Mechanical Characterization and Experimental Investigation on ZA27/SiCp Metal Matrix Composite

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ABSTRACT: In the present work silicon carbide reinforced zinc aluminium-27 metal matrix composite is fabricated by stir casting method. Composite with different compositions are prepared by varying weight percentage Silicon carbide (from 0% to 6% weight). This work is carried out to investigate the effect of filler material on the mechanical properties composite like hardness, impact strength, yield strength and ultimate tensile strengths and also know the effect of load and sliding speed on wear volume using wear test.

Keywords : ZA27/SiCp, sliding speed, wear volume, mechanical properties.

1. INTRODUCTION

Composite is a material, which is a combination of two or more distinct materials. In which, one of the materials is called reinforcing phase, which is present in the form of particles, fibers or whiskers. Which are embedded in the other material system (Base material) is called matrix phase. The main function of matrix material is to transfer stress between the reinforcing fibres/particles and protecting them from mechanical/environmental damages. Meanwhile improving mechanical properties such as strength, stiffness etc is the main function of reinforcing phase. Therefore the composite is a synergistic combination of two or more constituents which differ in both chemical and physical forms. Also they are essentially insoluble in each other. Composite materials are successfully replaced the traditional materials in several light weight and high strength applications. The reasons behind the selection for such applications are their high strength to weight ratio, high tensile strength at elevated temperatures, high toughness, and high creep resistance. In a composite, the reinforcing materials are strong with low densities, while the matrix materials are usually tough/ductile material. If the composite is fabricated in a proper way, it combines the strength of the reinforcing material with the toughness of the matrix material to reach the goal of obtaining desired properties in a single material, which is not available in a single traditional material. In the present work, Zinc-aluminium-27 alloy i.e. ZA-27 is used as the matrix material. Zinc-aluminum alloys 8, 12, and 27 comprises a new family of zinc casting alloys, they have proven themselves in a wide variety of applications. Silicon carbide (filler) is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice.

Chawla et al., [6] have reported that the incorporation of particle in the matrix and increase in volume fraction of the reinforcement improve the tensile strength, and elastic modulus but at the cost of ductility. With increase in volume fraction more load gets transferred to reinforcement which leads to increase in ultimate tensile strength, the work hardening rate increases with increase in volume fraction and lower ductility can be attributed to void nucleation with increased amount reinforcement and cracked particle in the composite because of processing of composite.

Abdizadeh et al., [7] found that with increase in zircon content and increase in sintering temperature the hardness of the metal matrix composite increases. With random distribution of zircon particles they agglomerate in a region and would not change during sintering with increase in zircon content and the direct contact between these regions causes weak binding between the boundaries and thus reduces the strength of the composites.

Seenappa et al., [8] found that hardness, tensile strength, yield strength and density increases with increase in copper content but impact strength decreases after 2 wt% of copper. The result showed that with increase in reinforcement content the ultimate tensile strength, yield strength and hardness of the composite increase while the ductility of the composite decreases. Increase in hardness was due to the hard TiO2 particles acting as barriers to the movement of dislocation and contribute positively to the hardness of the composites and decrease in ductility can be attributed to the embrittlement effect of hard TiO2 particle which causes increased local stress concentration sites. So there was a necessity of a compromise with the amount of reinforcement in the composite to enhance the mechanical properties.

2. OBJECTIVES

- To study the effect of reinforcement on the Mechanical characteristics of ZA27/SiCp MMCs.
- To study the effect of percentage of silicon carbide on the load carrying capacity of these composites.
- To study the
    - Tensile Strength
    - Impact strength
    - Hardness
    - Wear strength

3. EXPERIMENTAL DETAILS

3.1 Materials

3.1.1 Matrix material

In the present work, Zinc-aluminium-27 alloy i.e. ZA-27 is used as the matrix material. Zinc-aluminium alloys 8, 12, and 27 comprises a new family of zinc casting alloys, they have proven themselves in a wide variety of applications. The alloys designated 8, 12, and 27 based on the approximate amount of the aluminum content. Each alloy contains copper and magnesium to attain a combination of properties. Because of the popularity as a commercial materials these alloys has resulted in issuing of national and international standards. Chemical composition of this ZA-27 alloy according to ASTM B 669-82 ingot specification is shown in Table1.

MATERIAL	% by weight
Al	25.5-28.0
Cu	2.0-2.5
Mg	0.012-0.020
Fe	0.072 max
Zn	balance

Table1: Chemical composition of zinc-aluminium-27 alloy (ZA-27)

3.1.2 Filler Material – SiC (50 µm)

Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide is not attacked by any acids or alkalis or molten salts up to 800°C. In air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. Some typical uses of silicon carbide are found in fixed and moving turbine components, seals, bearings, heat exchangers etc.

