"Fatigue and Fracture Toughness Behavior of Al 2219/B_4C Particulate Metal Matrix Composites"

M. N.Choudhari[1], Jayant. K. Kittur[2]

[1] *Assistant Professor, Department of Mechanical Engineering, Alpha College of Engineering, Bangalore.*
[2] *Professor and Dean, Research and Development, K.L.S Gogte Institute of Technology, Belagavi.*

Abstract: **In the present study, the fatigue and fracture toughness behavior of Al 2219/B_4C particulate metal matrix composites is investigated. The composites were fabricated by reinforcing B_4C particles of 125microns with varying wt% of 2 and 4, using stir casting process. The performance of the prepared composites was compared with the alloy Al 2219 to study the improvement in fatigue and fracture toughness behavior as a result of reinforcement particles. The homogeneous dispersion of the reinforcement particles in the matrix was examined using optical microscope. The result reveals that the addition of B_4C improves both fatigue strength and fracture toughness of composites over the alloy, further by increasing the wt% of B_4C reinforcement in the matrix, there was a significant improvement in both the properties. As load increases there was decreasing cycles which indicates load has more effect on the fatigue strength. Overall, fatigue strength and Fracture toughness of the composites was improved to 63.97% and 33.34% respectively with respect to 4wt% B4C particles reinforcement compare to base alloy.**

Keywords:- **metal matrix composites (MMCs), particulate metal matrix composites (MMCp), stir casting, fracture toughness, fatigue strength**

I. INTRODUCTION

A composite material is defined as a multiphase structural material created synthetically or artificially by combining two or more materials having dissimilar characteristics.The constituents are combined at macroscopic level and are not soluble in each other and the material fabricated exhibits a desirable combination of the best properties of the constituent phases. Particle reinforced MMCs have become very important because they are inexpensive vis a vis continuous fiber reinforced composites and they have relatively isotropic properties compared to fiber reinforced composites. Aluminium MMCs have been widely developing in the recent past years due to their novel characteristics like light weight, low cost, good corrosion resistance, higher thermal and electrical conductivity. They offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix and the type of the reinforcement.

Aluminium alloys with discontinuous/particulate ceramic reinforcements have gained greater industrial importance, since they can exhibit enhanced mechanical performance, i.e strength, wear resistance and coefficient of thermal expansion [1-3], but the only drawback of these composites is that, the inclusion of ceramic reinforcement in Al matrix composites makes them brittle and exhibit low fracture toughness values [4-6]. The characters of particles play an important role in controlling the toughness of the composites, and the degradation of toughness is considered to be due to cracking of particles, non uniformity of particles and changes in matrix flow behavior [7]. It was commonly observed that an increase in volume fraction of SiC_P would decrease fracture toughness of the composite [2&7].

Literature evidences that, numerous studies have been done on mechanical behavior of particles reinforced MMCs but very few studies only have been explored on the mechanical properties of B_4C particles reinforced MMCs [8]. Thus the present study deals with the fabrication of Al 2219 alloy matrix composite reinforced with B_4C particles with varying wt% of 2 and 4 and analyzing its microstructure, fatigue strength and fracture toughness.

Toughness can be understood as a measure of energy absorbed in the process of fracture. The toughness of MMCs depends on, the matrix alloy composition, the reinforcement type, size and orientation and the processing method. Fatigue is the phenomenon of failure of a material or a component under cyclic loading. Non uniform distribution and improper bonding of reinforcement particles in the matrix phase, is the main reason for fatigue crack initiation and fatigue failure of the composites under cyclic loading [9].

II. METHODOLOGY AND EXPERIMENTAL PROCEDURE

The methodology adopted in the present work consists of the following steps:

1. Selection of materials.
2. Preparation of composite by Liquid metallurgy method (stir casting), by varying the amount of reinforcement.
3. Fabrication of cast products for the Preparation of test specimens, for evaluating fatigue and fracture behavior, for both unreinforced & reinforced Al 2219 alloy.

4. Preparation of specimens for Fatigue and Fracture toughness as per ASTM standards.
5. Microstructure study
6. Fatigue and fracture testing of specimens, as per standard test procedures.
7. Comparison of the results of composites with the results of base matrix Al 2219.

