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Fabrication & Analysis of Aluminium (Al-2024) and Tungsten Carbide (WC) Metal Matrix Composite by in-Situ Method

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***Abstract*— In this present investigation, aluminium (Al 2024) as base matrix metal and tungsten carbide (WC) as particulate reinforcement is fabricated by insitu casting method. Tungsten Carbide (WC) being one of the hardest ceramic particle can enhance the mechanical properties of aluminium by uniform blending. Experimental researches have largely stressed on studying contribution of these particulates in improving the properties of the MMC. The even distribution of Tungsten Carbide in the Al matrix has identified as being crucial for improved properties. In order to achieve uniformity fabrication of MMCs was done by stir-casting process. This paper concentrates on the stir casting process, process and material parameters, & preparation of aluminium Matrix Composite material by using aluminium as matrix form and Tungsten Carbide as reinforcement. Mechanical properties like wearness and micro hardness were studied for aluminium 2024 alloy and stir casted MMC (Al-WC). From the results, it was found that the microhardness and the wear properties of the prepared metal matrix composite improved.**

Keywords—Aluminium, Tungsten Carbide, MMC, stir casting, reinforcement

I. INTRODUCTION

The advent of 21st century has witnessed increase in need for advanced engineering materials for various engineering applications. To meet this huge demand conventional alloys were replaced by metal matrix composites which turned out to be reliable source. Composite materials are combined in convenient way so that better use of parent material is achieved while minimizing their deficiencies to some extent [1].

The very word 'composites' imply combinations of two or more material in order to enhance the properties. In the recent years, development in material science has shifted from monolithic to composite materials for adjusting to the global need for reduced weight, quality, low cost and high performance in structural materials [1]. In a metal matrix composite one constituent essentially should be a metal or an alloy (matrix of the system) forming one or more percolating network, the other constituents are embedded in the matrix. In a metal matrix composite the metal or alloy forms at least a percolating network embedding other constituents in the metal matrix, usually serving as a reinforcement [2]. Fibres, particulate and whiskers are usual reinforcements which enhance base metal properties like toughness, weight, conductivity, stiffness, strength, etc. Due to superior properties over the unreinforced alloys and polymers, MMCs have emerged a potential substitutes for various applications [3].

Aluminium matrix reinforced with particulate reinforcement materials are gaining more importance because of their isotropic properties, low cost and wide variety of tailored properties for fabrication of secondary components [6]. Recently there has been a paradigm shift to development of AMMCs based on the use of Aluminium Alloy[4]. Aluminium Alloys were conventionally used for the design of door profiles, medium strength window and many architectural works. Due to lower cost of processing and local availability aluminium alloys have been the best choice of material. Many techniques such as squeeze casting and powder metallurgy were developed for manufacturing particulate reinforced AMCs [3]. The driving forces that are leading to the utilization of AMCs are performance, environmental and economic benefits in areas of aerospace and automotive and industries [5]. The most widely used reinforcement materials are particulate reinforcement since they are easy to manufacture and are comparatively cheap. Fibrous, particulate and continuous reinforcements are generally used three types of reinforcement materials. Powders such as Tungsten carbide, silicon carbide, boron carbide etc are commonly used particulate reinforcement in the metal matrices. Fibrous reinforcements comprises graphite fibres or silicon carbide fibres dispersed in aluminium matrix. Continuous include carbon fibre, magnesium composites, filament-wound etc [3].

Physical properties of general ceramic reinforcements are given in Table 1.1. Experiments using Tungsten Carbide as reinforcement particulate is comparatively very less.

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Table 1.1: Properties of particulate composites

Properties	WC	SiC	Al_2O_3	B_4C	Si_3N_4
Density g/cm^2	13-15.3	3.21	3.7-3.97	2.51	3.31
Compressive Strength MPa	3100-5860	1725-2500	2070-2620	2900	689-2760
Modulus of Rigidity GPa	483-641	476	393	445	317