Figure 1: commercially available silicon carbide particles`

3.2 COMPOSITE FABRICATION

In this process melting of matrix alloy ZA-27 is separately carried out in a muffle furnace using graphite crucible about 500^{0}c. Then it is super superheated at approximately 650^{0}c temperature. After melting, the required amount of filler material SiC (0, 3, and 6 % wt) is preheated to around 400^{0}c in a separate crucible. Preheating is done to avoid amalgamation (clustering) of SiC particles. Then this melt is stirred manually about 2-3 minutes in order to get a vortex of the molten metal. The depth to which the stirrer was immersed was approximately one third of the molten metal from the bottom of the crucible. After this the preheated SIC particles are introduced into the vertex. The stirring is continued until the uniform distribution of SiC particles in the mixture, during stirring, to enhance the wet ability small amount of magnesium is added to the melt. Then the molten mixture in degassed using degassing tablets (Hexachloremethane). This is done to avoid the formation of blow holes in the castings. The molten metal is then poured into the preheated cast iron die of size 22 mm diameter and 170 mm length. Then the temperature will be lowered gradually. After solidification the castings are taken out from the die, and they are subjected to machining to get the specimens as required for further tests.

Fig 2: stages in casting: (A) crucible in furnace containing ZA27 ingots, (B) Molten metal in crucible, (C) Cast iron die in cold condition, (D) preheated Cast iron die, (E) pouring of molten MMC in to die, (F) ZA27/SiCp final castings, (G) degassing tablets (hexa-chloromethane)

3.3 MECHANICAL CHARACTERIZATION

3.3.1 Hardness Test

Hardness is a measure of resistance of a material to plastic deformation. The static indentation test was conducted in this test of hardness of the specimens in which a ball indenter was forced into the specimens being tested. The relationship of the total test force to the area or the depth of indentation provides the measure of hardness.

The hardness of the specimens is measured using a standard Brinell hardness testing machine (fig 3). The hardness tests are conducted according to the ASTM E 10-95 standards. A ball indenter of diameter 2.5 mm is used and a load of 62.5 kgf is applied over the specimen of diameter 30 mm and length 30 mm for period of 10 seconds. Three readings are taken for each specimen at different locations in order to find the average hardness.

Figure 3: A) Brinell hardness testing machine, B) Brinell hardness test specimens

Hardness is determined by taking the mean diameter of the indentation (two readings at right angles to each other) and calculating the BHN by dividing the applied load by the surface area of the indentation. Since the degree of accuracy attained by the Brinell test can be greatly influenced by the surface finish of the specimen. The surface of the specimen is polished so that the indentation was defined clearly enough to permit accurate measurement. Brinell hardness can be calculated by the formula given below.

$$BHN = (0.102*2*F)/\{\pi D(D-\sqrt{(D^2-d^2)}\} \quad \ldots\ldots (3.3)$$

Where F is the applied load, D is diameter of indentor ball, d is diameter of indetation.

3.2.2 Impact Test (CVN)

Charpy V notch Impact tests (CVN) were conducted using an impact testing machine. A pictorial view of the impact testing machine is shown in figure The machine consist of a massive base on which is mounted a vice for holding the specimen and to which is connected, through a rigid frame and bearings, a pendulum type hammer. The machine also has a pendulum holding and releasing mechanism and a digital indicator for displaying the test values

Figure 4: Impact testing machine

The pendulum shall consist of a single or multimember arm with a bearing on one end and a head, containing the striker, on the other. The arm must be sufficiently rigid to maintain the proper clearances and geometric relationships between the machine parts and the specimen and to minimize vibration energy losses that are always included in the measured impact resistance. Both simple and compound pendulum designs may comply with this test method.

Figure 5: V-Notched charpy test specimens

3.3.3 Tensile test

The various tensile properties of the as-cast materials like, ultimate tensile strength (UTS), Youngs modulus, toughness were evaluated using a standard 60 ton capacity computerized universal testing machine. The photograph of the machine is shown in figure 6

Figure 6: Computerized universal testing machine used in tensile test

Figure 7: Dog-bone typed tension test specimens

Tensile test involves subjecting the prepared dog bone shaped specimens shown in above Fig 7 of specified size and geometry to a gradually increasing uniaxial load until the failure of the specimen occurs. Simultaneously the readings are taken for the elongation of the specimen. This process is accomplished by gripping opposite ends (knurled portion) of the work piece and pulling it, which results in elongation of test specimen in a direction parallel to the applied load. The ultimate tensile strength tests were done in accordance with ASTM E8 standards. The tensile specimens of diameter 12 mm and gauge length 70 mm were machined from the cast specimens with the gauge length of the specimens parallel to the longitudinal axis of the castings. The results are analysed to calculate the tensile strength of the composite samples.