2.1 Material selection

The Materials chosen for the fabrication of the composite is, Al 2219 alloy as base matrix and B_4C particle as reinforcement material. Alloy Al 2219 has been chosen because of its applications in tip truck bodies, rail car, pressure vessels, ship building, mine skips and cages. The B_4C particle is selected for reinforcing with the base matrix due to its high hardness ranked next to diamond and cubic boron nitride. The density of the alloy and B_4C are 2.71 gm/cm^3 and 2.51 gm/cm^3 respectively. Chemical composition of Al 2219 is as shown in Table 1. Al 2219 alloy in the form of ingots and particulate B_4C are as shown in Figure 1 and 2.

Table – 1: Chemical composition of Al 2219 by weight percentage [%]

Cu	Fe	Mg	Mn	Si	Ti	V	Zn	Zr	Al
5.8-6.8	0.3max	0.02	0.2-0.4	0.2	0.02-0.1	0.05-0.15	0.1	0.1-0.25	Bal.

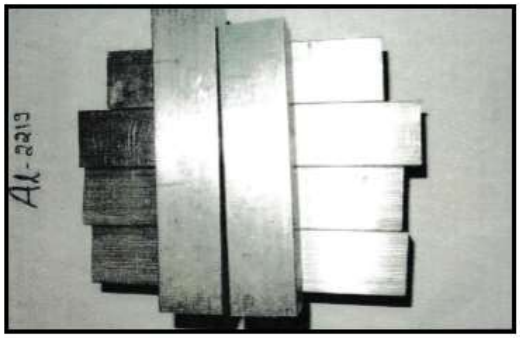

Fig -1: Al-Alloy Ingot

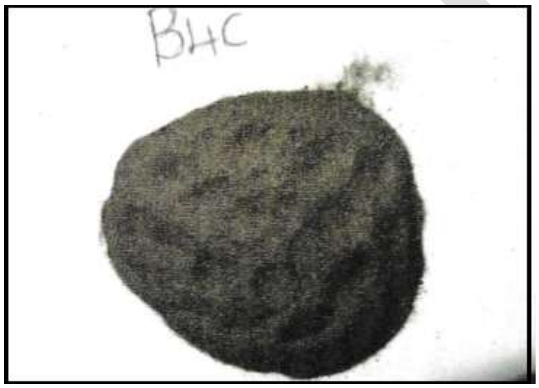

Fig-2: Boron carbide Powder

2.2 Fabrication of composites

Stir casting technique was adopted for the preparation of Al 2119/B_4C MMC. The weighed quantity of matrix metal Al 2219 was melted in a graphite crucible in an electric resistance furnace by heating it above 730^{0}C. At this stage preheated B_4C powder of particle size 125microns with varying wt% of 2 and 4 was introduced in to the vortex of the molten metal and slurry was stirred continuously for about 5 to 10 minutes by rotating the impeller at a speed of 450 rpm to ensure homogenous dispersion of reinforcement particles in the composite and then the composite melt was degassed using hexachloroethane. Again the melt was superheated above 800^{0}C and finally poured in to a preheated permanent cast iron moulds, prepared for cylindrical shape of size 15mm diameter and 125mm length and a rectangular shaped mould of size 75mm*15mm*15mm respectively for fatigue and fracture specimen preparation.

2.3 Preparation of specimens

Fatigue test specimens were machined as per ASTM (E 206) standard and charpy impact test specimens with V notch at the centre were also machined and finished as per ASTM standards, are shown in Figure 3 and 4.

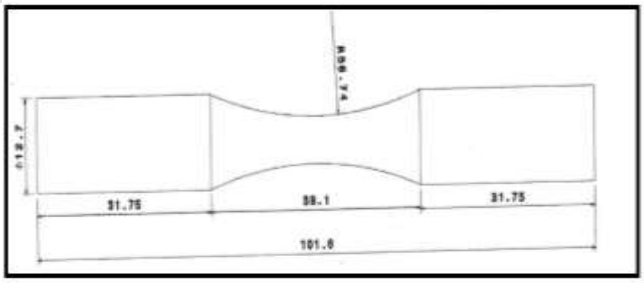

Fig-3: Fatigue test specimen, ASTM (E206)

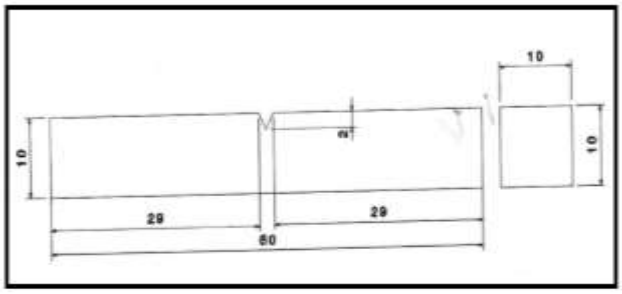

Fig – 4: Fatigue test specimen, ASTM
(Note: All dimensions in mm)

