



# Fatigue Analysis of Hybrid Aluminium 7075 Composite Gears

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**Abstract** Aluminium has got a greater potential in wide range of applications due to its low weight, higher resistance to corrosion. But its low strength and less resistance to wear make it unsuitable for large number of the application. Therefore, these aluminium alloys are added with some of the reinforcements in order to create hybrid aluminium metal matrix composites (HAMCs). HAMCs are used in applications like automotive, aerospace, marine and specifically in preparations of gears. These HAMCs gears can be used in gear pumps, gear box, gear reducers, actuators, etc. Through simulation study, these HAMC gears can be analysed for their fatigue characteristics. Therefore, in this study, gears of Al 7075 with varying wt.% of SiC and fixed wt.% of Al<sub>2</sub>O<sub>3</sub> are considered for their fatigue characteristics. ANSYS Workbench is used as a simulation tool to predict the fatigue life of these gears. Simulation results indicated that with increase in wt.% of reinforcements, fatigue life increases.

**Keywords** Hybrid aluminium metal matrix composites (HAMCs) · Al 7075 · SiC · Al<sub>2</sub>O<sub>3</sub> · Fatigue life · ANSYS

## Introduction

HAMCs having incomparable properties of high fatigue strength and hardness, less weight with improved wear resistance. Especially, these are substituting ferrous-based materials in various sectors like automotive, defence, aviation [1]. Aluminium MMCs has provided excellent fatigue behaviour due to its low crack propagation rates when associated with their unreinforced counterpart [2]. SiC has developed hardness and better chemical resistance in diverse variation of atmospheres [3]. In various automobile applications like car brakes, clutches SiC grains can be sintered to make harder ceramic material [4]. Flexural strength increased up to 450 MPa with inclusion of 10 wt.% of SiC in Al 7075 [5]. Similarly, Al<sub>2</sub>O<sub>3</sub> has achieved its application in preparation of refractories, polishing [6]. Enhancement of wear resistance was observed when Al<sub>2</sub>O<sub>3</sub> was reinforced into Al 7075 [7]. Simulation studies illustrate use of Al MMCs reinforced with SiC in creation of gears [8]. FEM (Finite Element Method) analysis found that maximum stress is accumulated at the tip of the teeth [8]. Through FE (Finite Element) analysis, it was demonstrated about use of Al MMCs reinforced with SiC to carry power up to 24 kW with lesser possibilities of failure [9]. Simulation analysis provides proof about usage of Al MMCs instead of cast iron for application of gears [10]. Amongst available grades of Aluminium, Al 7075 has shown greater potential in many of the applications therefore, most of the research work on Al MMCs is focussed on this material [11]. Experimental investigation has illustrated about damage in Al-bronze gear when operated at 3N-m [12]. Through published research work, it is observed that most of the simulation study on Al MMCs gears is on stress analysis, whereas there is lack in study of fatigue life. Fatigue life is also a critical parameter that should be analysed during study of gears. Therefore, in

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this present work, firstly, experimentally S/N curve values are determined for HAMCs with varying wt.% SiC (3,6,9) and fixed 5 wt.% of Al<sub>2</sub>O<sub>3</sub>. These S/N curve values are used to build material library in ANSYS and finally, through simulation fatigue life is determined.

### Materials and Methods

#### Processing of HAMCs

Stir casting process an economical and convenient process used in preparation of Al MMCs is used for processing of HAMCs. Two reinforcements namely SiC and Al<sub>2</sub>O<sub>3</sub> are added to Al 7075 alloy to make it HAMCs. SiC added in varying wt.% of 3,6,9 and Al<sub>2</sub>O<sub>3</sub> with a fixed wt.% of 5. Al 7075 alloy was melted in a mild steel crucible at about 750 °C. Subsequent to melting degassing process was accomplished by adding tablets of hexachloroethane. The molten metal was stirred by using zirconium coated mild steel stirrer with 400 rpm for a time duration of 15 min. During this stirring process, SiC and Al<sub>2</sub>O<sub>3</sub> were added which were preheated at 250 °C. At the end, HAMCs melt is poured into heated metal die. Once molten metal gets solidified, the ingots are separated for metal die. Later these ingots are machined to prepare fatigue specimens as per ASTM standards.