3.3.4 Wear Test

To study the dry sliding wear behavior of composites, different experiments have been conducted. The matrix and reinforcement material used for fabrication of composites are discussed below. The experimental details for dry sliding wear test to study wear behavior of ZA43 reinforced with SiC composites are discussed in details in the following sections.

The wear specimens (pin) of 6mm diameter and 30mm length according to ASTM G99-95standar were cut from cast as samples and machined. Surface irregularities on the cylindrical end surface were mechanically polished with progressively finest grade of silicon carbide impregnated emery paper to remove all scratches and to get a perfectly smooth and flat surface perpendicular to the disc of the wear testing machine.

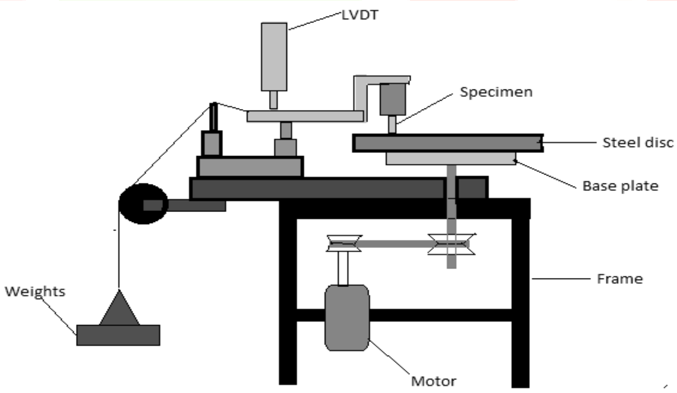


Figure 8: Pin on disc wear testing setup.

4.RESULTS AND DISCUSSIONS

In the present investigation, the various properties of ZA27/SiCp metal matrix composites like, ultimate tensile strength, toughness, hardness, impact strength and fracture toughness are evaluated in order to characterize their properties and to study the effect of Silicon carbide content on zinc-aluminium alloy.
The experiments were conducted to study the effect of applied load, sliding distance and sliding speed and amount of reinforcement on the wear behavior of material. The following sets of tests were conducted with a track radius 64 mm.

Table.2 Allotment of testing Parameters for various levels

Particular	Level 1	Level 2	Level 3
Load in N	9.81	19.62	29.43

Speed in rpm	300	400	500
Distance in m	500	750	1000

By varying one parameter at a time we will get 81 set of readings. The weight loss in a specimen was measured by recording the initial and final weights using electronic digital balance with accuracy of 0.001g. Weight losses are recorded by varying the three parameters load, speed, sliding distance. There are three phases of testing the specimens, in first phase, applied load is varied where as speed and sliding distances are kept constant. During second phase speed is varied, load and sliding distance are kept constant .During the third phase sliding distance is varied where as the load and speed are kept constant. The above procedure is repeated for the 0%, 3% and 6% composition of SiC.

Ffig 9. Pin on disc wear testing apparatus

Fig 10. Pin on disc wear test rig

4. RESULT AND DISCUSSION

4.1 HARDNESS PROPERTIES OF ZA27/SiCp MMC

Hardness is considered as one of the most important factors that govern the wear resistance of any material. In the present work, micro-hardness values of the ZA-27 metal matrix composites (with and without particulate fillers) have been obtained by a Brinell hardness tester. The variation of hardness with different filler content in the composites is shown in Figure11.

composition	Hardness BHN (MPa)
ZA27 alloy	81.986
ZA27+3% wt SiC	102.70
ZA27+6% wt SiC	144.9

Table 3: Measured hardness values of the composite.

Among all the materials under this investigation, the maximum hardness value is observed for ZA-27 filled with 6 wt% of SiC. The test results show that with the presence of hard ceramic particles, hardness of the ZA-27 metal matrix composites improved from 81.98 BHN to 144.098 BHN SiC filled ZA-27 metal matrix composites.

