addition of bagasse ash resulted in decrease in overall density of the composite [44].

Red mud Reinforcement with 7075

In tensile test, the composite containing 10 vol. % Red mud showed the maximum strength of 215MPa increased by about 40 MPa [45]. The corrosion rate of the composites was lower than that of the corresponding matrix alloy. The corrosion by weight loss of the composite decreased with increase in the weight percentage of the reinforcement [46]. Micro hardness of the composite material was increased with an increase in reinforcement from 0% to 15% volume fraction [47]. An increase in red mud content enhances the precipitation of silicon particle which is strengthening alloys [10]. As the percent of red mud increases, the hardness of the composite increases. The density of the composite material decreases with increase of red mud[11].

Al4032 Fabricate with Zrb2 and Tib2

The Al 4032 matrix materials is well mixed and distributed uniformly by the reinforcement particles such Zrb2 and Tib2 in various Wt. % volume fraction through stir casting process and successfully fabricated composites is made in to specimen as per required size and shape to conduct various experiments [2]. the mechanical test such as tensile strength, compressive strength and hardness has been measured according to the ASTM standards for three sets of specimens with various Wt. % of reinforcement. The results prove that the value of mechanical properties is considerable increased in all three properties in the Al 4032 matrix composites due to the addition of reinforcement [7].

The variation of mass loss, wear rate and coefficient of friction of the Al 4032 composite is measured as a function of composite Wt. %, speed (rpm) and load (N). The values obtained are minimum when adding of reinforcement particles in various Wt. % and wear resistance of the composite alloy is increased with increase in content of Zr₂ and Ti₂ particles in the composite increases.[15]

Al4032 Fabricate with SiC:

Al-4032/SiC AMCs have been fabricated using bottom pouring stir casting set-up for different reinforcement ratios by weight [1]. Each composite exhibits distinctive enhanced property, indicating suitability as alternative material for engineering applications [8]. There is an increasing trend in theoretical density, while a decreasing trend in the experimental density, with increase in the SiC reinforcement. A maximum 1.52% increase in theoretical density, while a maximum 2.92% decrease in experimental density has been recorded for 8% reinforcement. Addition of the SiC particles (up to 6% by weight) to the matrix in general results in improvement in UTS and micro hardness of the AMC. At higher weight fractions i.e., 8%, the properties start decreasing due to coagulation of the reinforcement, and weak interfacial bonding.[16]

Al4032 Fabricate with Granite Powder

In this study, Al-4032/GP composites have been fabricated using stir casting set up for different reinforcement ratios by weight [22]. The GP, an industrial waste ceramic (particles) has been utilized to form the Al-alloy based composites. Addition of the GP particles to the matrix in general results in improvement in mechanical properties of the AMC [1]. The tensile strength and microhardness of the AMC samples increase with increase in the reinforcement ratio up to 6% (by weight). Beyond this, the properties start deteriorating, possibly due to coagulation of the reinforcement, and weak interfacial bonding at higher weight fractions. The impact strength of the AMCs appears to be higher than that of the Al-alloy matrix. The highest value of the impact strength occurs corresponding to 3% weight fraction of the reinforcement. The impact strength follows a decreasing trend beyond this value, possibly due to increase in brittleness of the composite with increase in the reinforcement fraction.[3]

APPLICATIONS: pistons, transmission valves, master brake cylinders, bushings for rack and pinion steering systems, brake discs/drums in railway vehicles, industrial valve body, etc....

2.2 CASTING PROCESS

The Aluminum metal matrix composite material has been prepared by casting method in an induction furnace. The molten alloy is cast or molded into the desired shape and form using casting techniques such as sand casting, die casting, or investment casting, stir casting and ultra sonic stir casting.

2.2.1 SAND CASTING

Sand casting also known as sand molding is a metal manufacturing process categorized by utilizing sand as an aggregate material for making the mould. The sand-casting process encompasses, moulding, metal melting, solidification, shake out and fettling. The mould is a cavity where the molten metal is poured into and allowed to solidify. During the sand-casting process, the sand is rammed around the pattern to produce the mould cavity [25]. A pattern is a reproduction of the final casting. The mould must have adequate strength to carry the metal during casting and it must be permeable enough to allow gases to pass through during solidification. After solidification, the casting is removed from the mould and the sand is reused again in the process. Sustainability in manufacturing is driven by cleaner and more efficient productions. Sustainable manufacturing involves a variety of concepts that encompasses profit, environmental impact, product life cycle, operator knowledge and recyclability. [25-26]

2.2.2 DIE CASTING

Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a mould cavity. The mould cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mould during the process. Most die castings are made from non-ferrous metals, specifically zinc, copper, aluminum, magnesium, lead, pewter, and tin-based alloys. Depending on the type of metal being cast, a hot- or cold-chamber machine is used [27].

The casting equipment and the metal dies represent large capital costs and this tends to limit the process to high-volume production. Manufacture of parts using die casting is relatively simple, involving only four main steps, which keeps the incremental cost per item low. It is especially suited for a large quantity of small- to medium-sized castings, which is

why die casting produces more castings than any other casting process. Die castings are characterized by a very good surface finish (by casting standards) and dimensional consistency [27].

