Characterization of WO_3 Particulate Reinforced Al-3Mg-3Zn Metal Matrix Composite

Pradeep Khutle[1], Anit Kumar Jaiswal[2]

[1]*Student, Department of Mechanical Engineering, Chouksey Engineering College, Bilaspur, Chhattisgarh, India*
[2]*Assistant Professor, Department of Mechanical Engineering, Chouksey Engineering College, Bilaspur, Chhattisgarh, India*

Abstract - *The life of the slurry pump casing is reduced due to corrosion and abrasion by abrasive particle in slurry. In the present study, an attempt has been made to fabricate Al-3Mg-3Zn/WO_3-p metal matrix composites (MMCs) by two step stir casting method and analyzing their properties. 5XXX wrought aluminium alloys series is the highest strength non-heat-treatable aluminium alloy. This series is a marine application alloy which has high stress corrosion resistance property. 7XXX wrought aluminium alloys series is the highest strength aluminium alloy. This series has aerospace application due to very high strength to weight ratio. Al-3Mg-3Zn the combined grade of 5xxx and 7xxx Al alloy series. The Al-3Mg-3Zn reinforced with the 2 and 4 wt. % WO_3 particulates by using cost effective two step stir casting technique to enhance the mechanical and tribological properties. WO_3 particles also impart improved shielding property. The hardness, impact toughness and dry sliding wear test were carried out on the fabricated Aluminium Metal Matrix Composites (AMMCs) according to ASTM standards. The results show that the hardness and wear resistance properties are increased with increase in the wt. % of the WO_3 particulates on the Al-3Mg-3Zn matrix but the toughness was decreased.*

Key Words: AMMC, Composite, Wear, Hardness, Impact.

1. INTRODUCTION

The term composite material refers to the combination of two or more materials on a macroscopic scale to create a useful third substance [1]–[10]. A composite is a structural substance made up of two or more coupled elements that are not soluble in each other on a macroscopic level. The reinforcing phase is one of the constituents, while the matrix is the one in which it is embedded. Fibers, particles, or flakes can be used as reinforcing phase material. Materials in the matrix phase are usually continuous [5], [9], [11] The matrix phase is a more ductile and less hard phase that retains the reinforcing phase and shares a load with it. The reinforcing phase, also known as the scattered phase, is a discontinuous phase embedded in the matrix that is generally stronger than the matrix. The composite material is a mixture of materials with a distinct composition, in which the individual elements retain their own identities and operate together to provide the composite part the required mechanical strength or stiffness [12]. Metal, which is frequently ductile, is the matrix phase of a metal matrix composite. These composites are utilized in sectors such as automotive and aerospace because of their high strength-to-weight ratio, strong resistance to abrasion and corrosion, resistance to creep, good dimensional stability, and high temperature operability [13]. Cast iron and steel might replace by Al and Mg alloy, but as compare to cast iron and steel the cost of aluminium and magnesium alloys are more. Cast aluminium and magnesium components are potentially less expensive to manufacture due to their better machinability, reduced manufacturing cycle times, ability to have thinner and more variable wall dimensions, closer dimensional tolerances, reduced number of assemblies, and more easiness of assembly when compared to cast irons and steel. Wrought aluminum and magnesium components, on the other hand, are nearly always more expensive to manufacture than their ferrous equivalents [14]. Mostly, aluminium is used as the metal matrix. Various researchers are investigated the mechanical properties of AMMCs. Previtali et al. (2008) performed the wear test with A359 + 1% Mg (without reinforcement), Al/20% SiC and Al/7.5% B_4C. It can be determined that the Al/20% SiC AMMC has a uniform and homogeneous distribution of reinforcing particles, a healthy interface with the absent of brittle connections and the resistance to wear is higher than that of the AMMC with B_4C reinforced particles, the composite materials with ceramic reinforcement of SiC or B_4C have a similar value of the hardness. To improve the wettability of the carbide particles, 1% Mg was added to the original A359 composition. [15]. Sujan et al. (2014) examined the performance of metal matrix compounds and Al reinforced with Al_2O_3, SiC (5%, 10%, and 15%). They found that the coefficient of thermal expansion and density of Al-MMC reinforced with Al_2O_3 have higher values compared to Al-MMC reinforced with SiC. Al/SiC composites have relatively higher hardness, strength in tension and wear resistance compared to Al/Al_2O_3 composites. The wear rate increases with rising grinding speed [16]. Shorowordi et al. (2003) carried out a comparative study with three different ceramic particles Al_2O_3 (32 μm), SiC (40 μm), and B_4C (40 μm) as reinforcement in a pure aluminum matrix (99.99) in the stirring process. The distribution of the B_4C particles is better compared to the SiC particles and Al_2O_3 particles in the Al matrix. The B_4C reinforced Al matrix exhibits better interfacial adhesion compared to two other composite materials. In Al-SiC compounds, at the interface of matrix and the reinforcement, a reaction product was found after prolonged processing, but no reaction product was noted in the case of the Al-B_4C and Al-Al_2O_3 interfaces [17]. Patel et al. (2019) worked on the evaluation of the properties of hardness, toughness and resistance to sliding wear after replacing the content of Zn with SiC in Al5Mg5Zn / 3WO_3 MMC. They found that the hardness and wear resistance properties improved after the Zn content was replaced by SiC, but the toughness decreased. [18]. Patel et al. (2020) characterized the Brinell hardness, impact resistance and resistance to sliding wear of Al5Mg5Zn /WO_3 AMMC. MMC is made by the stir casting process using 3% by weight of the WO_3 particle reinforcement. They notified that the hardness and wear resistance properties were improved by adding 3% by weight. % of WO_3 particles in Al5Mg5Zn matrix, but impact resistance was reduced [19]. Hence, the effect of wt. % of WO_3 on the mechanical properties is need to investigate. This research work deals with the evaluation of the 2 and 4 wt. % of WO_3 reinforcement on the mechanical properties i.e. hardness, wear resistance and impact toughness of the Al-3Mg-3Zn.

