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Study on Fatigue Behaviour of Copper Coated Fly Ash –LM6 Metal Matrix Composite

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ABSTRACT

This paper describes the fatigue behaviour investigation carried on MMC, in which LM6 metal matrix and copper coated fly ash act as reinforcement. The MMC was obtained by liquid metallurgy and continuous stir casting process. The industrial by product fly ash (Cenospheres) were coated with copper using electro-less method of coating. After coating the density of cenosphere fly-ash increases. This coated fly ash is used as reinforcement. The variation of fatigue behaviour with varying volume percentage of reinforcement (i.e. 0Vol%, 2.5Vol%, 5Vol%, 7.5Vol%, 10Vol% 12.5Vol% and 15Vol%) was studied using rotating bending fatigue test machine of the constant bending moment type. During the fatigue test, with increase in volume percentage of Cu-coated fly ash reinforcement from 0Vol% to 10Vol% there is an increase in the number of fatigue cycles to failure in MMC from 11640 Cycles to 55381 Cycles, but with further increase in the volume percentage of reinforcement from 10Vol% to 15Vol% there is a decrease in the number of fatigue cycles required for failure to 22964 Cycles. The failure samples are subjected to microstructure analysis in metallurgical microscope, it revealed uniform dispersion of fly ash particulate as per volume percentage, further optical study of the micro structural analysis after failure of composites was conducted using SEM which suggested that, there is an addition in the brittle nature of MMCs with the addition of fly ash after 10 volume percent. It was reasoned out that Cu-coated fly ash can be used as reinforcement in aluminium composite, this composite give better fatigue life than LM6 Al alloy and fly-ash composite without copper coating and this MMC can be utilized as a replacement for materials used in aerospace and automobile industry to produce engine blocks, pistons.

Keywords: *MMC, Reinforcement, LM6, Fly ash, Copper coating, Fatigue, Rotating Bending fatigue test machine, Microstructure.*

I. INTRODUCTION

During recent years, composite materials are widely used in different fields like aerospace, automobile, shipping, energy etc., due to their good weight to strength ratio compared to any other base material.[1] A composite material is prepared by combining two or more materials, often material have dissimilar properties [2].

The improvement in properties, with respect to the un-reinforced alloys, strongly depends on the intrinsic properties of both matrix and reinforcement, i.e. size, volume fraction and distribution. The interest in aluminum alloys, discontinuously reinforced with ceramic particulates has developed considerably.

AMC's (Aluminum matrix composites) have been of interest as engineering materials because of their high specific strength and stiffness .Since they have distinct advantages in aerospace, automotive and other structural applications, their fatigue behaviour is an important factor that must be considered. [3]

A main and probable problem of particle-reinforced composite is non-uniform microstructure, often resulting on or after the manufacturing process, which can lead to the presence of group of particles, or region without reinforcement. This intrinsic material in homogeneity can give a wide scatter in strength, ductility, wear resistance, fracture toughness and in the fatigue behaviour. [4]

The response of the structural element to fatigue is critical for many applications. In case of MMCs (Metal matrix composites), the fatigue behaviour differs from that of unreinforced metals in many ways. In case of particle reinforced metals numerous studies have focused on understanding the influence of the reinforcing particle on the matrix microstructure and the corresponding effect on fatigue behaviour of the MMCs. In some cases, the increase in volume fraction and size of the reinforcement particles and is the reason for further reductions in low cycle fatigue responses. [6]

The objective of the present work is to study the behaviour of fatigue of LM6 metal matrix composite reinforced with Copper coated fly ash for various volume percentage of reinforcement. And Compare the fatigue behaviour with and without copper coated fly ash reinforced with LM6 metal matrix.

II MATERIALS AND METHODOLOGY

1. Materials

The materials used in this present investigation are LM6, fly ash, and copper coated Cenospheres fly ash.

A. Matrix used:

LM6 is a grade of aluminum in BS (British standards) 1490-1988 was used as matrix material. The chemical composition of the alloy is given in Table 1.