2.2.3 CENTRIFUGAL CASTING

Centrifugal casting is a casting technique that is typically used to cast thin-walled cylinders. It is typically used to cast materials such as metals, glass, and concrete. A high quality is attainable by control of metallurgy and crystal structure. Unlike most other casting techniques, centrifugal casting is chiefly used to manufacture rotationally symmetric stock materials in standard sizes for further machining, rather than shaped parts tailored to a particular end-use [28].

2.2.4 SQUEEZ CASTING:

Squeeze casting was utilized to produce the composites. The composition of the materials used for producing the aluminum metal matrix composites. The scrap aluminum alloy was collected from scrap stock, and dirt and grease were removed using acetone[29]. The wheels were cut into small pieces so that they could easily pass through the opening of the crucible. The permanent hardened steel dies (50 mm in diameter and 250 mm long) were preheated to 300 C. The temperature-controlled squeeze casting furnace was set to 750 C. The stirrer rod and stirrer were cleaned, and a non-stick boron carbide coating was applied at room temperature and dried at 250e300 C to withstand high temperatures and prevent erosion of the stirrer edges. The reinforcement particles were preheated in the preheater chamber at 300 C to eliminate dampness and reduce particle clotting. The matrix materials were charged into the furnace when the crucible temperature reached around 350 C, and the materials were further heated to 750 C to completely melt the alloy. The stirrer rod was then switched on and gently moved into a position 30 mm above the bottom of the crucible with a stirring speed of 650 rpm. One wt. % of magnesium was added to the molten matrix to improve the wettability between the matrix and the reinforcement. The preheated reinforcement particles were slowly added to the vortex formed during stirring and mixed for 10 min. The molten mixture was then transferred through a bottom tapping mechanism into the preheated pathway pipe connected to the die of the squeeze casting setup. A squeezing pressure of 200 MPa was applied immediately to the molten mixture poured into the die. The same procedure was followed for the fabrication of the remaining three samples. The procedure used for producing the aluminum metal matrix composites. The squeeze casting parameters for aluminum metal matrix composite fabrication [30].

2.2.5 STIR CASTING

stir casting Known as one of the less expensive methods [6], stir casting provides a varied range of manufacturing conditions. It can be used to form composites with a more satisfactory bonding of the matrix as a result of stirring. Keeping these advantages in mind, stir casting procedure has been used for manufacturing the composites.[9] Also, the stir casting technique for fabrication of AMCs has been quite popular for being economical, highly productive and simple [14]. The stir casting process costs as low as 1/3rd to 1/10th as compared to other fabrication methods, for mass production of the metal matrix composites [3]. Stir casting technique is one of the promising route for producing large size components and high volume production [37].

III. EXPERIMENTAL PROCEDURE

Reinforcement distribution in each composite was closely observed through the microstructural examination, Mechanical strength of alloy and each composite were analyzed and compared by performing Rockwell hardness test, tensile test, impact test, bending test and wear test.

3.1 MECHANICAL PROPERTIES

3.1.1 TENSILE TEST

Tensile testing is a basic materials science test during which a sample subjected to a controlled tension until failure it also known as tension testing. The results from the test usually used to choose a material for associate application, for quality control, and to predict how a material can react under very different forces [32]. The tensile test, was followed while preparing the tensile test specimens for aluminum composite material test Properties that obtained from this test are Ultimate tensile strength, maximum elongation and reduction in area. Properties like young's modulus and yield strength also are determined from these measurements The samples were machined as per ASTM E-8 specifications [40]. The test was carried out on a computerized UTM machine. The ultimate tensile strength of the specimens was calculated from the load at which fracture occurred. The specimen to be tested was placed between the self-locking jaws. The gradual application of tensile load at both specimen ends by pulling at a speed of 0.5 mm/min, broke the

specimen after neck formation. The micro tensile test was conceded out in harmony with different specimens as a dimension of 100 mm length and gauge length of 25 mm. [34]

3.1.2 HARDNESS TEST

The hardness test is usually applied for hard materials and it measures the hardness based on the indentation of point [33]. Rockwell hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Load applied was 100kgf and the ball indenter used was 1/16 inch [34] and it moved downwards with the help of lever against the surface of the specimen and load was applied the depth of penetration of the ball indenter was maintained for about 30sec against the specimen surface. After 30sec the load was released by moving the ball indenter upwards. The average hardness value of each sample was calculated by considering the hardness values at top, middle and bottom of the samples.[37]

3.1.3 IMPACT TEST

Impact Test is performed to determine how a material behaves when it experiences sudden dynamic loads, like impact or shock [38]. In this test, a notched sample is clamped and hit by a pendulum hammer at a specific height. The impact of the hammer causes the sample to break, and the energy absorbed is measured by how the pendulum swings after the impact. Higher energy values mean that the material is tougher. By doing impact testing, engineers can figure out how well it can handle sudden loads, predict how it will perform in real-life situations, and make informed decisions about what material to use and how to design components that have to deal with impacts. The sizes of specimen is 55mm length, 6mm width and 6mm thickness [36].

