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Fatigue Life and Fracture Behaviour of Aluminium Based Metal Matrix Composite by Stir Casting Process

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Abstract - *Recent Advancement in automotive, military, and aerospace industries requires supplanting the conventional materials with newer materials having properties that would accomplish high strength, low weight, and are energy efficient. Consequently, composite materials are found to be an alternative that would fulfill the areas of concern like environment and energy. Composite Materials are the results of a combination of two or more chemically and physically different phases where the reinforcement element and matrix are integrated with achieving optimum material characteristics like fatigue life and fracture toughness. In this project, we have chosen B_4C as the reinforcement material because B_4C is one of the third hardest man-made materials available. This composite is manufactured by the Stir casting process for different weight fractions of B_4C by increasing twice the % from 0 to 3%, 3% to 6%, and then to 12%. After getting the casted products, they are machined it as a cylindrical material for fatigue test and chevron notch material for fracture test as per ASTM standards. Materials are tested for different loads and results were obtained. It is evident that fatigue strength and fracture toughness of the composites were enhanced with the addition of the wt. % of the reinforcement.*

***Key Words*: Metal Matrix Composite, Stir Casting, Al6061- B_4C MMC's, Fatigue life and Fracture toughness, ASTM Standards.**

1. INTRODUCTION

The composite material is one which is composed of at-least two phases combined together to produce a material having properties that are different than the properties of those elements on their own. In practice, most composites consist of bulk material (the matrix) and a reinforcement of some kind, Matrix forms the continuous phase whereas the other acts as a discontinuous phase (reinforcement). A composite material in recent times is gaining a lot of importance due to their characteristics like high strength-to-weight ratio, higher stiffness, better fatigue, wear, and corrosive resistance. Few characteristics that make Al6061 Stand out from the rest are high specific strength, hardness, and fatigue properties, particularly fracture toughness. Low cost, better formability and optimum heat treatment to alter the strength of the material are properties that make it suitable for various applications majorly aerospace, automobile marine, and lightweight engineering applications. [1][2]. Hence, in this paper, attempts are made to develop Al6061- B_4C AMC's by varying 3, 6, 12 wt. % B_4C to study the fatigue life and fracture strength as per ASTM standards.

2. LITERATURE SURVEY

[1] Gopal Krishna U B et.,al. have fabricated a composite material by Stir Casting method, where Aluminium was used as matrix and 105Mm Carbon fiber used as reinforcement. The amount of boron carbide varied from 6, 8, 10, 12 weight percentage. The micro Vicker's hardness of AMCs was found to be maximum (121.31 VHN) for 12% weight fraction. The tensile strength was found to be maximum (176.37MPa) for 8%weight fraction.

[2] Vikas Kumar et.,al. worked mainly on fabrication of Al 6061 reinforced with 4% B_4C (particle size 100 mesh) & 4% Cu and method used for fabrication is stir casting method. The value of tensile strength increase up to 20% and hardness increase upto15% due to addition of B_4C & Cu particles.

[3] K. Ch. Kishor Kumar et.,al. studied the mechanical properties of Al6061 reinforced with B_4C particles of different weight fractions by stir casting technique. It was also thought- out that 4% B_4C composite shows better mechanical properties than the other compositions. Optical microscopy and scanning electron micrographs showed uniform distribution of reinforcement. The ultimate tensile strength is maximum of 153 MPa is at 2.5 % of reinforcement.

[4] Niranjan D.B. et.,al. worked on the fabrication of Al2219 reinforced with B_4C and MoS_2 with different weight fractions using Stir casting process. Studied the fatigue crack growth and fracture behavior of the aluminum composite according to ASTM standards and observed that maximum load bearing capacity to open the crack surface of prepared composite significantly increased. Effect of addition of reinforcement increased the fracture toughness by 27% maximum for Al2219-3%B_4C-MoS_2 composite.

