Evaluation of Hardness, Toughness and Sliding Wear Resistance after Replacing Zn into SiC in Al5Mg5Zn/3WO_3-p Metal Matrix Composite

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Abstract — **The present era is the modern era in which Al Metal Matrix Composite (MMC) plays an important role as compared to conventional materials. In this research work 5 wt. % Zn present in Al-5Mg-5Zn + 3 wt. WO3 particulate reinforced Al Metal Matrix Composite is replaced with 5 wt. % SiC particulates and fabricated the Al-5Mg + 3 wt. % WO3 + 5 wt. % SiC hybrid MMC. To fabricate these particulate reinforced Al MMC, two step stir casting method is used. The stir casting route is simplest and most cost effectiveness method for liquid state processing. Hardness, impact toughness and dry sliding wear of the developed MMCs are investigated by following ASTM standards of the tests. The results show that by using SiC particulate instead of Zn improved the hardness value of the MMC but decrease the values of impact toughness, weight loss, sliding wear rate and volumetric wear rate. This advance material have many application i.e. satellite & helicopter structures, static and rotating components of engine and compressor blade due to its wear resistance with lightweight properties.**

Keywords* — *Hardness, Impact toughness, MMC, SiC, Wear, WO_3.

I. INTRODUCTION

At the present time, Metal Matrix Composite (MMC) is the most advanced and flexible engineering material. This is produced by the macroscopic assembly of reinforcement and matrix materials. MMCs have very good combination of mechanical, tribological as well as corrosion resistance properties [1]–[5]. Al MMCs provides good combinations of strength to weight ratio and it has been used for lightweight applications like aerospace, automobiles [6]–[8]. Rolling, forging and extrusion process can be applicable in particulate reinforced Al MMCs, which enhanced its mechanical properties. Particulate reinforced Al MMCs also provides isotropic property in nature [7], [9].

Y. C. Feng, L. Geng, P. Q. Zheng, Z. Z. Zheng, and G. S. Wang [6] have fabricated and characterize the Al-based hybrid composite reinforced with tungsten oxide particle and aluminum borate whisker. They found that WO_3 possess good photo absorbability which can be applied as a radiation protection material. This hybrid composite provides improved ultimate tensile strength, yield strength & modulus. Y. C. Feng, L. Geng, G. H. Fan, A. B. Li, and Z. Z. Zheng [10] have evaluated the mechanical properties and microstructure of hybrid composites. In this hybrid composite WO_3 particles used for radiation absorber and ABO whiskers used to improve the mechanical properties. They noted that when the particle/whisker ratio decreases then the ultimate tensile strength and elongation of composites increase. This hybrid composite possesses good mechanical properties as well as good radiation shielding properties. M. M. Hasan, A. S. M. A. Haseeb, and H. H. Masjuki [11] also worked on the structural and mechanical properties of nanostructured tungsten oxide thin films. They found the improved scratch hardness and wear resistance properties in the case of tungsten oxide thin film coating on the glass at different temperature. T. Sangpraserdsuk, M. Phiriyawirut, P. Ngaotrakanwiwat, and J. Wootthikanokkhan [12] have investigated the mechanical properties of tungsten trioxide reinforced polycarbonate

 DOI : 10.35291/2454-9150.2019.0179

composites, they observed the tensile strength and modulus of the composites are increase upto 2 % WO_3 reinforcement, beyond this limit these properties are decrease.

B. Venkataraman and G. Sundararajan [13] have reported the sliding wear rate and the coefficient of friction (COF) of SiC-p reinforced AMMCs. They also found the wear resistances of AMMCs are superior to the Al matrix and this property increases with increase in volume fraction of SiC-p, but the corresponding effect on COF is only marginal. I. M. El-Galy, M. H. Ahmed, and B. I. Bassiouny [14] have observed in the range 7.5-10 wt. % SiC-p, maximum improvement of wear resistance could be achieved. The improvement in wear resistance with increase in SiC-p content in Al matrix is also found by S. Pradhan, T. K. Barman, P. Sahoo, G. Sutradhar [15] and T. B. Rao [16].