2. MATERIALS AND METHODS

The work materials chosen for experimental studies according to literature survey are the combination of 5xxx Al alloy (in which Mg is the principal alloying element) due to its corrosion resistance property and 7xxx Al alloy (in which Zn is the principal alloying element) due to its high strength to weight ratio are chosen for the matrix material. The 5xxx aluminium alloys series is the highest strength non-heat-treatable aluminium alloy. This series is a marine application alloy which has high stress corrosion resistance property [20]. Mg contents in the aluminium alloy also increase the wettability and distribution of the reinforcing particles in the aluminium alloy matrix and also increase the mechanical properties [21]. For present study the 3wt. % of Mg and 3wt. % of Zn are used to make Al-3Mg-3Zn matrix. For making two samples of aluminium MMC two step stir casting technique is used. In sample-I pure aluminium (≥99.6 wt. % Al) with 3 wt. % of magnesium (Mg) and 3 wt. % zinc (Zn) aluminium alloy matrix is reinforced with 2 wt. % tungsten trioxide (WO_3) and in sample-II pure aluminium (≥99.6 wt. % Al) with 3 wt. % of magnesium (Mg) reinforced with 3 wt. % of zinc (Zn) aluminium alloy matrix is reinforced with 4 wt. % of tungsten trioxide (WO_3). The particle size of tungsten trioxide (WO_3) is varies from 5μm-40μm. The chemical compositions of these two samples are shown below in the table 1.

For composites, the route used for casting is the two-stage stir-casting process. This is a method of manufacturing composite materials in a fluid state in which a dispersed phase is mixed with a matrix of molten metal by stirring. Stir casting is the easiest & most economical manufacturing method in the liquid state [7], [22]–[24]. In the present work, this two-step stir casting technique is utilized for the fabrication of the particulate reinforced aluminium MMCs. In this process, the particles are mixed into the melt of the aluminum alloy with the help of the mechanical stirrer and then the material is allowed to solidify in the mold under normal ambient conditions. With this technique, the required amount of aluminum was collected in the Gr crucible and melted in an electric furnace at 800 ° C. The powders of reinforcement with alloying elements were charged to the melted Al before the stirring process. During stirring process, the impeller was kept approximately at a distance of 2/3rd in the melt, so that the melt should not be thrown upward which will increase the porosity of the composite. For better mixing of reinforcing particle the composite slurry was mechanically stirred upto cooled at semi-solid state to ensure the homogenous distribution of particulate in the melt. Then again put it in the furnace for melting in liquid state. The composite slurry is again stirred and then melt was transferred to the metal mould of cast iron of dimension 300×75×15 mm^3 and one another cylindrical mould of cast iron with dimension 10 mm diameter with 300 mm length. and then allowed solidifying at room temperature. The two samples were prepared by using tungsten trioxide (WO_3) as reinforcement for Al-3Mg-3Zn Al alloy