B. Reinforcement used:

Fly ash is the most inexpensive and low density reinforcement available in large quantities as solid by product during combustion of coal in the thermal power plants. Due to the mineral component of coal and combustion technique, Fly ash is produced [5]. Fly ash particles obtained from electrostatic precipitators vary in size from 5-75 microns [7].The two types of fly ash are precipitator ash (solid part) and Cenospheres (hollow microspheres). Cenospheres of fly ash generally float on water in the collection ponds. Cenospheres are generally spherical in shape. From literature survey it is reveals that the Cenosphere fly ash is having less density and tends to float on top of matrix material as percentage of reinforcement increase. To improve density of cenosphere fly ash it was coated with copper using electro-less method of coating and the coated cenosphere fly ash is used as Reinforcement [1]. The composition of fly ash is shown in Table 2.

2. Experimental Methodology

A. Electro-less coating of copper on ceramic microspheres of fly ash

The general steps involved in this electro less copper coating process are; Etching, Sensitization, Activation and coating.

The following is the procedure for copper coating of ceramic microspheres:-

1. 25g of ceramic microspheres of fly-ash particles are first thoroughly washed in distilled water and filtered, to remove all the heavy particles present in it.
2. The Etching process is carried out using (20g/l) NH_4F to clean particles surface.
3. After Etching process the particles were stirred in an acidic bath solution containing Stannous Chloride ($SnCl_2$) (10g/l) with (40ml/l) of concentrated Hydrochloric acid (HCl) for the period of 2 hours.
4. The Sensitized particles were washed & filtered again.
5. Then the Sensitized particles transferred to standardized aqueous bath i.e. activation solution containing ($AgNO_3$) (0.2g/l) and HCL (0.25ml/l) stirred in this bath for 2 hours
6. After activation process, the activated particles were washed thoroughly in distilled water and filtered off.
7. The activated particles were transferred to beaker containing coating bath solution having (12g/l) ($CuSO_4$), (36g/l) Sodium potassium tartarate ($NaKC_4H_4O_6$), (20g/l) Sodium hydroxide (NaOH), and (5ml/l) reducing agent

formaldehyde (HCHO) for Cu-deposition. Then particles were stirred for 30minute or until the blue colour of bath solution disappear.

8. After this Cu-coated ceramic microsphere particles were filtered off and is washed with distilled-water then dried at 100^{0}C in vacuum oven for 1 hour.
9. The dried Cu-coated microspheres of fly ash are ready to use as reinforcement which is shown in figure 1.

Composites were produced with the addition of varying percentages (2.5%, 5%, 7.5%, 10%, 12.5% and 15%) of copper coated ceramic microspheres of fly ash.

B. Preparation of Composites:

The metal matrix composite used in the study was prepared by stir casting Technique. From all the available technique of casting for volume production of metal matrix composite, liquid metallurgy or stir casting is the most economical way for producing MMCs [8]. A stir casting setup consisted of an induction furnace and a stainless steel stirrer assembly.

The production of composite was carried out in electric Resistance furnace which was maintained at 650 to 661^{o}C which is the melting point of LM6 alloy. The casting Process was carried out in BMSIT&M Bangalore. The weighed LM6 ingot was put in Graphite crucible which is placed in furnace and it is melted at 720^{o}C. Preheating of reinforcement (copper coated fly ash at 380^{o}C) according to weighed volume percentage was done for hour to remove moisture from the surface of the particulates, then the metal matrix will be degassed with hexa chloroethane and slag is removed. The stirrer is used for stirring at the speed of 300rpm. Speed of stirrer is gradually increased up to 400 rpm to create vertex, after creating vertex pre-heated reinforcement is added into vertex and continue the stirring action up to 2-4 minute for proper mixing of reinforcement in matrix material. Then melt was poured into the die and allowed to solidify. The castings were also prepared with uncoated Cenospheres of fly ash as reinforcement for comparison. The percentage of reinforcement is varied at an interval of 2.5%, up to 15% vol. Percentage. For each vol. Percentage three specimens were prepared for fatigue test.

C. Testing Procedure:

The castings produced as mentioned above, were taken out of the die, cooled and then cut the elongated part from it.

The samples were then machined to get standard test specimens as shown in figure.3 for studying Fatigue Behaviour.

