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Fatigue Behavior of Fly ash reinforced in LM6 Aluminum Metal Matrix Composite

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ABSTRACT:

This dissertation describes the fatigue behavior investigation carried on MMC, in which LM6 aluminum form metal matrix and fly ash act as reinforcement. The MMC was obtained by liquid metallurgy and continuous stir casting process. The variation of fatigue behavior with varying volume percentage of reinforcement (i.e. 0 Vol%, 2.5 Vol%, 5 Vol%, 7.5 Vol%, 10 Vol% 12.5 Vol% and 15 Vol%) was studied using rotating bending fatigue test machine of the constant bending moment type.During the fatigue test, with increase in volume percentage of fly ash reinforcement from 0 Vol% to 10 Vol% there is an increase in the number of cycles to failure in MMC from 0.11×10^5 Cycles to 0.88×10^5Cycles, but with further increase in the Vol % of reinforcement from 10 Vol% to 15 Vol% there is a decrease in the number of cycles required for failure to 0.13×10^5Cycles.When these 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 fly ash can be used as support in aluminum composite, composite give better fatigue life than LM6 Al alloy and this MMC can be utilized as a replacement for materials used automobile industry to produce engine blocks, pistons etc.

Key words: *Metal matrix composite, reinforcement, LM6 Al, Fly ash, fatigue, rotating bending fatigue test machine, microstructure.*

1. INTRODUCTION

➢ *Why only composite is selected for the study*

It is very tedious job for a design engineer to find a suitable material for designing structures and machine components. Many research works are in progress to develop new materials, also procedure required to obtain these materials, so that it could be used in new design situations. The intense research study has contributed to the growth of novel and advanced materials which later came to be called as composite materials. Advantages of composite material over conventional material are, offers high strength to weight proportion, High stiffness to weight proportion, increased fatigue resistance and impact resistance, improved resistance to corrosion and pitting, higher immunity to thermal expansion, excellent optical and magnetic properties.

- *Why LM6 Aluminum was selected as metal matrix*

o Aluminum is the third abundantly available element inside the earth's crust. Its weight is low compared to strength and stiffness so because of its following nature and easy casting process has made it to be broadly used in engineering industries (P K Suragimath et al). [1] Aluminum because of the desirable properties is used in automotive engines (N Suresh et al 2010, Suliman et al 2008). [2] and [3].LM6 include Aluminum and silicon content at high quantity or percentage is used as matrix material because of its following favorable properties such as,Good strength at high temperature, High strength to weight ratio, Fabrication can be managed easily and also at reasonable expenditure, good thermal conductivity and good resistance against corrosion, reliable, wear resistance properties.

- *Why fly ash is used as reinforcement*

Fly ash is formed at thermal power stations due to burning of coal, there are two varieties of fly ash, namely precipitate (solid particle) and censosphere (hollow particle),Fly ash improves mechanical properties like damping, hardness, etc. of MMCs as reinforcement, since it containsAl_2O_3, SiO_3At large percentage per unit volume [T, PD, Rajan et al 2007]. [4]Some of the properties of fly ash, which makes it as suitable reinforcement are, high electrical resistance, it has low thermal conductivity, low density, it is a waste material available at low price.

- *Why stir casting is selected for composite preparation*

Only simple fabrication technique, large quantity or volume production of metal matrix composite and utilizing cheaper reinforcements can reduce the cost of MMCs [Madhu Kumar Y C et al, 2012]. [5] Of all the available technique of casting, stir casting or liquid metallurgy is the most economical route for the production of metal matrix composite [6]

- *Why fatigue test*

The process of progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stress and strain at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations. So that we are able to know the service life of the component made from composite. Fatigue test should be conducted according to ASTM E466-07. [7] With the help of rotating bending fatigue test machine.

A M Usman et al 2014. [8]Showed there is an increase in fatigue property with increase in volume percentage of bagasse ash to LM6 Al, Mr. Vijay Kumar S Maga et al 2014. [9] In his study used MMC, where the metal matrix is the aluminum of LM6 grade, reinforcement is SiC, red mud and fly ash, came to conclusion that with an increase in weight percentage of reinforcement there is increase in impact strength and brittle property of the material. Mohammed Zafaruddin Khan et al 2015. [10] Focused their investigation on use of industrial waste like bagasse ash and fly ash, they concluded that with the increase in the reinforcement weight percentage there is an increase in tensile strength and Brinell hardness number. From paper [11] it is understood that the morphology of the microstructure of the reinforcement will also decide the property of MMCs.