3. METHODOLOGY AND APPROACH

Al6061 based composite is prepared using a stir casting process. An electric melting furnace with graphite crucible is used for melting. Aluminium alloy is melted in a crucible by heating it in a melting furnace at 900°C for two to three hours. The aluminium particles and the permanent moulds of cast iron are heated in order to reduce the effect of chilling during solidification. Coverall is added to increase the wettability and separation of slag. After degassing, the preheated aluminium particles are added slowly into the crucible while continuing the stirring process. Stirring is maintained up to 10 minutes using a mechanical stirrer. The amount of reinforcement is varied with 3%, 6% and 12% of B_4C [3].

3.1. Preparation of the Specimen

1. Turning is a metal cutting process used for the generation of cylindrical surfaces. Typically the work piece is rotated on a spindle and the tool is fed into it radially, axially or both ways simultaneously to give the required surface. The term turning, in the general sense, refers to the generation of any cylindrical surface with a single point tool. [4]

2. For fracture test specimens the castings are machined in the milling machine and wire-cut EDM to generate chevron notch shape as per the ASTM standards to evaluate fracture toughness. [4]

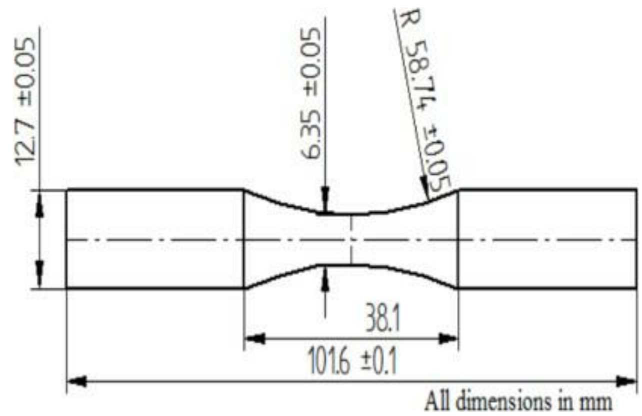


Fig.1. ASTM standard fatigue test specimen is ASTM E606 with specified tolerances

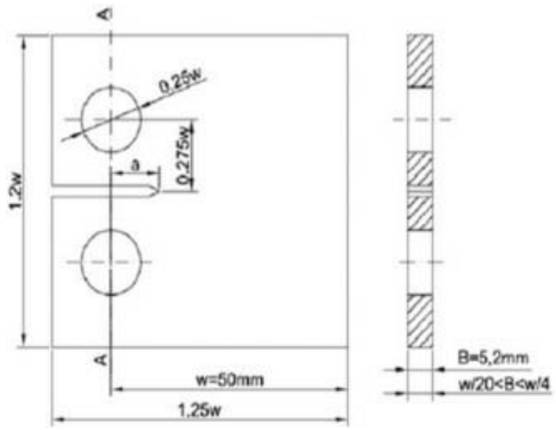


Fig.2. ASTM standard for fracture test specimen is ASTMC1421-18 with specified tolerances.

3.2. Test Description

1. Fatigue test is performed by Rotating bending machine as per ASTM E606. A cylindrical smooth specimen is mounted and loaded from both ends using rotating chucks. A weight is suspended from one side of the specimen to vary the bending stresses experienced by the specimen surface. Initially, the specimen will experience tensile stresses at its top surface and compressive stresses at its bottom. As the specimen rotates 180 degrees, the stresses will be reversed and the top will be under compressive stresses while the bottom will be under tensile stresses. When the specimen completes one full rotation, the specimen surfaces would have experienced one full loading cycle. Numbers cycles for failure were recorded to calculate fatigue life. Similar Analyses were carried out for different weight fractions of B_4C. [4]