2.4 Microstructure study

The specimens for microstructure study were machined from cast specimens, then grinded in bench grinder and belt grinder for burr removal and rough finish respectively. Later specimens were polished with emery sheets of fine grade for smooth finish. The polished specimens were etched before their micro structural examination under optical microscope

III. RESULTS AND DISCUSSIONS

3.1 Micro structure evaluation

Micrographs were captured by optical microscope. Figure 5 (a) shows a microstructure of Al 2219 alloy with no reinforcement, figure 5(b) and 5 (c) shows the microstructure of Al 2219 with 2wt% of B_4C and Al 2219 with 4wt% of B_4C. From the microstructure, it is observed that white area is Al matrix and remaining dark grey area is B_4C particles reinforcement. From micrographs 5 (b) and (c) it is obvious that, more uniform distribution of reinforcement particles in composite was observed with 4 wt % of B_4C over 2 wt% of B_4C. The homogenous distribution of the reinforcement particles in the composite was observed due to the greater wettability of the B_4C with the aluminium alloy [10].

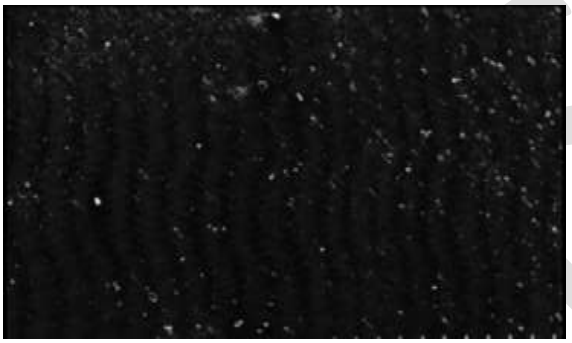

Fig - 5 (a) Al 2219 + 0 wt% B_4C

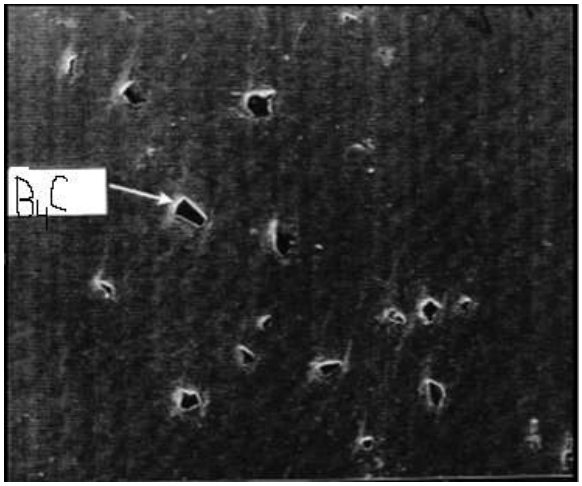

Fig- 5 (b) Al 2219 + 2 wt%B_4C

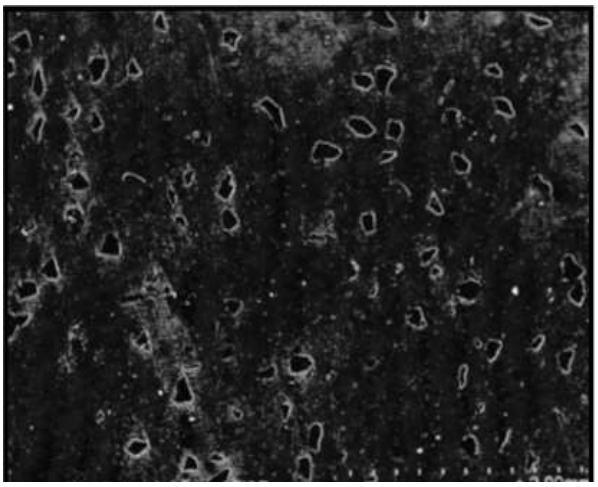

Fig – 5 (c) Al 2219 + 4 wt% B_4C

3.2 Fatigue Behavior

Fatigue behavior of Al2219/B4C composite was evaluated in terms of fatigue life. Fatigue tests, on prepared specimens were conducted on single end rotating cantilever testing machine at a constant speed of 2000rpm. Data of the test is tabulated as shown in Table-1 and specimens before and after failure are as shown in figure 6(a) and (b)