1. MATERIALS AND METHODS

1.1 Materials

LM6 wasprocured from a certified producer of non-ferrous casting materials peenya industrial area in the shape of bricks weighing 2kg each of about 10kg for the liquid metallurgy and stir casting process the chemical composition of LM6 is shown in **table 1**.

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	rest

Fly ash, was received from a company manufacturing fly ash brick, its chemical composition is shown in **table 2**.

Table 1.3: Chemical composition 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

1.2 Composite production

The percentage of the ash used to produce the composite was 0-15vol% at an interval of 2.5vol%, with each volume percent (vol%) containing three specimens each. The production was carried out in electric furnace which was maintained at $660^0C \pm 20$ which is the melting point of aluminum alloy, casting process was carried out at BMSIT & M Bangalore. Weighed amount of LM6 ingots was put into the crucible of electric furnace and heated in the furnace for 1 hour at a temperature of 600^0C, by that time the reinforcement will be weighed according to its volume percentage and will be heated in another crucible at about400^0C, then the metal matrix will be degassed with hexacloroetahane (C_2Cl_6) and slag is removed, later the reinforcement will be added along with small piece of Mg (to improve wettability) to the LM6 metal matrix and will be rotated at 500RPM with the aluminum coated impeller submerged at 60% of the height of the molten metal, then the molten metal in poured into the preheated dies at 200^0C. The castings are left in mold for next 20min for molten metal to settle. The produced composite were prepared for fatigue test. The process of casting is explained in 10 stages using the below diagram.

Step 1:Introducing Al into crucible

Step 2: Preheating the mold

Step 3: Degassing of molten metal

Step 4: Removal of Slag

Step 5: Stirrer is introduced

Step 6: Formation of vertex

Step 7: Addition of reinforcement Step 8: Clamping of mold

Step 9: Pouring of molten metal Step 10: Solidified casting

Figure 1: Stepwise procedure for casting of MMCs

1.3 Fatigue test procedure

Fatigue test was conducted on base alloy and MMCs according to ASTM E466-07 using computerized constant bending moment type rotating bending fatigue test machine, this equipment is available in AIT Bangalore. The standard specimen required for the fatigue test should be of following dimensions indicated in **figure 2**, and thus produced component from casting after various machining process is indicated in **figure3**

Figure 2: Standard specimen for fatigue test

Figure 3: Standard fatigue test specimen after machining

The fatigue test conducted using rotating bending fatigue test machine involves the following steps, Insert the test piece in the bearing housing of the machine and measure its diameter. Check by means of a dial gauge and rotating the test piece that the eccentricity (run out between the two bearings) is proper as specified by the manufacturers (generally not more than 0.003 cm). Applying 100N load by adjusting the jockey weight, this weight is close to 40% of the ultimate fatigue strength of aluminum to achieve high cycle fatigue strength. Lay out the revolution counter to zero and adjust the speed to 1500Rpm, to bring down the vibrations created during the operation. Switch on the motor of the machine.Enter the number of revolutions after which the specimen has to fail. We maintain a constant load and test other specimens in a similar way, since we have seven different types of three specimens each. Note down the stress applied in each trial. Plot the stress versus load graph.

Figure 4: Constant bending moment type rotating bending fatigue test machine

2. RESULTS AND DISCUSSION

2.1 Fatigue life

The results obtained from fatigue test are represented in form of coloumn chart shown in **figure 5**, each volume percentage type (0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15%) contains3 specimens each indicated in three different colour series. Then the average of 3 specimens at each volume percentage is shown in **figure 6**