D. Fatigue Test

Fatigue test was conducted on base alloy and MMC according to ASTM E466-07 using rotating bending fatigue testing machine, this equipment is available in Acharya Institute of Technology Bangalore. The standard specimen required for fatigue test is shown in figure.2

Rotating bending fatigue test machine consists of two loading points and two support points. It can rotate the specimen at maximum speed of 3000 RPM and can be subjected to a maximum load of 1000N.With each 1kg of weight introduction to load bearing, there will increase of load by five times on the test specimen.

The fatigue testing process involved the following steps:

- Insert the test specimen into the bearing housing of the fatigue test machine.
- Test specimen should be introduced such that there should be no eccentricity between the support points (generally not more than 0.003 cm).
- Apply a load of 100N by adjusting the jockey weight, this weight is close to 40% of the ultimate fatigue strength of LM6.
- Adjust revolution counter to zero and set speed to 1500 RPM, to bring down the vibrations created during the operation.
- Switch on the motor of the machine.
- Maintain a constant load throughout the test.
- Note down the number of cycles at which specimens fail.
- Plot the graph for number of cycles versus varied volume percentage

E. Studies on Microstructure

The micro structural study of the metal matrix composites was performed using a metallurgical microscope. The flat specimen having less than 1mm thickness with good surface finish was cut from the standard specimen where the area of the specimen has not failed due to fatigue. The Keller's reagent was used to each the polished specimens. Etched specimens were observed under the metallurgical microscope.

The failed surfaces of MMC were cleaned and observed through a Scanning Electron microscope (SEM).The scanning Electron microscope used for this purpose was the ZESSIS Neon 40 model.

III. RESULTS & DISCUSSION

A. Fatigue life

The results obtained from fatigue test are represented in form of column chart shown in figure 7. shows the variation in the number of cycles for failure versus the variation in the volume percentage of reinforcement Each volume percentage type.(0Vol%, 2.5Vol%, 5Vol%, 7.5Vol%, 10Vol% 12.5Vol% and 15Vol%) contains three specimens each indicated in three different colour series**.** Then the average of 3 specimens at each volume percentage is shown in figure 8.

It is clear from the figure 9. That with increase in fly ash reinforcement there is an increase in the service life or fatigue behaviour of the composite. Hence the number of cycles for failure is more in case of MMC than in the case of base alloy up to 10 volume percentages. After 10 volumes percentage there is drop in number of cycles for failure up to 15 volume percentage. This could be due to increase in the brittle nature of MMC.

With the growth in the brittle nature of the material the small or minute crack present between the atoms will spread at a faster rate. Therefore, with an increase in the amount of reinforcement into LM6 metal matrix after certain volume percentage there will be a fall in the number of cycles for failure.

Figure 10.shows the variation in the number of cycles for failure versus the variation in the volume percentage of reinforcement (copper coated cenosphere fly ash) added, figure 11 shows the average of 3 specimens at each volume percentage. It is clear from figure 12. That with increase in Cu-coated fly ash reinforcement there is an increase in the fatigue behaviour of the composite. Hence the number of cycles for failure is more in the case of MMC than in the case of base alloy up to 10 volume percentages. After 10 volume percentage there is decrease in number of cycles for failure up to 15 volume percentage. This could be due to the increase in the brittle nature of MMC. With the growth in the brittle nature of the material the minute crack present between the atoms will spread at a faster rate. Therefore, with an increase in the amount of reinforcement into LM6 metal matrix after certain volume percentage there will be a fall in the number of cycles for failure.

Table 5.5 shows the Comparison on fatigue test results of with and without copper coated fly ash reinforced metal matrix composites.

Figure13. Shows the comparison between with and without copper coated fly ash reinforced metal matrix composites, when they compared the fatigue life cycles for failure for copper coated fly ash is 7.03% increases at 10 vol. % when compared without coated fly ash reinforced metal matrix composites.

B. Microstructure studies

Metallurgical microstructure of LM6 alloy copper coated Cenospheres of fly ash composites

Fig.6. Shows the microstructure of the composite with LM6 matrix and various volume percentages of reinforcement (2.5%, 5%, 7.5%, 10%, 12.5% and 15%) by weight of copper coated Cenospheres. Flakes of silicon and the Cu-coated Cenospheres are clearly visible.