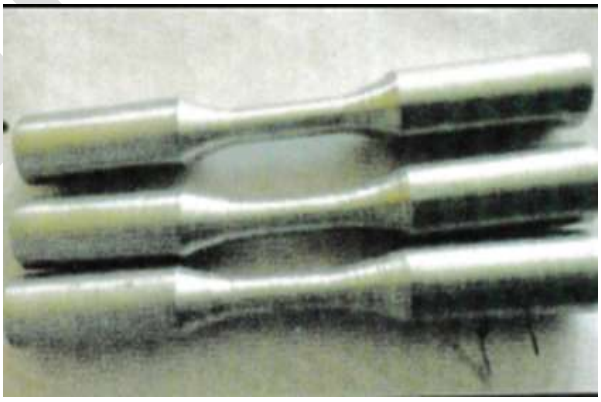

Figure 6 (a)

Figure 6 (b)

Sl.No.	Material	Load (kg)	Stress amplitude S (MPa)	Speed (RPM)	No of cycles to failure (N)
1	Al 2219	2	0.70	2000	73465
		3	1.05	2000	55691
		4	1.40	2000	31269
2	Al2219+2%B4C	2	0.70	2000	85983
		3	1.05	2000	68477
		4	1.40	2000	43289
3	Al2219+4%B4C	2	0.70	2000	98421
		3	1.05	2000	76985
		4	1.40	2000	48876

Table – 1: Fatigue test data

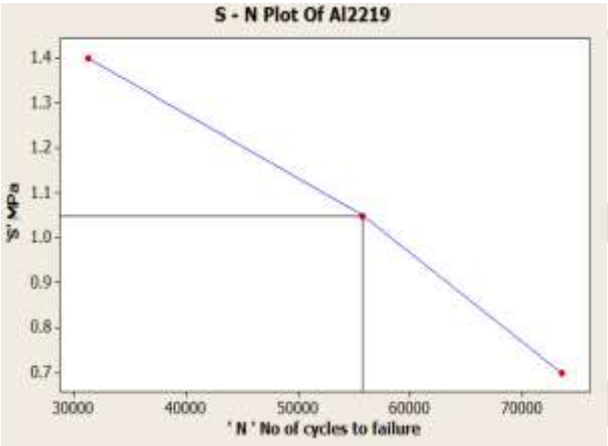

Figure 7 (a)

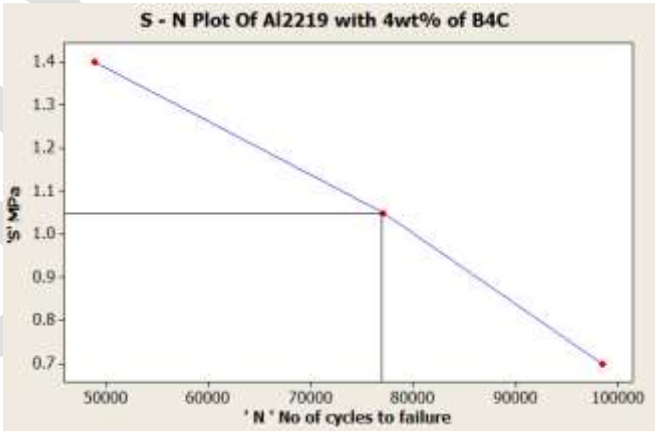

Figure 7 (c)

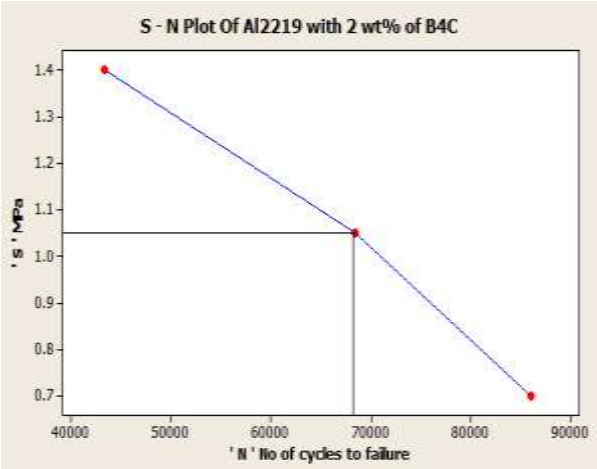

Figure 7 (b)

Fatigue behavior of all test specimens is depicted from S-N plots as shown in Figure 7, where all the components exhibited typical S-N behavior, reaching the fatigue limit before 10^5 cycles, which was set as the run- out point for the fatigue experiments.