Table: 1 Chemical compositions of the samples of aluminium alloy metal matrix composites

Sample No.	Matrix Material (wt. %)			Reinforcement Material (wt. %)
	Mg	Zn	Al	WO_3
Sample-I	3	3	Bal.	2
Sample-II	3	3	Bal.	4

2.1 Hardness Test

The hardness of a material surface refers to its resistance to abrasion, scratching, and cutting. The hardness tests performed on the aluminium alloy reinforced with 2 wt. % tungsten trioxide (WO_3) composite material as sample-I and aluminium alloy reinforced with 4 wt. % tungsten trioxide (WO_3) composite material as sample-II specimens on a Brinell hardness testing machine (Model No. ALZ B187.5, SR. NO. 56). The specimens were metallographically polished by P800 sand paper for conducting the hardness test. A mechanically defined force is exerted on the sample for approximately 30 seconds. The Brinell hardness tester included a main screw, loading system, and a dial gauge. These aluminium alloy metal matrix composites are frequently tested by using an indenter, which is a steel ball of 5mm Diameter (D) under a load 60 kgf (P) applied into the specimen. For a known time and measuring under the microscope the mean diameter (di) of the indentation remaining on the surface after the load is removed. Measurements were taken at various points on each sample to assess its reproducibility. The BHN is obtained by-

$$\text{BHN}=\frac{2P}{\pi D(D-\sqrt{D^2-di^2})}$$

Where; BHN (kgf/mm^2) is Brinell Hardness Number, P = kilogram-force applied load (kgf), D is the indenter's diameter (mm), di = indentation diameter (mm).

2.2 Charpy Impact Test

The work required to rupture a test specimen is measured in impact energy. The impact test is a way of determining the engineering materials' toughness. This test is most commonly used to assess the toughness of metals, although it can also be used to assess the toughness of polymers, ceramics, and composite materials. An impact pendulum of already known mass & length is released from a known height to impact a notched sample of material in the charpy impact test equipment. It is a dynamic test in which a test specimen with a V-notch in the middle and supports at both ends is broken by a single hit from a freely swinging pendulum or hammer. The transfer of energy to the material at the time of blow can be measured by comparison between the height difference of the blow hammer before & after the standard specimen fracture. This energy absorption is a measure in terms of impact toughness, which is indicated by friction pointer on the scale. This test was conducted as per ASTM E23 on the fabricated AMMCs. The standard size dimension of the specimen is 55mm×10mm×10mm with V-notch of 2mm at 45° in the middle of the specimen.

2.3 Dry Sliding Wear Test

The wear characteristics of the prepared composites is analysed by dry sliding wear test carried out using pin-on-disc wear test machine (Ducom Instruments, Product-Pin on Disk, SL NO. – 556, W.O. - 1271, Bangalore, India). The sliding wear test has been done as per ASTM G-99 standard. This test conducted on cylindrical specimens of 10 mm diameter and 30 mm long with flat end, against a 65 HRC rotating steel disc. Test pins or specimens were ground to a smooth finish on 800 grit sand paper. The track was thoroughly cleaned with acetone before each test. All of the wear tests were carried out on the new wear tracks to ensure that the test circumstances were equivalent. Wear tests were conducted for 10 min at room temperature with applied load of 20N and 350rpm, the wear track diameter is chosen 100mm for each sample.