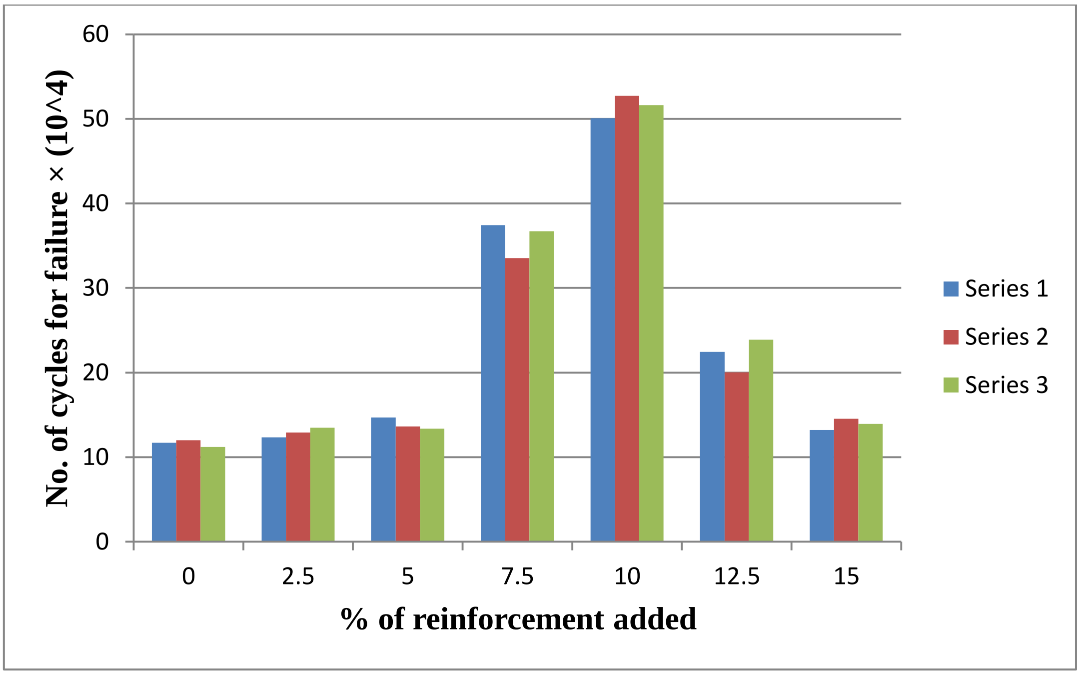


Figure 5: Column chart of fatigue data

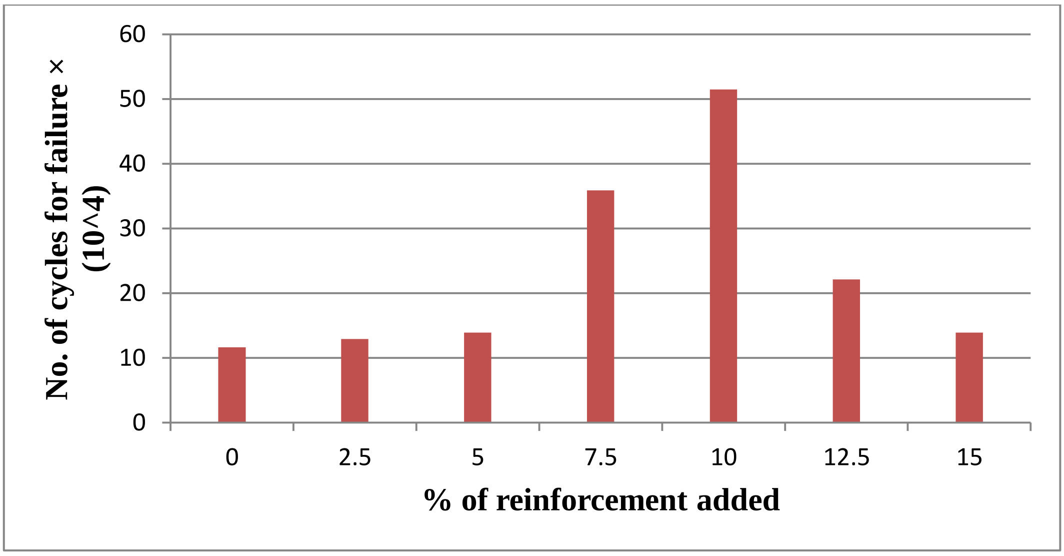


Figure 6: Average of the number of cycles for failure

In **figure 7,** theline chart representsa variation of fatigue life in Y- axis with respect to volume percentage in X-axis.