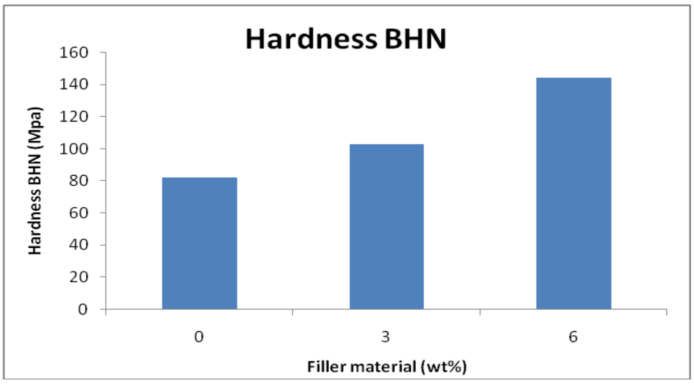


Fig 11: Variation of Hardness of composite with filler material

4.2 IMPACT TEST

The impact strength of a material is its capacity to absorb and dissipate energies under shock or impact loading. The selection of a composite for certain applications is determined not only by usual design parameters, but also by its impact or energy absorbing properties. Thus, it is important to have a good understanding of the impact behaviour of composites for both safe and efficient design of structures.

Composition	Energy absorbed in (J)	Impact strength (KJ/m^2)
ZA27 alloy	3.4	42.5
ZA27+3% wt SiC	3.9	48.75
ZA27+6% wt SiC	4.2	52.5

Table 4: Measured values of Impact strengths

Figures 12 shows the measured impact energy values of the ZA-27 metal matrix composites filled with SiC particulate fillers respectively. It is seen from the figure that the impact energies of the composites increase gradually with increase filler content increasing from 0 to 6 wt%.

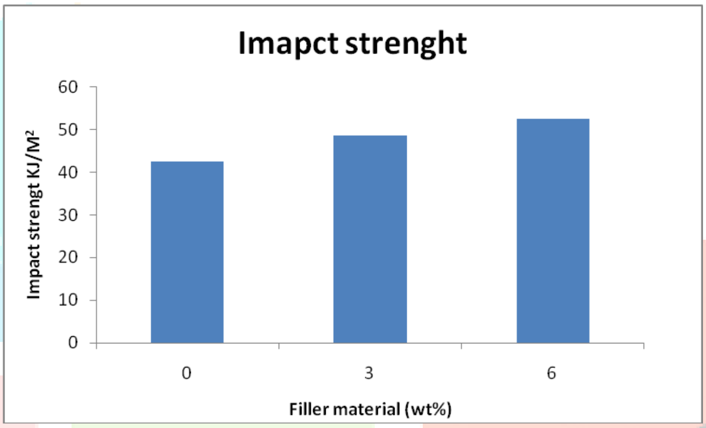


Fig 12: Variation of Impact strength of composite with filler material

4.3 TENSION TEST

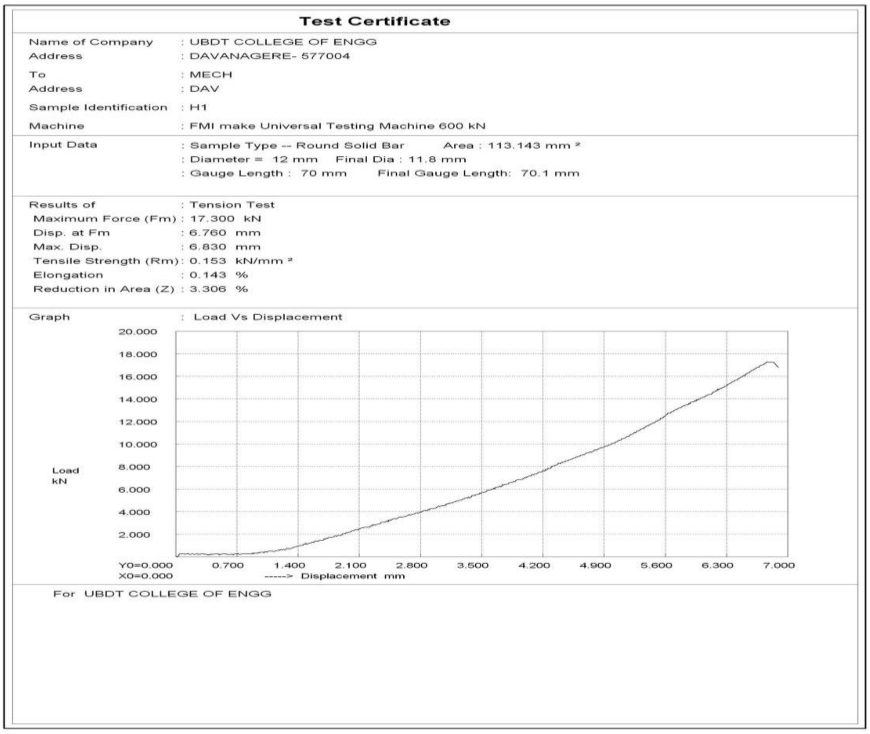
The test results for tensile strengths of the composites with SiC reinforcement is shown in Figures 13 and 14 respectively. It is seen that in all the samples tensile strength of the composite increases with increase in filler content. The unfilled ZA-27 metal matrix composite has a strength of 151 MPa in tension and it may be seen from Table 5 that this value improves to 224 MPa with addition of 6 wt% of SiC.