The functionally graded centrifugal cast Al/SiC-p MMCs fabricated and characterized by I. M. El-Galy, M. H. Ahmed, and B. I. Bassiouny [14]. They observed in the cast tubes, SiC-p concentrations and hardness in the outer zone reach its maximum value and followed by a gradual decrease in concentrations and hardness in the direction of inner diameter. With increase in wt. % of SiC-p, proportionally increase in outer zone hardness but beyond 10 wt. % SiC-p the increasing rate is decreases slightly. They found that the ultimate tensile strength is proportional to the percentage of SiC-p and inversely proportional to the size of the particles. T. B. Rao [16] has done an experimental investigation on mechanical properties of Al7075/SiC-p MMC and he also found that by increase in SiC-p size and wt. % considerably enhanced the tensile strength and hardness of the AMMC but the ductility of the AMMC is decreased. M. Patel, B. Pardhi, M. Pal, and M. K. Singh [17] also gives the detailed review on SiC reinforced MMC, according to this review SiC improved the mechanical as well as tribological properties of the Al and Al alloys.

In this study the Brinell hardness, charpy impact toughness and dry sliding wear properties of Al5Mg5Zn + $3WO_3$ MMC and Al5Mg + $3WO_3$ + 5SiC hybrid MMC have been investigated and compared their results.

II. EXPERIMENTAL STUDIES

A. Materials and Methods

The combination of 5xxx and 7xxx series of Al alloy (Al5Mg5Zn) has been chosen as a matrix material and 3 wt. % WO_3 (avg. particle size of 23μm) has been used as a reinforcement material for MMC-I. WO_3 is used for the gas sensors, x-ray screen phosphors as well as for fireproofing fabrics. In MMC-II, 5 wt. % of Zn in alloy matrix is replaced with 5 wt. % of SiC particulates to determine its effect on the mechanical and tribological properties of MMC-I. So the MMC-II is a hybrid composite which is composed of Al5Mg+$3WO_3$+5SiC. Presence of Mg in the Al alloy increase the wettability as well as distribution of the reinforcement particulates in the Al alloy matrix [18]. In this work, two-step liquid state stir casting processing route is used for the development of MMC-I and hybrid MMC-II. Firstly to fabricate MMC-I, 87 wt. % Al, 5 wt. % Mg and 5 wt. % Zn was taken in a clay-graphite crucible and melted it at 800˚C in electric resistance furnace for 2 hours. The dross product formed and floating over the molten alloy was removed, after that the melted alloy was cooled at the semi-solid state and then the 3 wt. % of WO_3 particles was added in alloy matrix. With the help of mechanical stirrer, reinforcement particulates were mixed in alloy matrix. After that the composite slurry was reheats at 800˚C for half an hour then again stirring was continued for 10 min. at 350 rpm to ensure the homogenous distribution of the particulate in the molten alloy. Then the composite slurry was transferred to the permanent cast iron mould of required shape and then allows solidifying at room temperature. To fabricate MMC-II, 87 wt. % Al, 5 wt. % Mg was melted same as MMC-I but it is reinforced with 3 wt. % of WO_3 particulates and 5 wt. % of SiC particulates and follow the same procedure as followed to develop MMC-I. The setup of stir casting and casted cylindrical pin samples are shown in Figure 1 and Figure 2 respectively.

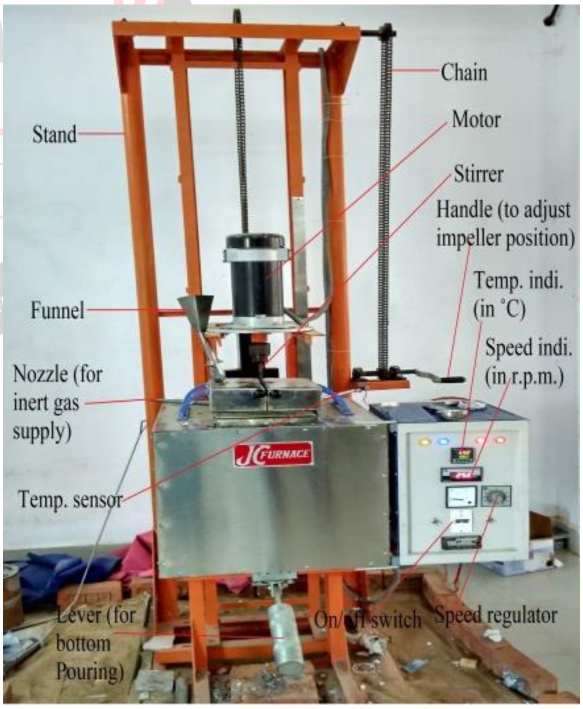

Figure 1 Setup of stir casting furnace

Figure 2 Casted cylindrical pins of MMC

 DOI : 10.35291/2454-9150.2019.0179

B. Hardness Test

For the Brinell hardness test of the developed MMC specimens were metallographically polished by P800 grade emery paper and cleaned with acetone. A definite force (P) of 60 kgf is applied on the specimen for 30 seconds. The steel ball indenter of 5 mm diameter (D) has been used for this test. The mean diameter (d) of the impression left on the surface after removal of the applied load is measured by using microscope. Measurements were taken at five different points of each sample of MMC-I and MMC-II to assess its reproducibility. The specimen before and after hardness test are shown in Figure 3. The Brinell Hardness No. (BHN) is calculated by using equation (1).