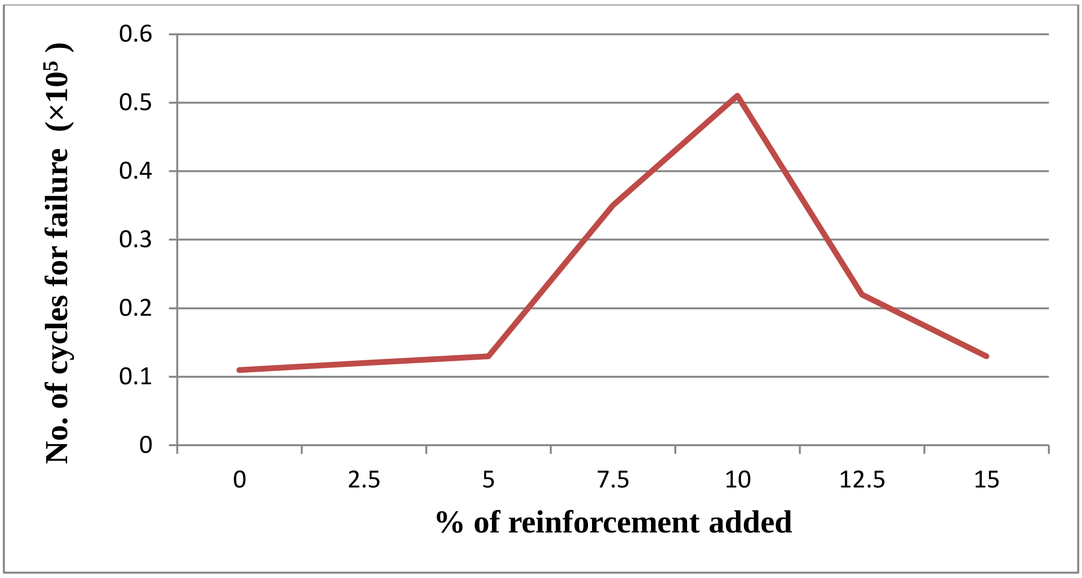


Figure 7:Line chart for fatigue data

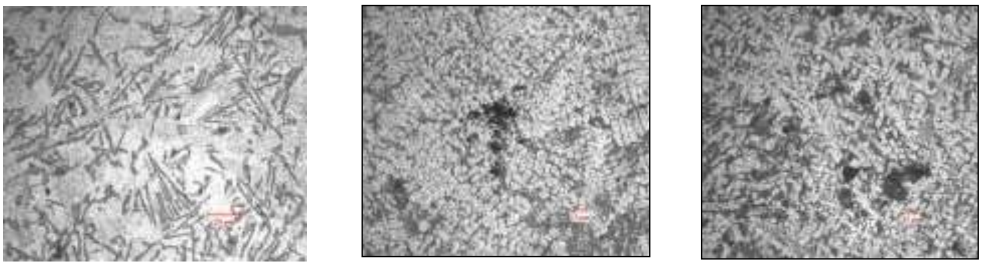
It is clear from the above results that with an increase in the fly ash reinforcement there is an increase in the service life or fatigue behavior, hence the number of cycles for failure is more in case of MMCs than in the case of base alloy. Since more of the load is carried by high stiffness reinforcement particles in the composite, therefore the matrix material in the composite will be subjected to lower stress than similar material in the unreinforced alloy [12] & [13].

But there is a decrease in the fatigue life or number of cycles before failure, after a certain amount of addition of fly ash reinforcement because, the ductility decrease or there is an increase in the brittle property of MMCs with an increase in the weight fraction of reinforced fly ash (brittle property also increases with increase in size of fly ash particle, with increase in fly ash particles by 15 weight percent the tensile strength is reported to decrease [14].

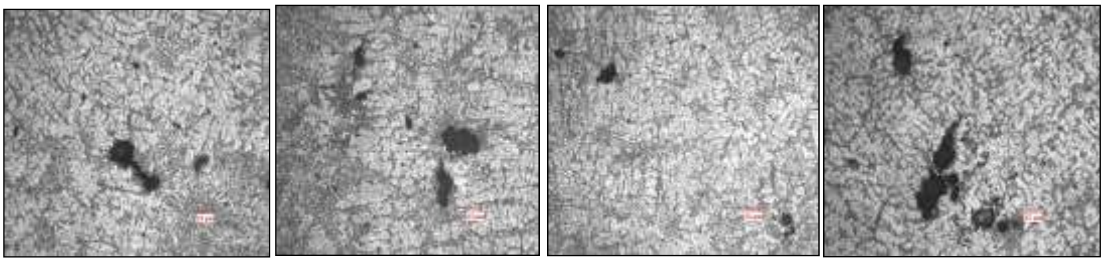
With the growth in the brittle nature of the material the micro crack present between the atoms will propagate at faster rate to increase in the brittle nature of MMCs [15].

2.2 Evaluation of microstructure using metallurgical microscope

The optical micrographs of LM6 Al base alloy and MMCs after addition of various volume percentage of reinforcement (2.5%, 5%, 7.5%, 10%, 12.5% and 15%)at the region where there is no rupture formed after fatigue test, are shown in below **figure 8**; it shows the etched microstructure image with the resolution of 200×.