#### Fatigue Test

Fatigue failure usually begins with a small surface crack, undetectable with naked eyes and grows rapidly deeper causing the component to fail. Repeated loads can be applied in four fashions namely reversed axial loads, reversed bending loads, reversed torsional loads and combined loads. The subject machine applies load in reversed bending fashion so that the fibres of the test specimens are stressed once in tension and once in compression, and the stresses vary in a Sinusoidal form. The bending moment in the cross section of specimen is constant during the test. Fatigue test is performed on fatigue testing machine (Model Number: FTG-8D). To obtain S–N curve for HAMCs, specimens rotating

bending fatigue tests were performed. The applied stress is determined by below mentioned equation [13]:

$$\sigma_b = \frac{125.7 * 32 * P}{\pi d^3}$$

where  $\sigma_b$  = bending stress (MPa),  $P$  = Applied load (N),  $d$  = minimum diameter of fatigue sample (mm).

The procedure followed during fatigue test is as follows:

1. Measure the diameter and length of test specimen using Vernier callipers.
2. Slide one end of the specimen into the shaft end and the other end at the load end.
3. Apply the load required, depending upon the bending moment to be imposed by moving the loading weight and lock the loading weight by using locking screw
4. Reset the counter to show all ‘0’s before running the test.
5. Start the motor, thus starting the test. The motor will stop automatically after the specimen fails the counter will have recorded the number of revolutions completed by specimen.

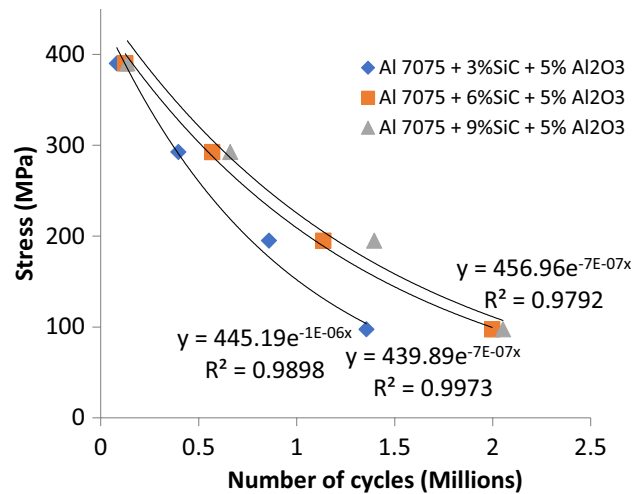


Fig. 1 Effect of reinforcement on fatigue life of HAMCs

**Table 1** Fatigue test results (Applied stress Vs Number of cycles) for HAMCs

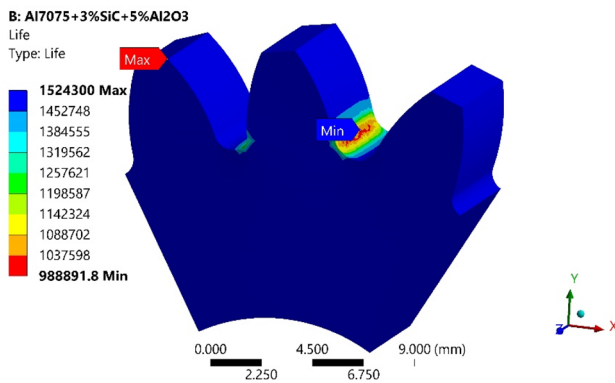
Applied Stress (MPa)	Al 7075 + 3%SiC + 5% Al <sub>2</sub> O <sub>3</sub>	Al 7075 + 6%SiC + 5% Al <sub>2</sub> O <sub>3</sub>	Al 7075 + 9%SiC + 5% Al <sub>2</sub> O <sub>3</sub>
390.19	8.2569E4	1.25535E5	1.36235E5
292.65	3.96520E5	5.68852E5	6.61102E5
195.1	8.58605E5	1.135956E6	1.395670E6
97.55	1.355680E6	1.996986E6	2.052310E6



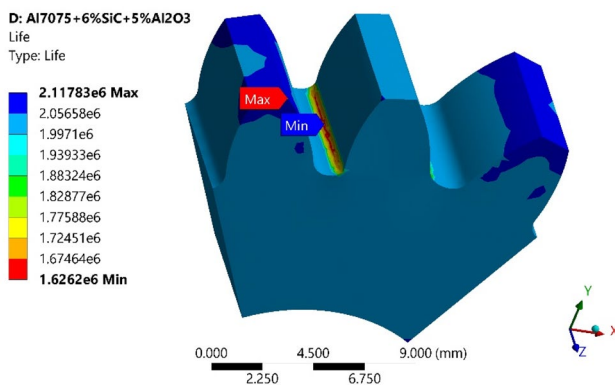
**Fig. 2** Fatigue test specimens, A—Before testing, B—After testing