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \quad (1)$$

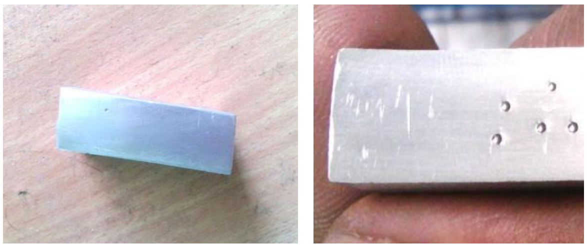

Figure 3 Sample before and after Brinell hardness test

C. Charpy Impact Toughness Test

Impact toughness of the developed MMCs was investigated by doing Charpy impact test of the prepared test sample according to ASTM E23. The Charpy impact test performed on the prepared test samples at room temperature. The test sample has broken by a single blow of freely swinging pendulum or hammer. The energy transferred to the material during blow was indicated by friction pointer on the scale. The absorbed energy indicated on the scale is a measure of the impact toughness of the developed compositions. The test samples before and after Charpy impact test are shown in Figure 4.

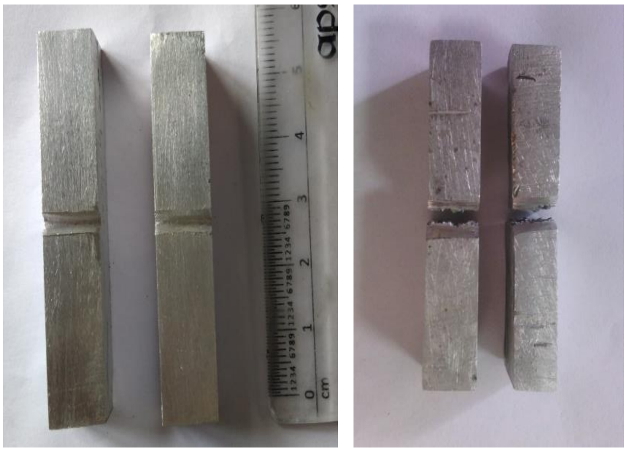

Figure 4 Charpy impact test samples of MMC-I and MMC-II before and after test

D. Dry Sliding Wear Test

The wear behaviour of the MMC-I and MMC-II is analysed by using computerized pin-on-disc wear tester as shown in Figure 5. The test was conducted as per ASTM G-99 standard. Wear test was conducted on 10 mm diameter and 30 mm long cylindrical pin of the developed MMCs against a rotating EN-32 steel disc having hardness 65 HRC. Test specimens were ground to a smooth finish on 800 grit emery paper before conducting the test. Before each test, the track was properly cleaned with acetone. Wear tests were conducted at room temperature with applied load of 20N and at 350 rpm for 20 min., the wear track diameter is chosen 100 mm for each test sample. The weight loss (Δw), sliding wear rate (S_{wr}) and volumetric wear rate (V_{wr}) of the test samples were calculated by using equation (2), (3) and (4) respectively.

$$\Delta w = w_b - w_a \quad (2)$$

$$S_{wr} = \frac{w_b - w_a}{S_d} \quad (3)$$

$$V_{wr} = \frac{A \times \Delta h}{S_d} \quad (4)$$

Where 'w_b' is weight of the sample before test in g, 'w_a' is the weight of the test sample after test in g, 'S_d' is the sliding distance in m, 'A' is the cross sectional area of the test sample in mm^2 and 'Δh' is the change in height of the pin during test in mm.