An electronic weighing equipment with an accuracy of 0.00001 g was used to measure the initial and final weight of the specimens of sample-I and sample-II. Weight loss was determined by the difference in mass before & after the test. The WR of cast composite samples was investigated as a function of applied load, sliding distance and sliding velocity. The wear rate was determined using the equation below based on the difference in mass of the specimens.

$$WR=\frac{\Delta h\times a}{d}$$

Where; WR = wear rate (mm^3/m), Δh = change in height during test (mm), a = contact area of test pin (mm^2), and d = distance of sliding during test (m),

3. RESULTS AND DISCUSSION

3.1 Hardness

Brinell hardness test performed at the five different point of each test sample of the prepared AMMC. The BHN at 5 different points of the sample-I and sample-II are showing in table 2 and table 3 respectively.

Table: 2 BHN values at five different points of sample-I (Al-3Mg-3Zn/2WO_3 MMC)

No. of Test Point	**1**	**2**	**3**	**4**	**5**
Indentation dia. (mm)	0.99	0.98	0.99	0.95	0.96
BHN (kgf/mm^2)	77.17	78.77	77.17	83.87	82.12

Table: 3 BHN values at five different points of sample-II (Al-3Mg-3Zn/4WO_3 MMC)

No. of Test Point	**1**	**2**	**3**	**4**	**5**
Indentation dia. (mm)	0.95	0.94	0.93	0.96	0.95
BHN (kgf/mm^2)	83.87	85,69	87.56	82.12	83.87

The average hardness of sample-I (Al-3Mg-3Zn reinforced with 2 wt. % WO_3) has been found 79.82 BHN and average hardness of sample-II (Al-3Mg-3Zn reinforced with 4 wt. % WO_3) has been found 84.62 BHN. It is noted that when increasing the WO_3 particulates wt. % in the Al-3Mg-3Zn matrix, then the BHN value increases.

3.2 Impact Toughness

Charpy impact test of sample-I and sample-II specimens as per ASTM 23 standard have been done. Fig. 1 shows the impact toughness of the sample-I and sample-II. It observed that the impact toughness of sample-II has less value as compare to the sample-I. It means the addition of the WO3 particulates reduced the impact toughness of the fabricated AMMCs due to increase in the brittle nature of the samples.

3.3 Wear Resistance

The sliding wear experiments were performed using Pin-on-Disc wear tester and test samples were slides on EN32 steel disc. This wear behaviour of the fabricated AMMCs is represented in the form of wear rate. The ASTM G99 standard specimens of the sample-I and sample-II are tested under load of 20 N; 100 mm wear track diameter and sliding distance of 1.1 km. The graph of dry sliding wear test for the sample-I and sample-II is shown in Fig. 2. The weight loss during this test is shown in table 4. Table 5 illustrate the wear rate of test samples, it is reveal that the wear rate and weight loss of the sample-I is greater than the sample-II due to large no. of hard WO_3 particles in sample-II.

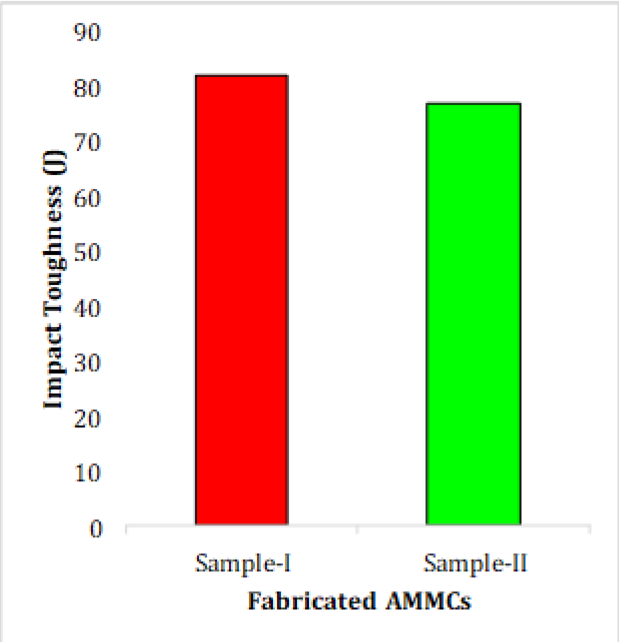

Fig. 1 Impact toughness of fabricated AMMCs

Table: 4 Wight loss during dry sliding wear test

Sample	Weight before wear test (mg)	Weight after wear test (mg)	Weight loss (mg)
Sample-I	6537.20	6286.10	251.10
Sample-II	6615.25	6412.51	202.74