Stir casting technique (Fig 1.1) for metal matrix composites was introduced in 1968 by S. Ray by introducing alumina particles into an aluminium melt by stirring molten aluminium alloy containing the ceramic powders. Mechanical stirring in the furnace is the key factor in this process [1]. In a stir casting process, the reinforcing particles are distributed into molten matrix by mechanical stirring. The resultant molten alloy with ceramic particles are then used for permanent mould casting, die casting or sand casting. For manufacturing materials with up to 30% volume fractions of reinforcement ceramics, Stir casting technique is used [1]. Further extrusion is done for reduction of porosity, refining the microstructure, and homogenizing the distribution of the reinforcement after casting the material [1].the major concern in stir casting technique is uneven Segregation of reinforcing particles, which can be the result of settling or surfacing of the reinforcement particles during the casting. The final uniform distribution of the particles in the matrix depends on process parameters and material properties such as strength of mixing, the wetting condition of the particulates with the melt, relative density, and solidification rate [6]. The uniform distribution of the particles in the matrix also depend on the stirring parameters, mechanical stirrer geometry, mechanical stirrer placement in the furnace, melting temperature, and particulate characteristics [7]. Recent method used in stir casting technique is a two-step mixing process. In this process, the metal matrix is allowed to heat at least above its melting temperature so that the metal is fully melted. Then the melt is cooled down to a temperature range between the liquid and solid point and material is kept in a semi-solid state. During this stage, the preheated particles are added and thoroughly mixed by using stirrer in the apparatus. The slurry is then heated at high temperature so that slurry is fully turned out to liquid while thorough mixing is ensured by stirrer actuation. This two-step mixing process [8] has been used in the fabrication of aluminium metal matrix composite. stir casting technique is the most economical among other well-established metal matrix composite fabrication methods. For this reason stir casting has turned on to be the most popular commercial viable method of manufacturing AMMCs.

Fig 1.1: Stir casting equipment.

II. EXPERIMENTAL PROCEDURE

2.1 Materials

Aluminium 2024 alloy plates and Tungsten Carbide (Fig 2.1 & 2.2) are the two materials used primarily in this experiment.

2.2 Stir casting Process Parameters.

Operating parameters of stir casting is crucial for manufacturing of metal matrix composite. Improved characteristics can be achieved for each MMC by optimised operation parameters.

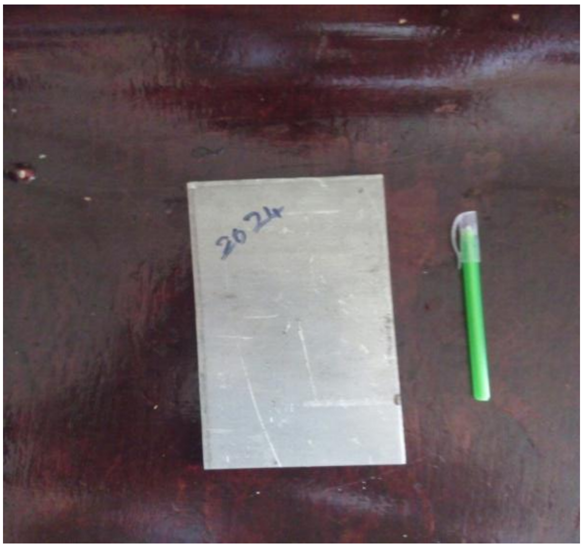

Fig 2.1: Aluminium 2024-metal plate.

Fig 2.2: Tungsten Carbide powder.

Table: 2.1 Chemical composition of Aluminium 2024 (in wt.%) [9].

Fe	Si	Cu	Mn	Mg	Zn	Ti	Cr	Al
0.40	0.41	4.50	0.50	1.50	0.20	0.12	0.07	Balance

A. Stirring speed:-

Stirring speed is the most crucial factor governing the right blending of reinforcement along the metal matrix. Wettability of material can be enhanced by optimum stirring of the composition [10]. The molten material flow pattern is directly influenced by the stirring speed [11]. The parallel flow pattern will do no good for enhancement of properties even with proper composition of reinforcement. Controlled turbulent flow is hence for achieved. Inward to outward directional flow can bring out best flow pattern as well as right properties. Throughout the experiment the rpm was kept constant between 300- 600 rpm. Wettability of composition increases with faster solidification rate [12].

B. Stirring temperature:-

Stirring temperature is really important process parameter. Usually it refers to the melting point of matrix of the system, here it is aluminium. Aluminium generally melts at 650°C. Viscosity of the molten aluminium is affected by processing temperature which is crucial to enhance wettability. The distribution of particulate along the matrix is affected by the viscosity of the matrix [3]. Higher the processing temperature means lower the viscosity of the melt liquid, with increasing holding and stirring time at elevated temperature increase the chance of even distribution of reinforcement [13]. It also accelerates the chemical reaction between reinforcement and matrix. Here the temperature is generally kept at operating temperature which is at 630°C which keeps Aluminium (Al-2024) in semisolid state.

C. Preheat temperature of reinforcement:-

Reinforcement is preheated at a temperature of about 1000°C in order to remove moisture as well as unwanted gas [14]. Preheating enhance the wettability of reinforcement and improve even spreading over the matrix.