SEM of Cu coated Cenospheres

SEM of the Cu coated Cenospheres is shown in Fig 6(a). It indicates a mix of whole microspheres is coated with copper on its surface. The thickness varies from 1.1µ to 1.3µ. Fig.6 (b) shows LM6 base alloy SEM microstructure with 300 times magnification, there is a uniform distribution of (SiC) silicon carbide and aluminum oxide (Al_2O_3) so the microstructure is shiny in appearance, there are no pores formed in the form of dark patches and also there is only blunt edge after failure which suggest the elastic nature of material. Fig.6 (c) shows LM6 with 10% Cu-coated fly ash SEM microstructure, there is an uniform distribution of fly ash in LM6 matrix material, and the small spherical shape shows the Cenosphere fly ash and blunt edge shows the matrix material.

IV. FIGURES AND TABLES

Fig. 1: Copper coated Cenosphere fly ash

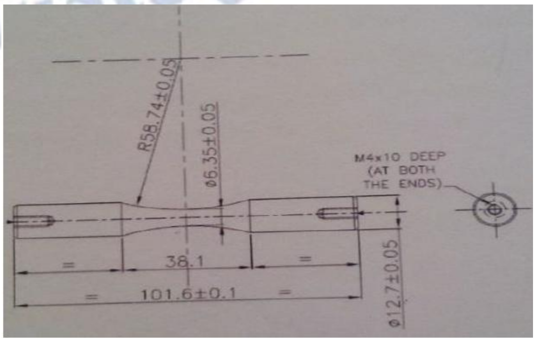
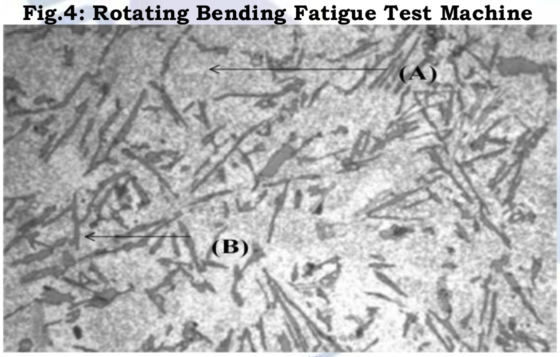


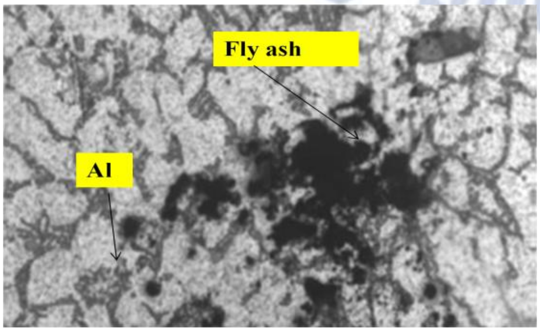
Fig.2: Standard Test specimen Dimensions

Fig.3: Test specimen

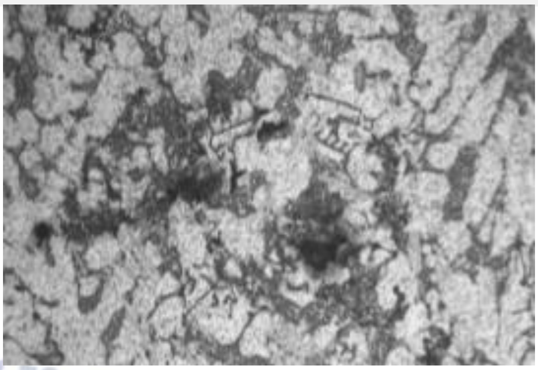
Fig.4: Rotating Bending Fatigue Test Machine