**Simulation**

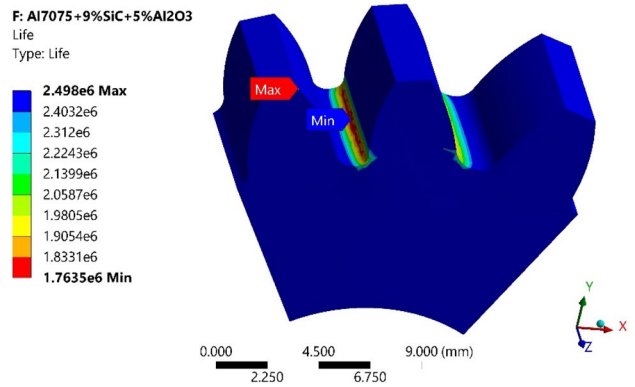
The 3-dimensional CAD model of gear having three teeth was done using SolidWorks platform. The CAD model in IGES format is imported in Ansys Workbench 2023R1 version for behaviour of gear under fatigue. The new material library is build considering mechanical properties and along



**Fig. 3** Fatigue life results for Al 7075 + 3%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load



**Fig. 4** Fatigue life results for Al 7075 + 6%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load



**Fig. 5** Fatigue life results for Al 7075 + 9%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load

with S-N curve data of HAMCs. The material data, mesh type, mesh element size and applied boundary conditions play a vital role in getting reliable and accurate results using Ansys tool. The maximum element size of 0.5 mm is taken for the study. The boundary condition includes applying fixed support and force by creating coordinate system on the gear flank with Z axis rotated by 19° load angle. Load of 587 N, 1175 N and 1762 N was applied on the gear tooth at load angle of 19°; these loads were taken from experimental study. The three teeth gear model was subjected to static structural. Equivalent stress and total deformation results were obtained from static structural analysis. The stress-based approach was used for fatigue analysis. Fatigue tool with life, damage, factor of safety was also inserted to obtain results related to fatigue behaviour of gear. Strength factor Kf for fatigue is taken as 1 with complete reversal of load with constant amplitude, stress life analysis; mean stress correction as Goodman failure criteria was selected for the analysis. The design life of the gear model is assumed to 1E06 cycles.

**Results and Discussion**

**Fatigue Test**

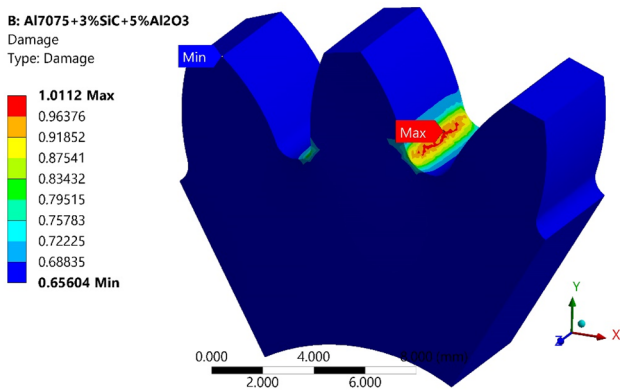
Specimens for the fatigue test were with 8 mm diameter and 96 mm length at gauge whereas 12 mm diameter and 65 mm length at gripping region. The total length of the specimen was 226 mm. The attained fatigue results are tabulated in Table 1. The S-N curves as represented in Fig. 1 indicates that as the weight fraction of reinforcement increases fatigue life increases. Since here weight fraction of SiC is varied, it can be attributed that SiC has influenced greatly in increase of fatigue life of HAMCs. Same is been reported

**Table 2** Fatigue life values for different HAMCs

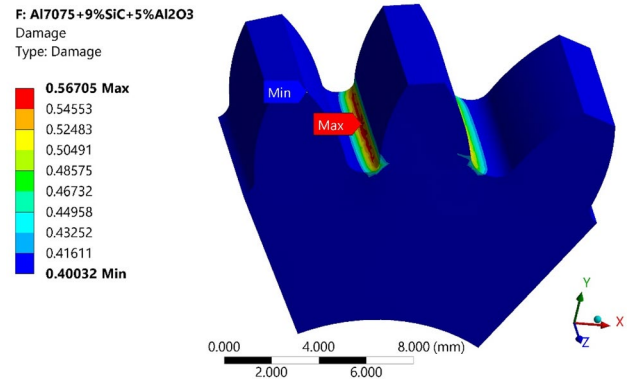
Load in N	Al 7075 + 3%SiC + 5%Al <sub>2</sub> O <sub>3</sub>	Al 7075 + 6%SiC + 5%Al <sub>2</sub> O <sub>3</sub>	Al 7075 + 9%SiC + 5%Al <sub>2</sub> O <sub>3</sub>
587	9.8889E5	1.6262E6	1.7635E6
1175	4.2616E5	7.0275E5	8.7784E5
1762	2.4767E5	6.094E5	7.8176E5