LM6 **2.5% Fly ash** **5% Fly ash**



7.5% Fly ash 10% Fly ash 12.5% Fly ash 15% Fly ash

Figure 8: Microstructure images of fly ash reinforced in LM6

In case of base alloy LM6 microstructure, consists of fine eutectic silicon dispersed in inter dendritic region and fine precipitates of alloying elements in the matrix of aluminum solid solution. Now with addition of reinforcement according to volume percentage (2.5%, 5%, 7.5%, 10%, 12.5% and 15%) microstructure consists of uniformly dispersed fly ash according to their volume percentage.

2.3 Microstructure evaluation under SEM

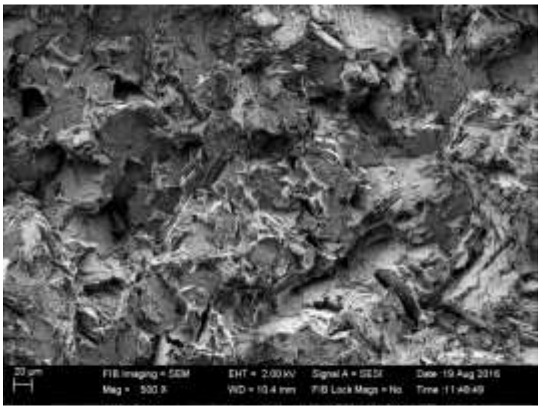
The morphologies of the broken surfaces of base alloy and 6 varying volume percentage components after fatigue test for an applied load of 100N were examined on Scanning Electron Microscope (SEM) at the region of failure.**Figure 9**shows the microstructure images of failed surfaces of various volume percentages of MMCs

Figure 9 shows the SEM microstructure image of LM6 basealloy and reinforcement added at various volume percentage(2.5%, 5%, 7.5%, 10%, 12.5% and 15%) with 500 times magnification

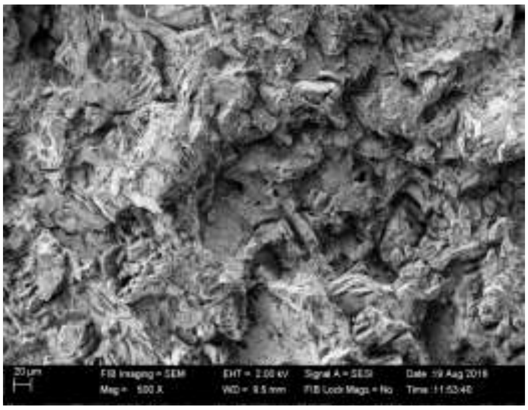
Initally there is a uniform distribution of (SiC) silicon carbide and aluminum oxide (Al_2O_3) So the microstructure is shiny in appearance, there are no pores formed in the form of dark patches and also there is only blunt edge after failure which suggest the elastic nature of material.

But as the percentage of reinforcement added to the metal matrix increases there is decrease in the shiny nature of LM6, since fly ash adds a dark grey nature to the microsturucture, then blunt ends changes to sharp edges and number of dark pores formed are more which we can observe in

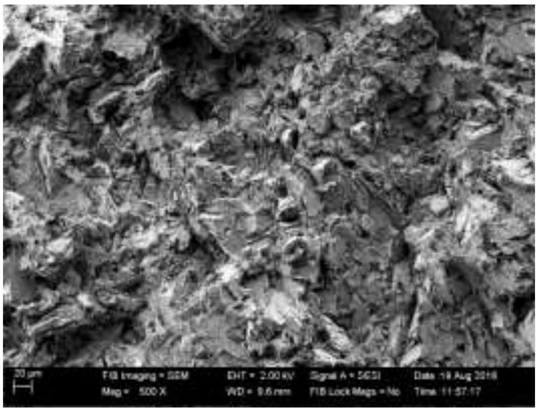
figure 9, suggesting increasing in brittle nature of the MMCs with increase in the reinforcement addition.