The enhancement of tensile strength with incorporation of particulate fillers can be explained as follows. With the presence of hard particulates, the load on the matrix gets transferred to the reinforcing elements thereby increasing the load bearing capability of the composites. With increase in volume fraction of the filler material, more loads get transferred to reinforcement which leads to increase in tensile strength. Moreover, with the presence of hard ceramics like SiC, there is a restriction to the plastic flow as a result of dispersion of these hard particles in the matrix, thereby providing enhanced tensile strength in the composite.

Composition	**Peak load (KN)**	**Max Displacement mm**	**Yield strength MPa**	**Toughness MJ/m^3**
ZA27 alloy	17.3	6.83	153	5.9643
ZA27+3% SiC	17.05	7.74	151	6.694
ZA27+6%SiC	25.4	7.71	224	10.43

Table 5: Tensile properties of ZA27/SiCp MMC

4.3.1 LOAD-DISPLACEMENT BEHAVIOR


Test Certificate

Name of Company : UBDT COLLEGE OF ENGG
Address : DAVANAGERE- 577004
To : MECH
Address : DAV
Sample Identification : H1
Machine : FMI make Universal Testing Machine 600 kN
Input Data : Sample Type -- Round Solid Bar Area : 113.143 mm ²
: Diameter = 12 mm Final Dia : 11.8 mm
: Gauge Length : 70 mm Final Gauge Length: 70.1 mm

Results of : Tension Test
Maximum Force (Fm) : 17.300 kN
Disp. at Fm : 6.760 mm
Max. Disp. : 6.830 mm
Tensile Strength (Rm) : 0.153 kN/mm ²
Elongation : 0.143 %
Reduction in Area (Z) : 3.306 %

Graph : Load Vs Displacement

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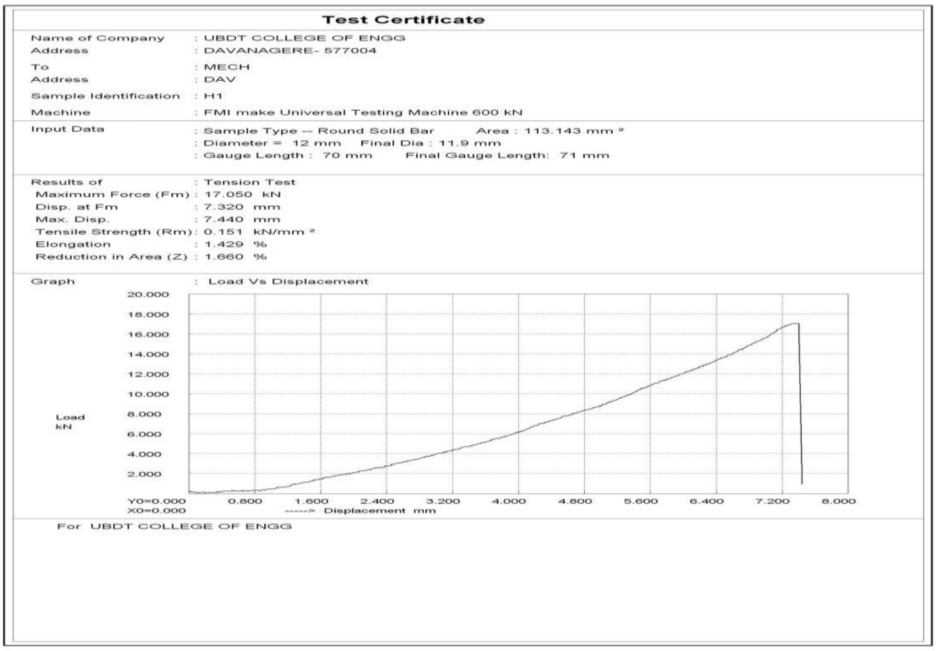
Figure 13: Load v/s Displacement curve for ZA-27 Alloy

Figure 13 shows the load v/s displacement graph for ZA-27 alloy with no SiC content. From the figure it is observed that the maximum force that the specimen can withstand is 17.3. It is also observed from the figure that the tensile strength is 153MPa. The curve showed linear response up to maximum force then the curve drops down showing non-linear behaviour up to failure.