2. Fracture test is conducted using UTM for different weight fractions of B_4C reinforced composites as per ASTM C1421-18. Fracture toughness tests are conducted on pre-cracked specimens using a relevant fixture. The test procedure involves the manufacture of fixtures which depends on the geometry of test specimen. Pin and clevis fixture is used to hold the specimen between upper and lower jaws. Specimen is mounted on UTM and loaded from both ends using fixtures. As the jaws move away, the specimen will experience tension initially due to the pulling action. As load increases crack nucleation will occur in the specimen. This crack will propagate across slip planes under the influence of shear stress. Readings from UTM were recorded for different weight fractions of B_4C. [4]

4. RESULTS AND DISCUSSIONS

4.1 Fatigue Behavior of Al6061- B_4C AMC

Fatigue tests are conducted for Al6061 with different Weight fractions of B_4C on a rotating bending machine and number of cycles of failure are recorded and tabulated in the Table.1 as shown below.

Table -1: Average no. of Cycles of Failure

Wt. % of Reinforcement	Average No. of Failure cycles
0	5,28,368
3	1,76,339
6	1,55,941
12	31,023

During the test, presence of B_4C particle in the matrix forms micro cracks at the interfaces which in-turn forms weak interphase between the matrix and the reinforcement particulates. This results in formation of voids leading to the propagation of cracks at faster rate, hence number of cycles before failure decreases. Addition of the hard B_4C particles leads to a growth in the brittle nature intern reduces the fatigue life and faster failure of the composite material. Values of ‘S’ for different weight fraction of a composites were calculated to draw the S-N curve (Chart 1).

$$S= (14.479/\sqrt{N})+96.5 \text{ Mpa}$$

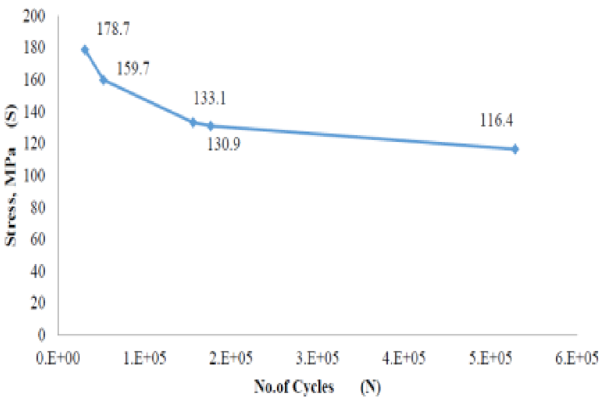


Chart -1: Stress v/s Number of Cycles

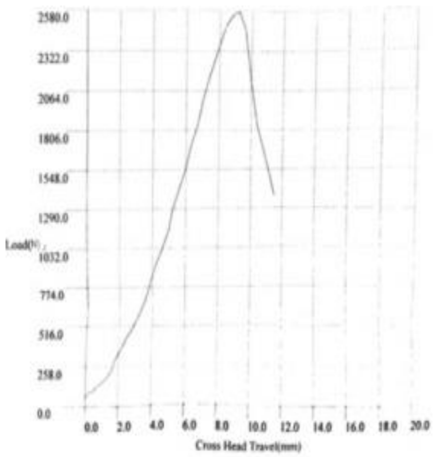
Fig.3.Fatigue Failure Specimens

Fatigue failure specimens (Fig.3) are observed after test, it is found that as the percentage of the B_4C increases, the surface near the failure area has more sharp edges which indicate increase in brittleness. Thereby material with less amount of B_4C experiences ductile nature of fracture and the material having larger amount of B_4C experiences brittle nature of fracture.

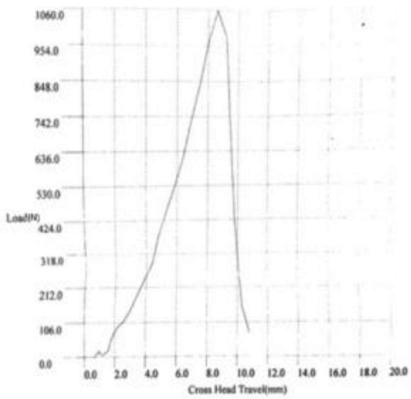
4.2 Fracture Behavior of Aluminum Metal Matrix

A fracture test on different weight fractions of B_4C is conducted to determine the fracture toughness and stress intensity factor. The maximum load carrying capacities of each specimen are noted to estimate stress concentration factor.