Figure 5 Pin-on-Disc dry sliding wear test of developed MMC

III. RESULTS AND DISCUSSION

A. Hardness Test

Brinell hardness test has been done on the sample of the developed MMCs. The values of Brinell Hardness Number (BHN) at five different points of the MMC-I and MMC-II are listed in Table 1 and compare their avg. BHN values. The average hardness of $Al5Mg5Zn+3WO_3$ named as MMC-I have been found 98.28 BHN. Average hardness of $Al5Mg+3WO_3+5SiC$ named as MMC-II have been found 103.92 BHN which is 5.7% higher than the avg. hardness of

 DOI : 10.35291/2454-9150.2019.0179

ISSN : 2454-9150 Vol-05, Issue-03, June 2019

the MMC-I. Hence it is observed that when replacing the Zn content present in the Al alloy matrix of MMC-I composite by SiC particulates and making a hybrid composite or MMC-II then we gets addition of SiC particulates enhanced Brinell hardness value. This is due to the high hardness of SiC particulates reinforcement and its good bonding with the alloy matrix. It may also be concluded that SiC particulates impart higher hardness as compared to Zn.

Table 1 BHN values at five different points of the test sample of MMC-I and MMC-II

Composition	Brinell hardness no. (BHN)					Avg. BHN
MMC-I	105.3	101.8	104.5	104.6	103.4	103.92
MMC-II	98.8	95.4	93.5	104.9	98.8	98.28

B. Impact Toughness Test

Charpy impact test of MMC-I and MMC-II specimens have been done as per ASTM 23 standard. Figure 6 shows the results obtained from charpy impact toughness test, it is noted that the impact toughness of Al5Mg5Zn+WO_3 MMC or MMC-I has higher toughness value as compare to the Al5Mg+3WO_3+5SiC MMC or MMC-II. Hence it is observed that the addition of same amount of SiC instead of Zn in the alloy matrix decreases the value of impact toughness. This is because of the brittle nature of the SiC as compared to Zn due to high hardness of SiC, which decreases the ductility of the alloy matrix. The impact toughness of the MMC-I is decreases upto 27.5 % due to replacement of Zn into SiC particulate.

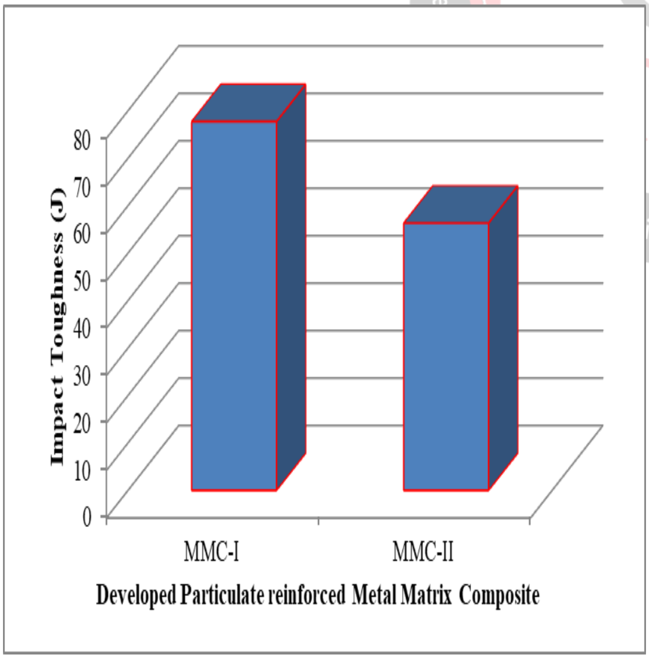

Figure 6 Impact toughness of the developed MMCs

C. Sliding Wear Test

The ASTM G99 standard specimens of the MMC-I and MMC-II are tested on pin on disc wear tester and the obtained weight losses, sliding wear rate and volumetric wear rate during dry sliding wear test are shown in Figure 7 Figure 8 and Figure 9 respectively. The weight loss, sliding wear rate and volumetric wear rate of the hybrid MMC-II is 2%, 7% and 7% lesser than the MMC-I. Hence sliding wear resistance increases more with the addition of SiC instead of Zn. This is due to the high strength bonding between hard SiC particulates with Al-Mg alloy matrix. The distributed SiC and WO_3 particulates between the matrix increase the wear resistance of the MMC due to their high hardness and well bonding with the matrix material.