Test Certificate

Name of Company : UBDT COLLEGE OF ENGG
Address : DAVANAGERE- 577004
To : MECH
Address : DAV
Sample Identification : H1
Machine : FMI make Universal Testing Machine 600 kN
Input Data : Sample Type -- Round Solid Bar Area : 113.143 mm ²
: Diameter = 12 mm Final Dia : 11.9 mm
: Gauge Length : 70 mm Final Gauge Length: 71 mm

Results of : Tension Test
Maximum Force (Fm) : 17.050 kN
Disp. at Fm : 7.320 mm
Max. Disp. : 7.440 mm
Tensile Strength (Rm) : 0.151 kN/mm ²
Elongation : 1.429 %
Reduction in Area (Z) : 1.660 %

Graph : Load Vs Displacement

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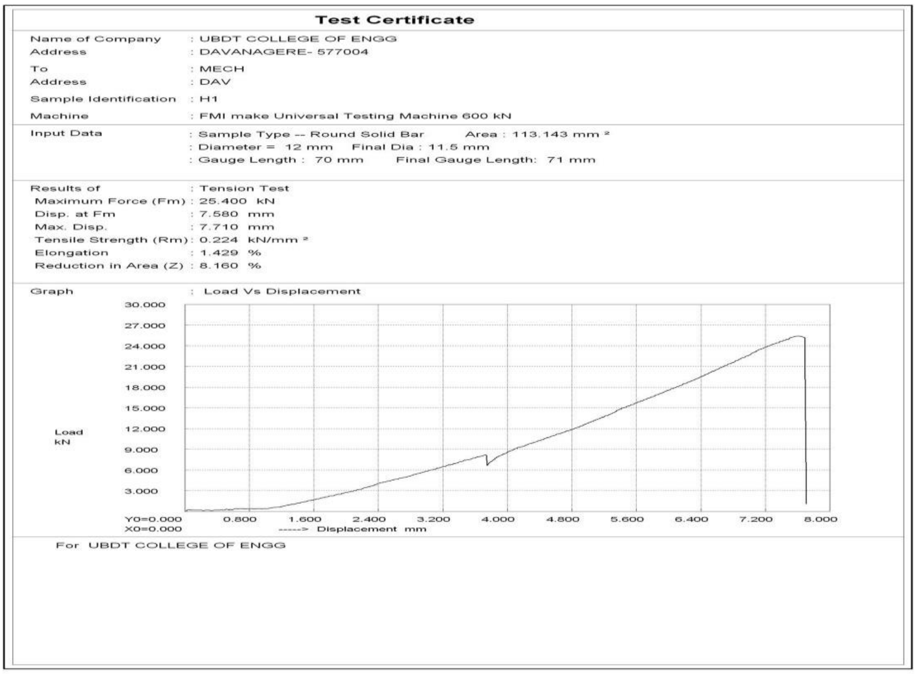
Fig 4.4: Load v/s displacement curve for ZA27+3% SiC MMC

Figure 14 shows the load v/s displacement graph for ZA27 MMC reinforced with 3% by weight of SiC. From the graph it is found that tensile strength of the composite is 151Mpa. The curve showed linear response up to maximum force then the curve drops down showing non-linear behavior up to failure.


Test Certificate

Name of Company : UBDT COLLEGE OF ENGG
Address : DAVANAGERE- 577004
To : MECH
Address : DAV
Sample Identification : H1
Machine : FMI make Universal Testing Machine 600 kN
Input Data : Sample Type -- Round Solid Bar Area : 113.143 mm ²
: Diameter = 12 mm Final Dia : 11.5 mm
: Gauge Length : 70 mm Final Gauge Length: 71 mm

Results of : Tension Test
Maximum Force (Fm) : 25.400 kN
Disp. at Fm : 7.580 mm
Max. Disp. : 7.710 mm
Tensile Strength (Rm) : 0.224 kN/mm ²
Elongation : 1.429 %
Reduction in Area (Z) : 8.160 %