D. Stirring span:-

E.

Stirring span is crucial for creating a proper interface bond between matrix and reinforcement[15]. Stirring span is important factor in the processing of particulate composite for even distribution of reinforcement throughout the matrix (The metal flow pattern should be from outward to inward).

F. Blade Angle:-

Number of blades and blade angle is a considerable factor in the case of mixing the reinforcement. Normally blade with angle of 45° or 60° are used for uniform distribution[16]. A clearance of 20mm should be provided between bottom of crucible and tip of the stirrer. Flow pattern of the material is affected considerably by the blade profile or pattern.

G. Inert Gas:-

Molten aluminium react with atmospheric oxygen to form oxide layer at the top layer of the melt. It is hard to machine once the oxide layer is formed. This can negatively affect the properties of the composite mixture. Inert gas like nitrogen should be used to prevent oxidation.

H. Preheating of Mould:-

Primary defects in casting is formation of voids or air gaps which is called porosity. Preheating of mould can reduce the porosity to a considerable amount. This will avoid entrapping of gases within the slurry in the mould. This should obviously elevate the property of AMC [1]. Pouring the molten metal in the properly preheated mould at constant rate can reduce the formation of air bubbles in the composite.

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I. Powder Feed Rate:-

Uniform feed rate of reinforcement powder is advisable to prevent agglomeration of the same. Non uniform feed rate promotes particulate clustering at various places which can result in porosity and inclusion defect [1].

2.3 Preparatory functions

Aluminium 2024 and Tungsten Carbide are procured for desired quantity. Stir casting furnace is switched on for the preheating of furnace[17]. The crucible is heated at 900°C for an hour. The crucible used here is graphite crucible. Sudden heating or cooling of graphite crucible can result in cracking of crucible. For efficient melting and mixing of particulates within the matrix, Al 2024 as well as Tungsten Carbide (WC) is preheated before feeding in to the furnace (Fig 2.3). Tungsten Carbide (200g) is preheated at 1000°C in the electric pre heater for 20 minutes. Aluminium 2024 (997g) is heated at 450°C for 20 minutes. An ideal graphite crucible can be used for casting up to 7 to 8 times. Usually the graphite crucible used can only be used up to 3 to 4 times due to increase in ceramic content. Die is preheated at 500°C for 20 minutes. Die is made of high grade steel material. The slurry can be ensured molten throughout the pouring by this process. Die is preheated in order to attain uniform solidification [18]. If the die is not preheated uneven solidification takes place and crystalline structure and boundary formed will not be as desired.

Fig 2.3: Pre- heating furnace

2.4 Stir casting

In stir casting the reinforcing particulates get distributed into molten matrix by mechanical stirring. Mechanical stirring in the furnace is the key factor in the process [19]. The resultant molten alloy along with ceramic particulates can then be used for die casting, permanent mould casting, or sand casting. For a volume fraction of about 30% stir casting technique is ideal process. Surfacing or settling of reinforcement particle during casting or melting is serious concern. At the end of solidification of material the distribution of particulates along the matrix is guided by process parameters such as stirring parameters, geometry of the mechanical stirrer, melting temperature etc. material properties such as wetting property of the particles with the melt, mixing strength, solidification rate and relative density.

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Fig 2.4: Stir Casting Furnace

Fig 2.4 shows the stir casting apparatus. Placing an empty crucible in the furnace is the first step. It is conical shaped graphite crucible used to cast aluminium based composite since it can withstand higher temperature, which is much more than required temperature [680°C]. Graphite will not react with aluminium at this temperature. Furnace can reach up to 900°C within 45 minute of time span. Liquid aluminium form oxide layer while reacting to atmospheric oxygen. In order to prevent oxidation the melt is kept in isolated chamber filled with inert nitrogen gas.

EN 24 is the stirrer material since it does not oxidise at this temperature in presence of oxygen. Constant feeding rate is provided to prevent agglomeration of particulates. This is achieved by usage of hopper . Aluminium 2024 alloy ingots are preheated and then fed into furnace. Aluminium alloy (AA 2024) is used as Matrix alloy. Desired quantity by weight of aluminium alloy is cut from the raw material. Here 997g of Aluminium 2024 is dropped into the crucible. Aluminium alloy is cleaned to remove dust particles. The preheated aluminium is then poured on to the crucible for melting (Fig 2.5). Here 997g of Aluminium 2024 is placed into the crucible. Aluminium 2024 starts melting at 638°C. Nitrogen gas was the inert medium to create the inert atmosphere around the molten matrix. . Required quantities of reinforcement powder are weighed on the weighing machine. Tungsten Carbide with weight of 200g after preheating at a temperature of 1000°C for 20 minutes is then dropped in to the crucible. It is then the temperature of the system must have reached 760°C.