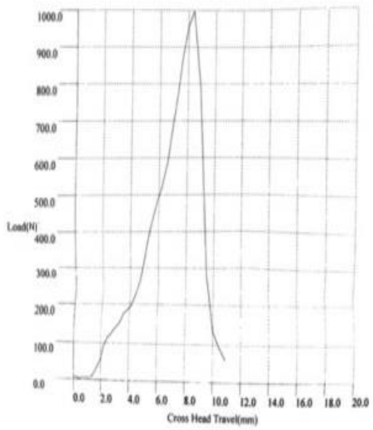
Load and displacement plots for Al 6061 and B_4C reinforced composite at different weight fractions.



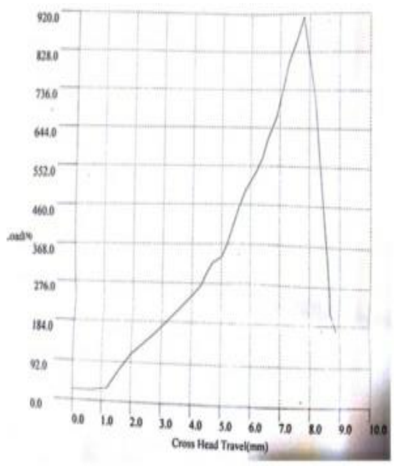
Al +0% B_4C



Al +3% B_4C



Al +6% B_4C



Al +12% B_4C

Chart -2: Load v/s Cross Head Travel (COD)

From the above graphs maximum load and displacement is considered and same is shown in the below table 2.

Table 2. Peak Load with Displacement % of B_4C

wt.% of B_4C	Load (N)	Displacement(mm)
0	2580	11.5
3	1060	11.2
6	1000	11
12	910	8.9

From the above table and graphs, it is noticed that with the addition of B_4C load carrying capacity decreases due to the clustering of B_4C particles in the neighbor matrix. Also, reinforcement enhances the energy required to open the crack and crack propagation. Hence, fracture toughness of B_4C reinforced composites increases. Increase in the fracture toughness shows the uniform distribution, formation of fine particles during the casting process, a strong interfacial mechanism developed between matrix and the reinforcement, the interaction of B_4C particles with a crack tip forms residual thermal stress which blocks the initiation of internal cracks in the composites. Due to these reasons, Crack opening displacement decreases with increase in wt. % of B_4C reinforcement.

Fig.4. Fracture Failure Specimens

Fractured test specimens (Figure 4) are observed after conducting the test, it is noticed that crack propagation takes place almost perpendicular to the load application direction; it is true for all conventional materials. Further, it is proven from the literature survey that composite developed with B_4C reinforcement is a homogeneous material; it indicates that B_4C particles are distributed uniformly throughout the casting. Hence the Al 6061- B_4C developed by stir casting process seems to be free of casting defects. Also, it is evident that an increase in the percentage of B_4C leads to the formation of the brittle phase.

Main objective of conducting these tests is to determine the stress intensity factor using Peak load (Pmax) or Maximum load using equation (a). Stress intensity factors for different weight fractions are tabulated in the table 3.

KIC = (Pmax / B X W) (pi x a) 1/2 ---- (a)

Where,
KIC = Stress Intensity Factor.

Pmax = Maximum Peak Load.

B = Thickness of the Specimen.

W=Width of the specimen.

a=Length of the notch in the specimen.