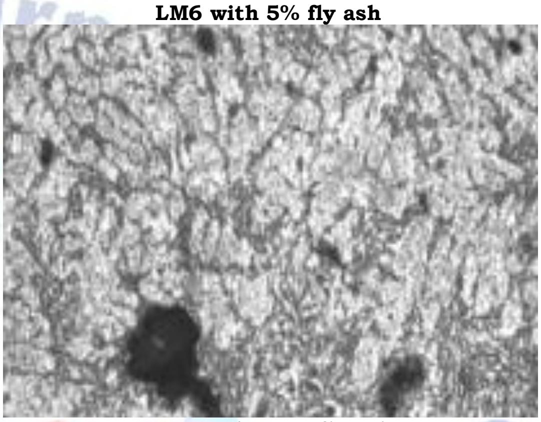
LM6 alloy



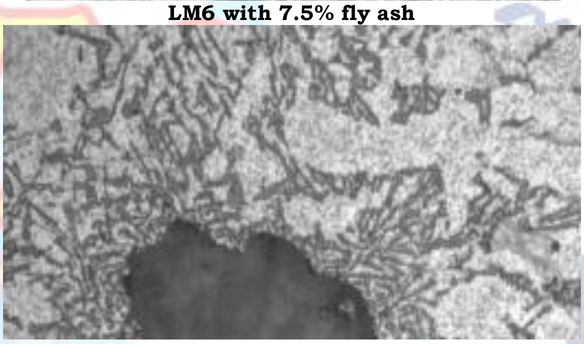
LM6 with 2.5% fly ash



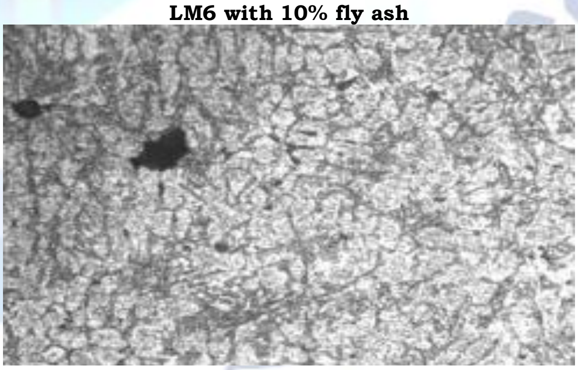
LM6 with 5% fly ash



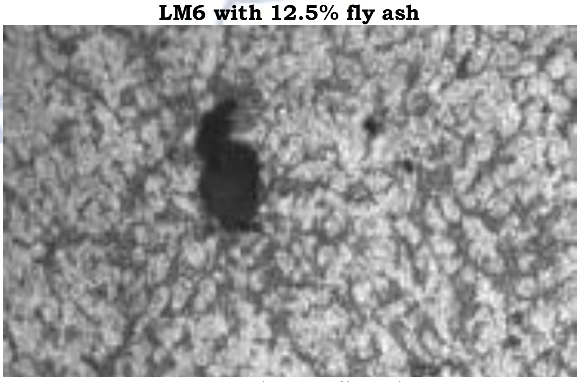
LM6 with 7.5% fly ash



LM6 with 10% fly ash



LM6 with 12.5% fly ash



LM6 with 15% fly ash

Fig. 5: Microstructure images of Cu-coated fly ash Reinforced in LM6

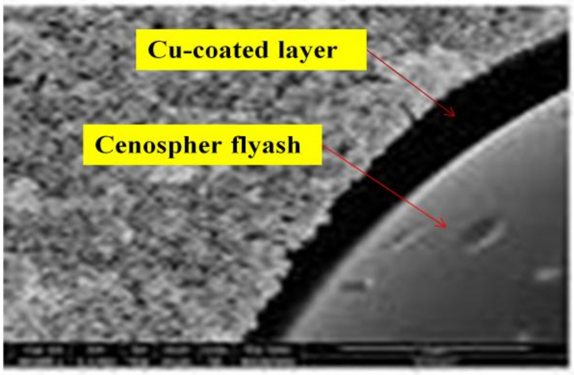


Fig.6 (A): Cu-coated Cenosphere fly ash

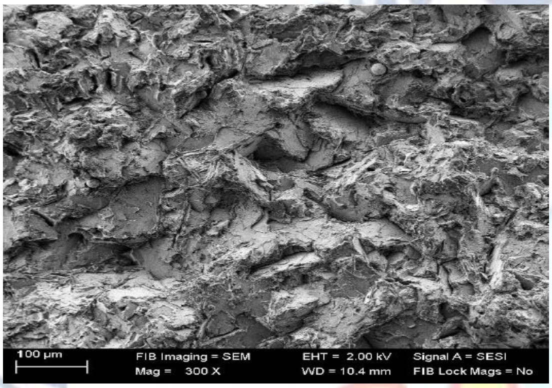


Fig.6 (B): LM6 Base alloy

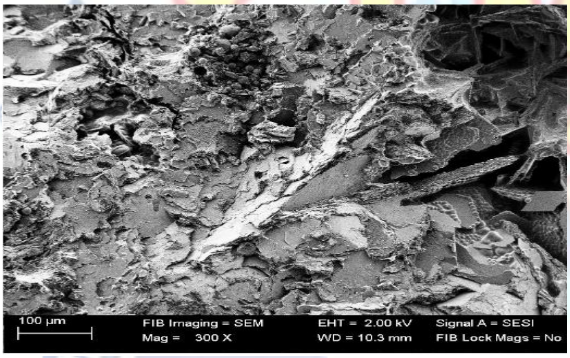


Fig.6 (c): LM6 with 10%Cu-coated fly ash
Fig.6: SEM images Cu-coated fly ash and LM6 composites