Once the reinforcement ceramic .i.e. tungsten Carbide is dropped in to the molten aluminium the molten matrix is left undisturbed for two minutes. When matrix was in the fully molten condition, Stirring is started after 5 minutes [20]. The dispersion dwell period is 5 minutes. Using a speed controller the speed rpm of stirrer is increased gradually from 0 to 300. Temperature of the heater is set to 630°C which is below the melting matrix temperature. A partial solid phase was observed throughout the mixture uniformly by using stirrer at constant rpm. Pouring preheated powder reinforcement at uniform rate in the semisolid matrix enhanced the wettability of the reinforcement [21]. This reduced settling of particulates at the bottom [22]. Ceramic particulate was poured with conical hopper manually. The powder was poured approximately at a rate of 0.5 gram/second. After stirring 5 minutes at semisolid phase slurry was then reheated and held at temperature just above 900°C to make sure slurry was fully liquid. Since the melting point of tungsten carbide is way high above 1000°C. So the WC particles remain suspended uniformly throughout the matrix adding to the properties. RPM of stirrer was gradually reduced and stopped. The stir casting apparatus was manually kept side and then molten composite mixture was poured in metallic mould. Preheated mould at temperature 500°C before pouring of the molten composition helped in keeping slurry in molten state throughout the pouring [23]. While pouring the molten mixture in the mould the flow of the same was cautiously kept uniform to avoid trapping of gas to form voids. Then it was quickly quenched in atmospheric air to reduce the chance of settling of particulates. After solidification the die is removed to get the casted plate (Fig 2.6).

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Fig 2.5: Aluminium 2024 sinking and melting inside the crucible inside the furnace.

Fig 2.6: Casted Al(2024)-WC Metal Matrix composite plate

2.7 Post procedure

The casted MMC plate is EDM machined and cut into desired shapes for microhardness and wear tests.

2.8 Micro-hardness test

The casted MMC plate is EDM machined and is cut into dimension of 30mm x20mm x10mm. Vickers diamond is used as hardness testing tool. The tool is used to put load on the work piece along the Y-axis of the work piece which in turn produce impressions at points were load was exerted using the tool. The diameter of impression is measured and hardness is calculated. Hardness is measured in the unit HV [24].

2.9 Wear test

The casted plate is cut into dimension of 30mm x 20mm x 10mm. Wearness tester is the testing machine. The testing is done by pin on disc method. The pin is moved at 1.5m/s at a load of 3Kg at a distance of 2000m at an average temperature of 290K.

III. RESULTS AND DISCUSSION

3.1 Wear test result

From the graph 3.1 it can be inferred that the wear value of base Al 2024 plate is above than that of casted MMC plate. The wear value of composite plate shows a uniform graph with gradual increase along time under constant temperature because of the uniform distribution of cremate particle on the aluminium matrix [25]. The particulate reinforcement in the MMC reduces the wearing effect. Due to the casting of Al 2024 with WC particulates, the intermetalic particulates got dissolved in the matrix medium which resulted in the modification of grain structure. It led to the improvement of wear properties of the composite.

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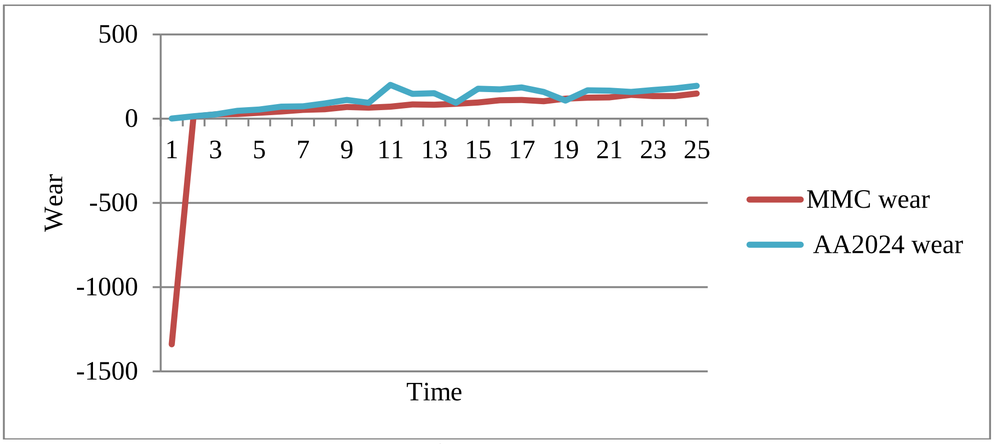

Fig 3.1: Graph of wear test result (Wear/Time).