Sample	Height change Δh(mm)	Pin area a (mm^2)	Sliding distance d (m)	Wear rate WR (mm^3/m)
Sample-I	1.149	78.54	1100	0.082
Sample-II	0.912	78.54	1100	0.065

Table: 5 Wear rate of samples

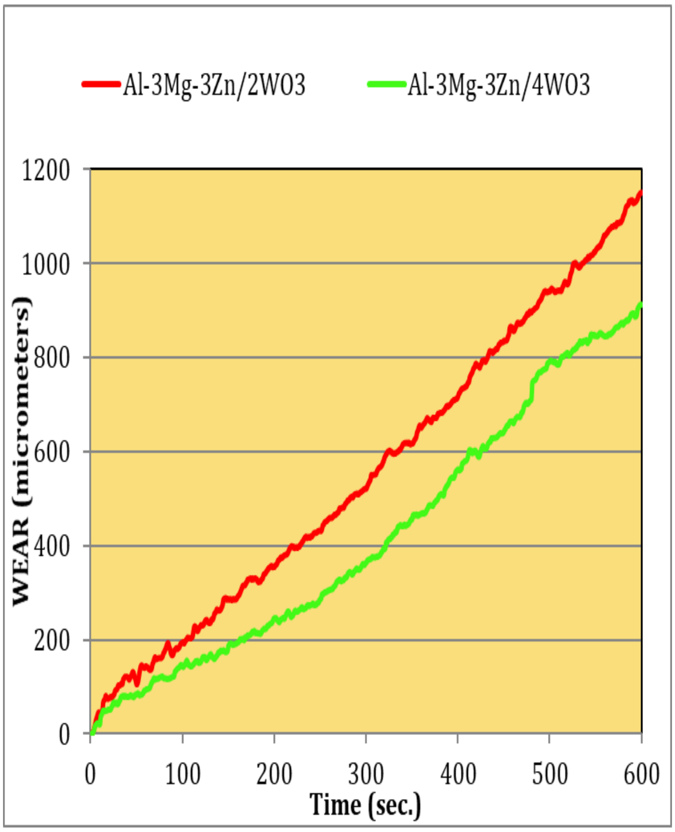

Fig. 2 Wear of the fabricated AMMCs

4. CONCLUSIONS

From this present study following points are concluded:

1. 2 wt. % and 4 wt. %WO_3 particulates reinforced Al-3Mg-3Zn AMMCs have been synthesized by cost effective and simple two steps stir casting method.
2. The hardness of the 2 wt. % WO_3 reinforced Al-3Mg-3Zn MMC has been realized at **79.82 BHN**, against at value of **84.62 BHN** obtain for the 4 wt. % WO_3 reinforced Al-3Mg-3Zn MMC. It shows increase in hardness with increase in the WO_3 content in Al-3Mg-3Zn.
3. The impact strength of 2 wt. % WO_3 reinforced Al-3Mg-3Zn MMC has been realized at **82 Joule**, against at value of **76.7 Joule** obtain for the 4 wt. % WO_3 reinforced Al-3Mg-3Zn MMC. It shows decrease in impact toughness value with increase in the WO_3 content in Al-3Mg-3Zn.

4. The wear rate of 2 wt. % WO_3 reinforced Al-3Mg-3Zn MMC has been realized at **0.082mm³/m**, against at value of **0.065 mm³/m** obtain for the 4 wt. % WO_3 reinforced Al-3Mg-3Zn MMC. It shows decrease in wear rate with increase in the WO_3 content in Al-3Mg-3Zn.
5. The wear resistance and hardness of the Al-3Mg-3Zn matrix improve with the increases in weight percent of WO_3 particulates reinforcement but the impact toughness property decreases.

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