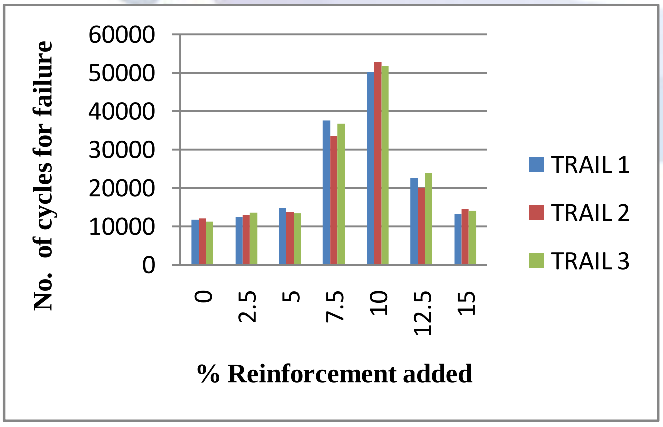


Fig.7: Chart indicating failure due fatigue loading

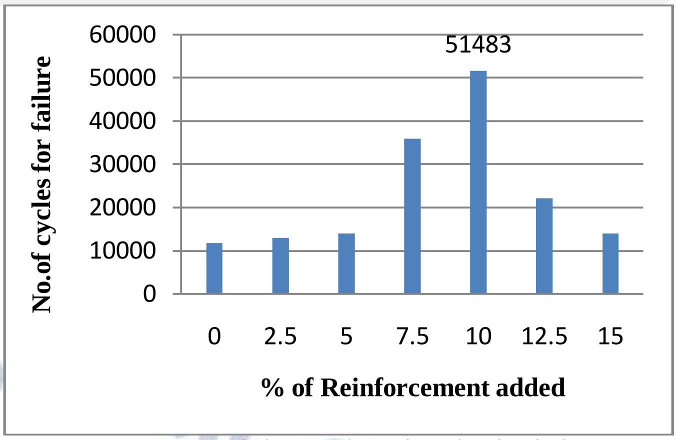


Fig.8: Average of the number of cycles for failure

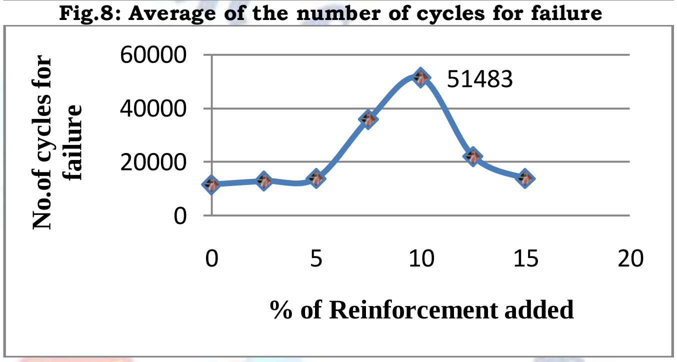


Fig.9: Chart indicating fatigue data

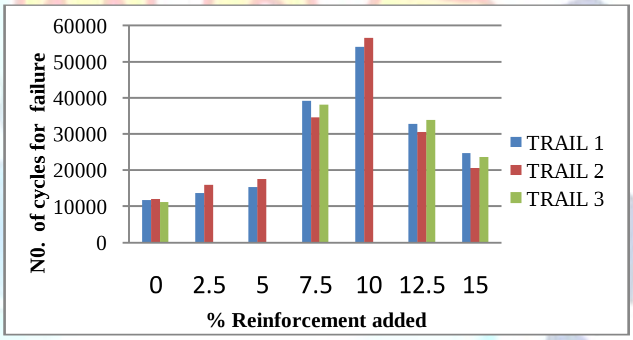


Fig.10: Chart indicating failure due fatigue loading

Fig.11: Average of the number of cycles for failure

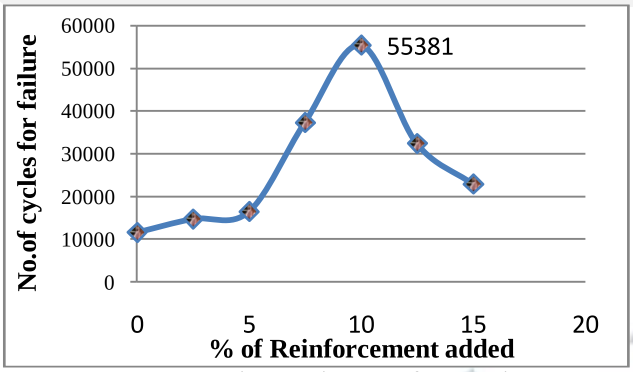


Fig.12: Chart indicating fatigue data

Table 3: Comparison of Fatigue test results of with and without copper coated fly ash reinforced MMC

Reinforcement added in percentage	Without copper coated fly ash (Average values)	With Copper coated fly-Ash (average values)	Difference
0	11640	11640	0
2.5	12920	14800	1880
5	13907	16472	2565
7.5	35897	37313	1416
10	51483	55381	3898
12.5	22126	32415	10289
15	13898	22964	9066

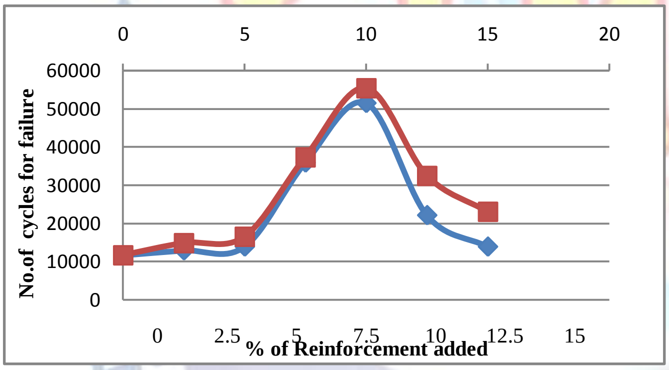


Fig.13: Comparison between with and without copper coated fly ash

Table 1: Chemical composition of LM6 Al

Component	Cu	Mg	Si	Fe	Mn	Ni	Pb	Sn	Ti	Al
Mass %	0.1	0.1	12	0.6	0.5	0.1	0.1	0.05	0.2	86.25

Table 2: Physical Properties of ceramic microspheres of fly-ash

Compound	MgO	Al_2O_3	SiO_3	K_2O	Cao	TiO_2	FeO	CuO
Mass %	1.72	29.65	51.4	1.57	2.82	2.54	5.39	4.86

V. CONCLUSION

The following conclusions are drawn from the results obtained.

- From the liquid metallurgy and stir casting process Cu-coated fly ash was successfully reinforced in LM6 Aluminium metal matrix for the volume percentage of (2.5%, 5%, 7.5%, 10%, 12.5% and 15%).
- As the percentage of copper coated fly ash increased from (0%-10%) there is a gradual increase in the number of cycles of load required for failure from (11640 to 55381) and further decreases due to increase in brittle nature of MMC.
- The experimental investigation shows that LM6 metal matrix composite reinforced with Cu-coated fly ash enhances fatigue life compared to without coating, there is increase in 7.03% fatigue life cycles for Cu-coated MMC.
- The microstructure evaluation using metallurgical microscope and SEM reveals that there is proper distribution of copper coated fly ash in MMC. And nature of failure is observed. The early fracture initialisation for higher percentage is due to brittleness of reinforcement
- From the investigation, it is concluded that the industrial by-product fly ash can be coated with copper and is used as reinforcement material for various MMCs to improve fatigue properties.

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