Table 3. Peak Load with Displacement % of B_4C

wt.% of B_4C	Peak load (Pmax)(N)	KIC (MPa.m1/2)
0	2580	68.12
3	1060	27.98
6	1000	26.40
12	910	24.02

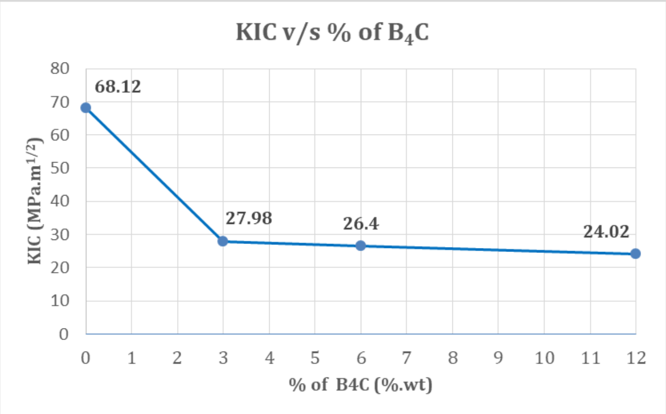


Chart -3: Load v/s Cross head travel (COD)

Table (3) shows the Stress Intensity Factor for the different B4C reinforcements. From the chart 3, it is observed that Al 6061 base alloy has KIC value as 68.12 MPa.m$^{1/2}$ whereas 12% B_4C reinforced composite material has KIC value as 27.98 MPa.m$^{1/2}$ for the same test conditions. It indicates that stress concentration near the vicinity of the crack tip decrease around 64.7% with the addition of the reinforcement hence the stress level in the components decreases with a reduction in stress intensity factor. This is due to the uniform distribution of B_4C particles, an increase in rigidity, and a continuous increase in fracture toughness.

5. SCOPE FOR FUTURE WORK

There are various modern industrial machinery parts that ought to be advanced for superior specific strength and stiffness of MMC. There is a lot of potential for researches especially to optimize the process route, time, and cost of production. The following may be the extent of research in the field of Al-6061- B_4C, these results applicable for Al6061- 3%, 6%, and 12% MMCs. To sum up the outcome, some more trials are required with an assortment of lattice blends. The Stir Casting process is adopted for the investigation of fatigue and fracture properties. Anyway, the improved outcomes can be acquired with a better gating framework.

1. The prime challenge is controlling the temperature of the melt in the furnace. Subsequently the impact of the kind of heater and its temperature control components are the area of research.
2. In the present work fatigue and fracture, properties are investigated. Other mechanical properties as required by the designer for the determination of material are to be researched.
3. Impacts of various filler material on the matrix combination are the areas that are still to be researched.
4. The effect of mold design, riser design in the production of metal matrix composites might be an intriguing field of examinations.
5. The future area of research can include a hybrid metal matrix process parameters.
6. Nano B_4C MMCs may attract the future researcher.

6. CONCLUSIONS

Fatigue strength and number of cycles to failure of Al 6061- B_4C composites were estimated using a rotating bending machine as per ASTM E606 standard.

1. It is noticed from the results that the service life of the composites decreases with an increase in wt. % of the B_4C intern enhances fatigue strength. Presence of B_4C particles forms micro-cracks and voids at the interfaces lead to weak bonding. between the matrix and the reinforcement which results in the propagation of cracks at a faster rate, hence the number of cycles before failure decreases with the addition of B_4C reinforcement.

2. It is observed from the results that fatigue strength of the composites developed was enhanced from 116.4 MPa to178 MPa with the addition of B4C particles.

Fracture toughness, Crack Opening Displacement intensity factor of Al 6061- B_4C composites were estimated per ASTM C1421-18 standard.

1. It is observed that Al6061 base alloy possesses stress concentration near the vicinity of the crack tip, and it decreases around 64.7 %from pure Al6061 to 12 % of B_4C Hence, the stress level in the components decrease with a reduction in stress intensity.

2. Increased rigidity and continuous increase in the fracture toughness are seen due to uniform distribution of B_4C particles.

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