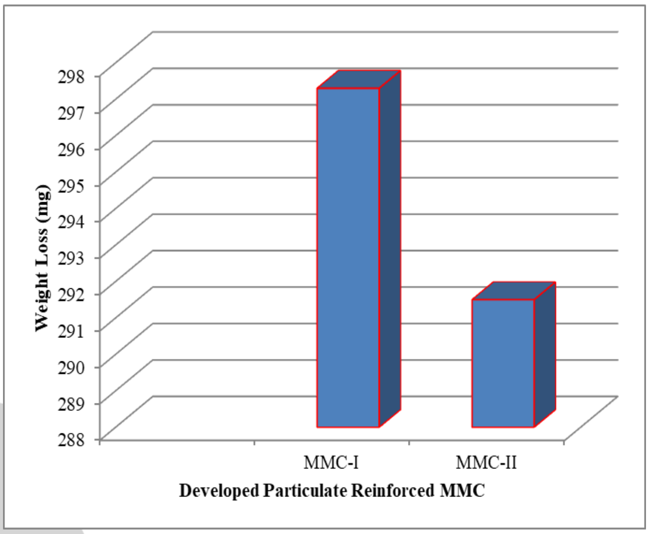

Figure 7 Weight loss of developed MMC during dry sliding wear test

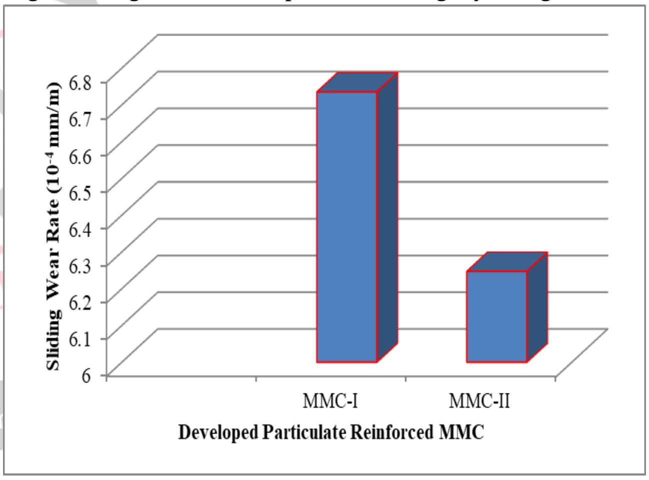

Figure 8 Sliding wear rate of developed MMC during dry sliding wear test

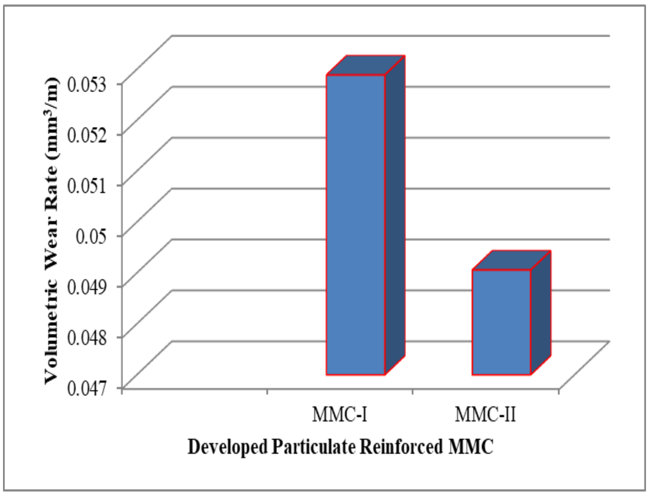

Figure 9 Volumetric wear rate of developed MMC during dry sliding wear test

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IV. CONCLUSIONS

In this study, Zn present in the matrix of Al-5Mg-5Zn + 3 wt. % of WO_3 particulate reinforced MMC or MMC-I is replaces with same amount of SiC and developed Al-5Mg+ 3 wt. % of WO_3 + 5 wt. % of SiC particulate reinforced hybrid MMC or MMC-II by two step stir casting method. The mechanical and tribological properties i.e. Brinell hardness, Impact toughness, weight losses during wear test, dry sliding wear rate and volumetric wear rate of the MMC-I and MMC-II have been investigated and compared. From this research the followings are concluded:

1. Due to the addition of 5 % SiC particulate instead of 5 % Zn, the value of Brinell hardness no. is increased upto 5.7 %.
2. Sliding wear rate and volumetric wear rate of MMC-II decrease upto 7 %, as compared to the MMC-I.
3. Weight loss of MMC-II is decreases upto 2 % and impact toughness decreases upto 27.5 % as compared to the Al-5Mg-5Zn + 3 wt. % WO_3 MMC or MMC-I.

These are due to the good bonding between the hard SiC particulates and Al-5Mg matrix.

ACKNOWLEDGMENT

The authors are highly grateful to the Director and all the faculty members of the Department of Mechanical Engineering of National Institute of Science and Technology, Berhampur, Odisha, India for providing the experimental facilities for this research.

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