**Table 3** Damage values for different HAMCs

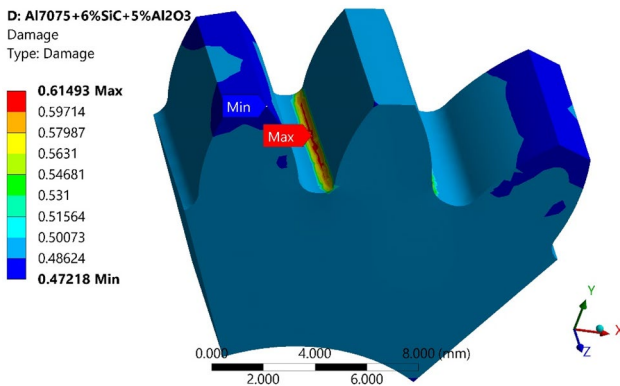
Load in N	Al 7075 + 3%SiC + 5%Al <sub>2</sub> O <sub>3</sub>	Al 7075 + 6%SiC + 5%Al <sub>2</sub> O <sub>3</sub>	Al 7075 + 9%SiC + 5%Al <sub>2</sub> O <sub>3</sub>
587	1.0112	0.6149	0.567
1175	2.3415	1.2792	1.1392
1762	4.0376	1.641	1.423



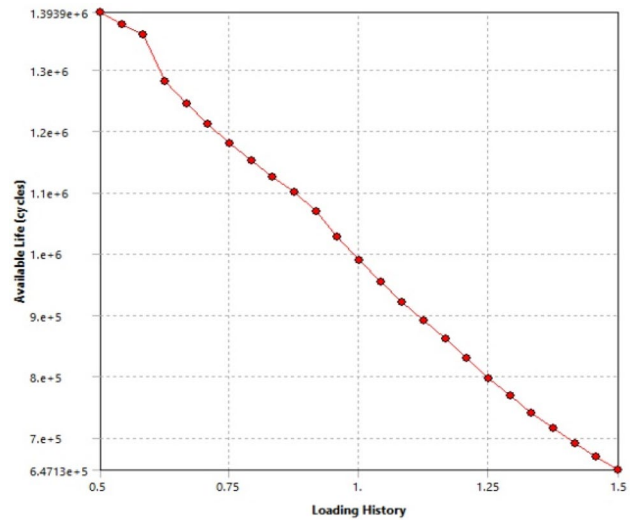
**Fig. 6** Fatigue damage results for Al 7075 + 3%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load



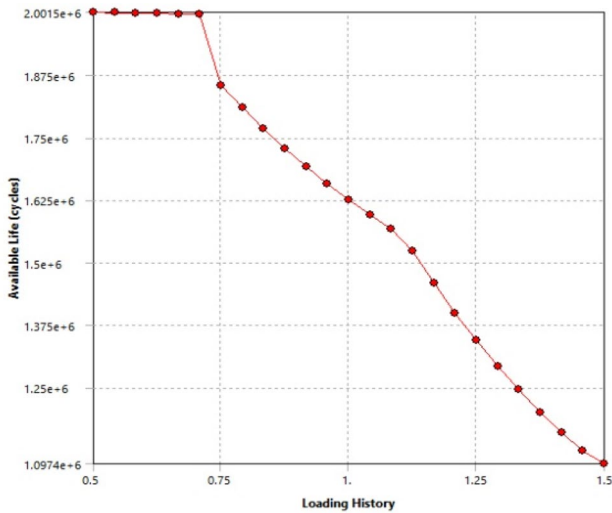
**Fig. 8** Fatigue damage results for Al 7075 + 9%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load



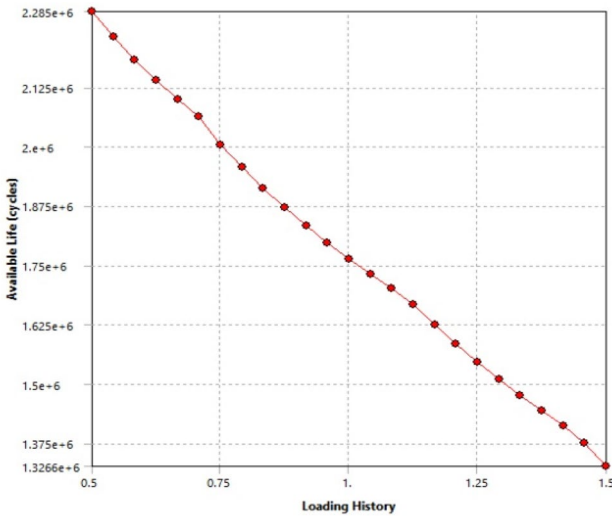
**Fig. 7** Fatigue damage results for Al 7075 + 6%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load