Graph : Load Vs Displacement

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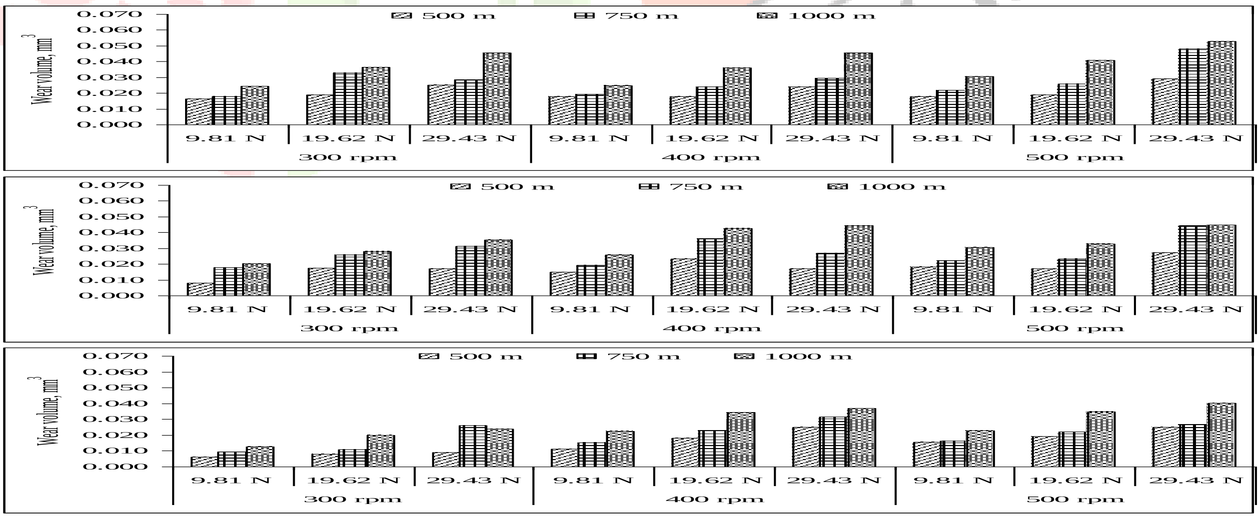
Fig 15: Load v/s displacement curve for ZA27+6% SiC MMC

Figure 15 shows the load v/s displacement graph for ZA27 MMC reinforced with 6% by weight of SiC. From the graph it is found that tensile strength of the composite is 224 MPa. The curve showed linear response up to maximum force then the curve drops down showing non-linear behavior up to failure.

4.4 WEAR TEST

Histograms are plotted for the results obtained during the wear test where for all the three parameters are presented on it. This method of projecting results will help in studying the variation of output during the experiment. Wear tests were conducted on the casted specimen under their different loads, speeds, and sliding distances. When two surfaces come in contact under sliding conditions, lot of friction develops at the interface. This friction will cause one of the surfaces to lose its material from its counterpart. This phenomenon takes place during the wear test where developed MMC loses some part of its material when it comes in contact with rotating steel disc. Here the disc is harder than MMC; hence loss of material takes place due to various mechanisms. **Figure 16. Gives results of the test conducted on MMC with 0%, 3% and 3% composition of SiC**



4.4.1 Effect of Load on Wear Volume

Load was the second important parameter which attributes to the wear volume during wear test. The graph was generated for results of wear volume with applied load. Three materials differing in their composition was subjected to wear test by varying applied load. MMC with 0% SiC shows wear volume of 0.024 mm3 at 9.81 N whereas the same material at 29.43 N shows 0.045 mm3. This trend of behavior represents increasing applied load during the wear test will increase the wear volume of the material as shown in Fig 17.

Oxidative wear occurred at low applied loads. In this wear process an aluminium oxide layer is formed on both the specimen surface as well as counter surface. Wear occurred firstly by oxidation of the asperities and then secondly by fracture and compaction of oxidized wear debris into the film [11].

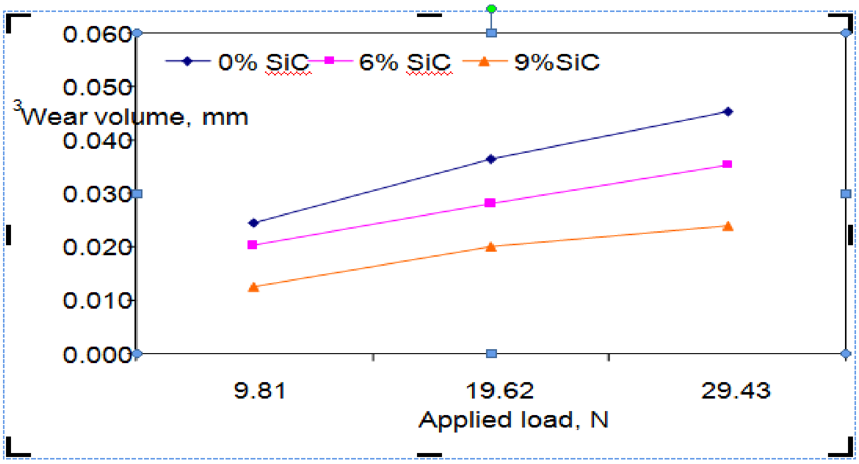


Fig 17. Variation of wear volume with applied load, sliding distance of 1000 m, sliding speed of 300rpm

Metallic wear became predominant wear process at higher applied loads. The surface of specimen was characterized by plastic deformation and fracture, significant transfer of the material between the sliding surface and the wear debris formation. The amount of plastic deformation and the higher wear rate prevented the formation of an oxide layer.