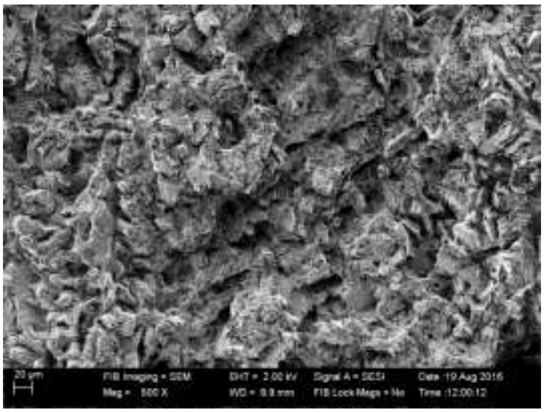
LM 6



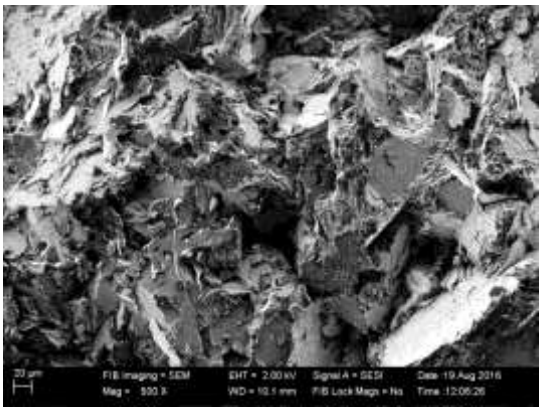
2.5%



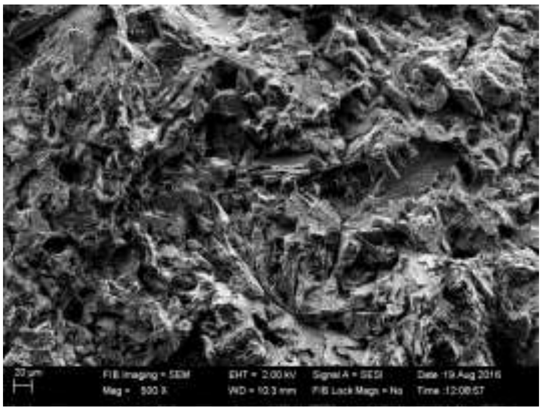
5%



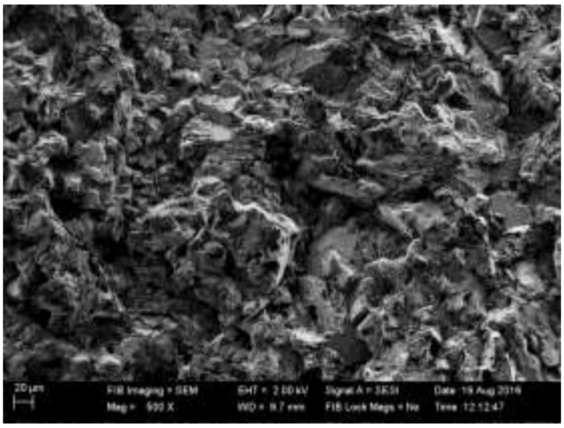
7.5%



10%



12.5%



15%

Figure 9: SEM images of LM 6 & MMCs at 500× resolution

3. CONCLUSIONS

From the results and discussions of the investigation on MMCs (fly ash reinforced in LM6 Aluminum metal matrix) the following conclusions were drawn on the fatigue behavior and casting process.

- From the liquid metallurgy and continuous stirring process fly ash was successfully reinforced in LM6 Aluminum metal matrix at the volume percentage of (2.5%, 5%, 7.5%, 10%, 12.5% and 15%).
- The microstructural study revealed the uniform distribution of fly ash reinforcement particles in the LM6 Aluminum metal matrix system with a minimal amount of porosity.
- The fatigue test conducted according to ASTM E-466 showed with an increase in fly ash reinforcement (0%-10%) into the LM6 metal matrix, there is gradual increase in the number of cycles required for failure from (0.11×10^5 to 0.51×10^5), which is the maximum increase achieved in a fatigue cycle of 52.61% from base alloy. It is because of the increase in AL_2O_3 and SiO_2within the fly ash.
- After 10% volume percentage from (12.5% -15%) there is a gradual reduction in the number of cycles to failure by 57.02% when compared with the number of cycles at 10%, due to increase in brittle nature.
- Addition of reinforcement thus increases the fatigue behavior up to the optimum volume percentage addition of fly ash, but after certain limit it decreases the fatigue behavior.

❖ The microstructure evaluation using metallurgical microscope and SEM suggest that there is uniform distribution of fly ash in the MMCs and nature of variation of fatigue behavior is observed at microscopic level after failure.

❖ From this work we can likewise conclude that we can utilize the industrial waste fly ash from which we can able to benefit economically and environmentally.

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