**Fig. 9** Fatigue sensitivity results for Al 7075 + 3%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load



**Fig. 10** Fatigue sensitivity results for Al 7075 + 6%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load



**Fig. 11** Fatigue sensitivity results for Al 7075 + 9%SiC + 5%Al<sub>2</sub>O<sub>3</sub> at 587 N load

by literature [14]. Specimens before and after testing are exposed in Fig. 2.

**Fatigue Life**

Fatigue analysis has been extensively worked upon by many researchers globally, and this has led to in the gathering of great amounts of understanding and theoretical records. The prediction of fatigue life for given member is based on two commonly used estimation techniques namely Stress life approach and Strain life approach. Both these has their own set of limitations. Since this fatigue life, predicting techniques have their own characteristic features in estimating

life of member precisely. It is very important to select correct method depending upon the application and loading condition. Stress life approach (Nominal Stress analysis method) is used for high cycle fatigue conditions whilst strain life-based approach (local stress–strain life analysis method) for low cycle fatigue condition. Figs. 3, 4 and 5 indicate fatigue life for different HAMCs, based on design life of 1E6 cycle of loading. The contour in blue colour indicates maximum fatigue life more than designed life. Whilst contour in red colour indicates minimum fatigue life. The corresponding minimum fatigue life cycles for different HAMCs are tabulated in Table 2. The lesser fatigue life is observed at the root region of the gear tooth because of higher stress accumulation at that region. It is evident from study carried by researchers [14, 15] that with increase in weight percentage of reinforcements (SiC and Al<sub>2</sub>O<sub>3</sub>) in HAMCs improved fatigue strength and thus, fatigue life of gear. From Table 2, it is evident that with increase in load, HAMCs gears showed decreased number of cycles but could not surpass design life. For 587 N load, HAMCs gears having 6, 9% wt.% SiC surpassed design life indicating infinite life.

**Fatigue Damage**

Fatigue damage is defined as the ratio of design life to available life. For Fatigue Damage, values greater than 1 indicate failure before the design life is reached [16]. The design life is set for 1E06 cycles. The fatigue damage for different HAMCs is indicated in Table 3. For 587 N load, HAMCs gears having 6, 9% wt.% SiC surpassed design life and corresponding fatigue damage values are less than 1 and hence, life is infinite. With increase in load, HAMCs gears showed increased number of cycles but could not surpass design life. Hence, fatigue damage values for higher load are more than 1 which is also an indication of finite fatigue life. Fatigue damage results are revealed in Figs. 6, 7 and 8. The contour in red colour indicates fatigue damage value more than 1 at root region of gear tooth region which results for finite life, whereas area shown in blue contour survives for infinite life.

**Fatigue Sensitivity**

Fatigue sensitivity is graphical representation of how the fatigue results change as a function of the loading at the critical location on the model. To study the sensitivity of HAMCs gear’s life, the load is set from 50% as lower variation of the load up to 150% as upper variation. From Figs. 9, 10 and 11, it is observed when the load is increased up to 150% upper variation, the life declines to 6.4173E5 cycles, 1.0974E6 cycle and 1.3266E6 cycles for HAMCs gears having 3, 6, 9% wt.% SiC, respectively.

## Conclusion

The present study investigated fatigue life prediction method using FE modelling. The Stress life approach (nominal stress method) is used. The experimental S-N curves with other mechanical properties for HAMCs were used to build new material library in Ansys. The HAMCs gear tooth is analysed for fatigue life, damage and sensitivity. From the analysis, following conclusions are drawn.

- With increase in weight percentage of reinforcements, fatigue life enhanced. When load is increased, HAMCs gear could not surpass design life of 1E06.
- The fatigue damage obtained for HAMCs gear with 6, 9% wt.% SiC for lower load is less than 1 which indicated infinite life.
- In order to study the influence of loading history on life, fatigue sensitivity can be used.

Using these fatigue design, one can successfully predict fatigue life of any member under study. With invention and application of newer materials, fatigue life investigation can be combined with new technologies to upsurge the applicability of fatigue life prediction techniques.

**Author Contributions** All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by SHB, SCD and SBM. The first draft of the manuscript was written by SHB, SCD and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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### Declarations

**Competing interests** The authors have no relevant financial or non-financial interests to disclose.

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