3.2 Micro-Hardness test results

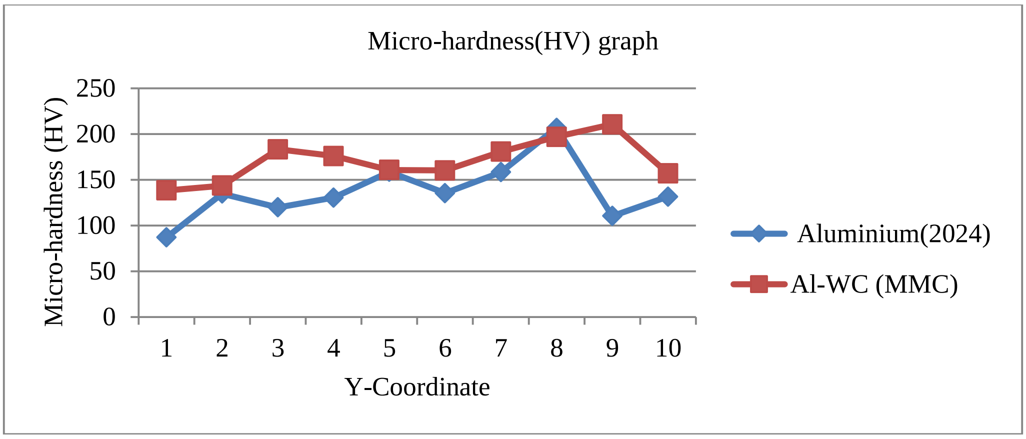

Fig 3.2: Micro-hardness (HV) graph Al(2024) Vs Al-WC(MMC)

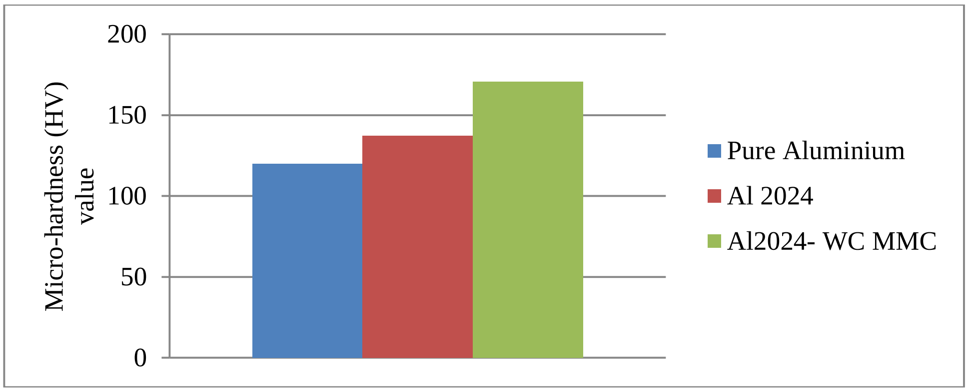

Fig 3.3: Bar chart showing average micro-hardness of pure Al, Al 2024, MMC

From the fig 3.2 it can be concluded that there is an increase in microhardness for the casted Al(2024)-WC MMC than the base plate. Average microhardness of Al base plate is 137.29 while average micro-hardness of MMC plate is 170.72. Figure 3.3 shows a bar chart comparing the average Micro-hardness value of pure aluminium, aluminium 2024 and Al2024- WC metal matrix composite.
MMC has the highest average micro-hardness among the materials surveyed this is because of presence of reinforced WC particles. Al_2Cu particles is get dissolved during the casting process which will lead to the improvement in hardness value.

CONCLUSIONS

The Aluminium 2024 – WC metal matrix composite was casted successfully by stir casting technique. The reinforced particles used here has enhanced the property of the plate. Microhardness and wear property of material has increased compared to the base alloy metal. The stir casting technique has proved to be best technique to cast the MMC with particulate reinforcement. Stir casting technique is best way for distribution of particulates within the material matrix. The property can even be increased by Friction stir processing of casted material [26].

Metal matrix composites (MMCs) casted with reinforcement particulate consist of a low-density metal aluminum reinforced with particulate ceramic material i.e . Tungsten Carbide. Compared with alloy metals, MMCs offer higher specific strength and stiffness, greater wear resistance higher operating temperature and opportunity to tailor these properties for a particular application.

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