4.4.2 Effect of Sliding Distance on Wear Volume

Figure 18 shows, the variations of wear volume with sliding distance. The graph was generated for results of wear volume with sliding distance, three materials differing in there compositions was subjected to wear test by varying the sliding distance. MMC with 0% SiC composition, at 500 m shows the wear volume of 0.016 mm^3 whereas the same material at 1000 m shows the wear volume of 0.051 mm^3. This trend of behavior represents the increase in wear volume with increase in sliding distance. This trend implies that at lower sliding distances friction was less and hence less temperature was developed, leading to lower rate of wear volume. As we increase the sliding distances the friction between the pin and disk increased leading to increase in the temperature wear rate increases due to softening of MMC.

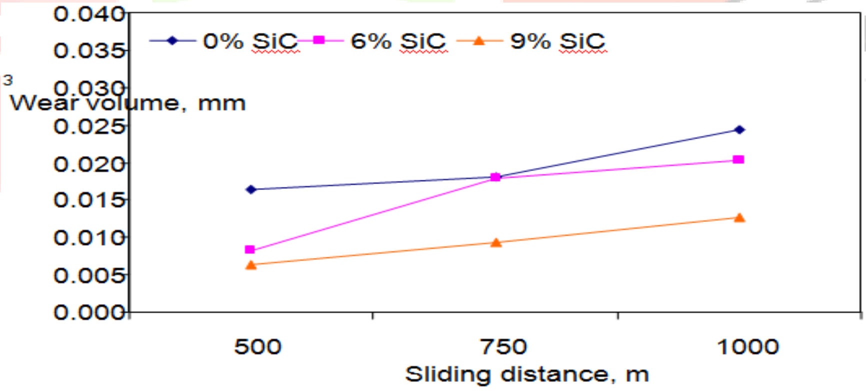


Fig 18. Variation of wear volume with sliding distance, sliding speed of 400rpm, load of 29.43N

There is another possibility where volume of material may also decrease due to the diffusion of disk material in to the MMC specimen. From the graph it is observed that, increase in the percentage of composition of SiC decreases the wear volume. As the amount of reinforcement increases, the wear resistance increases for all sliding distances.

5. CONCLUSIONS AND SCOPE FOR FUTURE WORK

5.1 CONCLUSION

In the present work ZA27/SiCp Metal Matrix Composites are used for experimental investigation. The experiments are conducted to evaluate the mechanical properties such as hardness, stiffness, yield strength, ultimate strength , impact strength and toughness of the SiC reinforced composite were evaluated to explore their suitability for various applications. And also fracture toughness of the material is evaluated for different weight fraction of the silicon carbide

This experimental investigation on SiC particulate filled ZA-27 MMCs has led to the following conclusions:

- These composites possess improved hardness(from 81 to 144 BHN) and Impact strength (from 42.5 to 52.5KJ/m^2) . It is observed that as the weight fraction of the filler material increase both the hardness and impact strengths increases.
- The SiC reinforced ZA27 alloy has shown maximum strength. Whereas the unreinforced ZA27 alloy is found to be very poor in strength aspects.
- Composite material containing higher reinforcement shows better resistant properties, MMC with 15% of SiC shows better wear wear resistant properties . compared to 5% and 10%. This is because proper bonding between SiC and matrix.
- Applied load is the contributing parameter cause high wear increase in load leads to friction. Ploughing of the material and even delamination the material takes place. Wear debries are formed in form of flakes the size of the flake increase with increase in applied load .
- Sliding distance is second contributing parameter to wear volume . increase in sliding distance leads to increase loss of material on the MMC.
- Sliding speed also as considerable affect on loss of material . increase in speed lead to softening of material . where abrasive affection of the disc takes place
- The result shows that load as the highest contribution followed by the sliding distance and disc speed.

5.2 SCOPE FOR FUTURE WORK

In the present work Fracture toughness and some mechanical properties are determined for ZA27 Alloy and ZA27/SiCp Metal Matrix Composites. Compliance is calculated for specimens of different crack lengths. However, different methods and techniques are still under investigation. Based on this investigation following suggestions can be given for the future work:

- This work can be continued to determine Wear of coated material and heat treated materials.
- Wear can be determined for composite with different reinforcing materials like Boron carbide, Graphite, Al_2O_3 , and even this work can be continued of hybrid composites
- This work can be extended to investigate the effect of some more parameters specimen geometry, different compositions, operating temperatures.

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