Al2219 with 4wt% of B4C, showed a higher fatigue life over 2 wt% B4C reinforcement and pure alloy Al2219. At a absolute stress level of 1.05MPa fatigue life of Al2219, Al2219 with 2wt% of B4C and Al2219 with 4wt% of B4C were recorded to be 55691, 68477 and 76985 cycles. This is due to uniform distribution and proper bonding of reinforcement particles in the matrix phase, which otherwise the main reason for fatigue crack initiation and fatigue failure of the composites under cyclic loading [9]. The composite with 4wt% B_4C particles reinforcement, showed an

improvement of 63.97% more fatigue life than Al2219 alloy.

3.3 Fracture toughness

Fracture behavior of the composites was evaluated in terms of fracture toughness and fracture strength through Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. Tests were conducted on pendulum type impact tesing machine and results are tabulated in table 2. Test specimens before and after fracture are as shown in figure 6 (a) and (b).

Sl.no.	Material	Width 'b' (mm)	Depth at notch 'd' (mm)	C/SArea 'A'(mm2)	Frictional Energy N-m	Fracture Toughness 'U' (Nm)	Fracture strength K=U/A Nm/mm2
1	Al2219	10	8	80	0.2	3.924	0.04905
2	Al2219+2%B4C	10	8	80	0.2	5.886	0.0745
3	Al2219+ 4%B4C	10	8	80	0.2	11.772	0.1471

Figure – 6 (a)

Figure – 6(b)

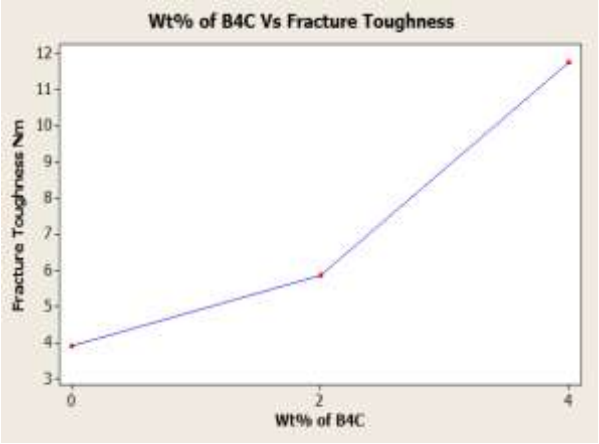

Figure 7(a)

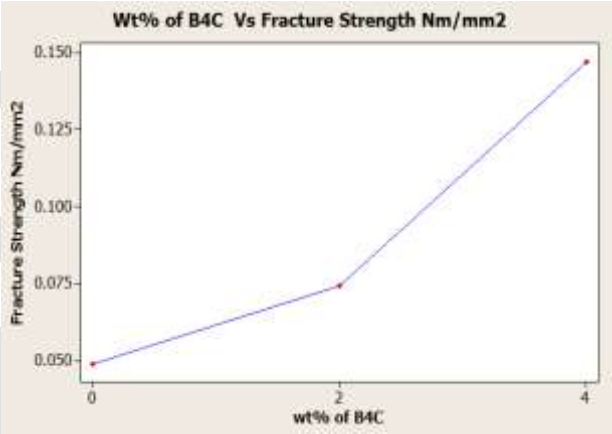

Figure 7(b)

From the plots shown in figure 7a and 7b it was clearly interpreted that as weight percentage of B4C particulates in metal matrix increases from 0, 2, and 4 there was drastic increase in fracture strength or fracture toughness. This is mainly due to good bonding between matrix and reinforcement particulates and good dispersion of B4C particulates in matrix. The 4wt% B_4C particles reinforced composite showed an increase of 33.34% fracture toughness more than Al2219 alloy.

IV. CONCLUSIONS

The present work focused on evaluation of fracture and fatigue behavior of Al 2219/B4C particulate metal matrix composites. MMC_P with varying wt% of 0, 2 and 4 were successfully fabricated using liquid stir casting process. The homogenous dispersion of B4C particles in the metal matrix was attained, since B4C particles exhibit a greater wettaability with aluminium alloy, was observed during microstructure evaluation under optical microscope. With the increment of B4C reinforcement in Al 2219 alloy matrix, both fatigue life and fracture toughness gets improved due to- reinforcement

type, size and uniform distribution of particles in the matrix. Analysis shows that, 4 wt% of B4C reinforcement in Al 2219 matrix has improved the fatigue life by 63.97% and fracture toughness by 33.34% over Al 2219 alloy.

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