3.1.4 BENDING TEST

Bending tests, also known as flexural tests, are mechanical tests used to assess the behavior of materials under bending stresses. In a bending test, a specimen is usually supported at both ends and loaded at the midway or another predetermined place. The imposed load creates bending or flexural stress in the specimen, causing it to deform. During a bending test, numerous parameters may be measured, including Flexural Strength: The highest stress sustained by the specimen at the moment of failure, usually measured in units of force per unit area (e.g., MPa or psi). The modulus of elasticity, also known as the flexural modulus or Young's modulus in bending, represents the stiffness or resistance to deformation of a material under bending loads [36].

3.2 TRIBOLOGICAL PROPERTIES

3.2.1 WEAR TEST

The sliding wear test has been conducted on the composite alloy at room temperature is carried out by using pin on disc apparatus [22]. At dry sliding condition with ASTM G99-05 standards, wear tests have been carried out at standard room temperature. Prior to testing, pin and discs have been washed using acetone, where it will take away all the dirt from the sample [23]. Pin sample is fixed perpendicular to the disc surface, the disk is attached to the holding unit and the pin is placed into its holder. Timer has been set to achieve the desired value. The test was carried out with the specimen in contact under load. The test was stopped when the required sliding distance was reached. The specific wear rate is calculated based on the pin's weight loss [24,29].

3.2.2 IMMERSION CORROSION TEST

Immersion corrosion was performed by subjecting Al4032 alloy specimens with a size of approximately 2.6 cm x 2.1 cm x 0.5 cm were used for this experiment. Each of the samples were heat treated differently. For all samples treated were polished with sandpaper [47]. The polished samples were cleaned with acetone, washed using distilled water, dried in air and stored over a desiccant. After immersion test, the specimen surfaces were cleaned by dipping in chromic-phosphoric acid as per ASTM G1 to remove the corrosion product [48]. The dependence of the corrosion rate on the concentration of the electrolyte solution with the greater the concentration of the electrolyte solution, the greater the corrosion rate [49].

3.2.3 POTENTIODYNAMIC POLARIZATION

The electrochemical corrosion of the alloys was evaluated through potentiodynamic polarization test using a computer-controlled electrochemical workstation. Samples were taken from the rolling plane of both the alloys to make specimens with an area of 20*20*6. The corrosion behavior of the samples was examined in 3.5% NaCl solution (mass fraction) prepared using reagent-grade NaCl salt and deionized water. The tests were carried out using a standard three-

electrode setup with platinum as the counter electrode, saturated calomel electrode (SCE) as the reference electrode, and the test specimens as the working electrode. A scan rate of 0.5 mV/s was used. All the scans were started from a potential of 300 mV below the corrosion potential. Prior to the experiment, the samples were ground with SiC papers up to 1000-grit followed by cleaning in acetone and water [50].

3.3 MICROSTRUCTURAL EVALUTION

3.3.1 SEM ANALYSIS

SEM offers the capability to visually inspect the surface morphology for detection of pores, fissures, and other surface materials/deposits [3]. For the purpose of studying the particle distribution, samples of different specimens were polished and examined through an optical microscope [39]. Scanning electron microscopy is achieved at high exaggerations, engenders high-resolution imagery and accurately measures very tiny facial appearance and objects. The specimen was polished with emery grades series (220,320,400,600,800,1000,1200) in order to remove the surface scratches [27]. SEM provides completed high-resolution imagery of the taster by restoring a focused electron beam across the surface and distinguishes derived or backscattered electron signal. An energy dispersive X-ray analyzer is also used to endow with elemental detection and quantitative compositional information [45].

3.3.2 XRD

X-ray diffraction (XRD) is a rapid investigative technique mainly used for phase identification of a crystalline material [3]. In XRD analysis, a beam of X-rays is directed at a crystalline sample, and the resulting diffraction pattern is recorded and analyzed to determine the atomic arrangement and lattice spacing within the sample. The specimen was polished with emery grades series (220,320,400,600,800,1000,1200) in order to remove the surface scratches [27]. At the final stages, these specimens were polished using velvet cloth polisher impregnated with very fine Al₂O₃ powder to get a mirror like finish. Super-finished specimens were etched with Keller's reagent, and their microstructures were observed [39].

IV. CONCLUSION

- From the recent study of composite material manufacturing is conclude that stir casting is most effective and efficient in all the conditions such as cost, simplicity of operation, distribution of reinforced particles etc.
- From the detailed literature, it has been clearly understood that the main problem associated with the Metal Matrix Composites is their higher cost of reinforcement. To overcome this obstacle, a need arises to look for low-cost reinforcements such as Red mud and bagasse ash. which result in better properties of the developed composite.
- From the above literature review conclude that the addition of red mud to the metal matrix which increases their properties at the weight percentage of 10%. And also conclude that the addition of bagasse ash to metal matrix which increases their properties at the weight percentage of 5%.
- From the detailed literature, it has been clearly understood that most of the research papers focused on the studies of different mechanical properties like tensile strength, compression strength, impact strength, hardness and yield strength of the reinforced Al4032 aluminum alloy matrix composite were enhanced significantly.

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