Fatigue Behavior of Aluminium Reinforced Metal Matrix Composites (Al6061+SiC+TiO₂+Mg)

G. Elatharasan and S. Krishnaraj

1Assistant professor, Department of Mechanical Engineering, University College of Engineering Pattukkottai Anna University, Rajamadam – 614701, Tamilnadu, India.

2Teaching Fellow, Department of Mechanical Engineering, University College of Engineering Pattukkottai Anna University, Rajamadam – 614701, Tamilnadu, India.

Received 28 February 2017; Accepted 22 May 2017; Available online 6 June 2017

Address For Correspondence: G. Elatharasan, Assistant professor, Department of Mechanical Engineering, University College of Engineering Pattukkottai Anna University, Rajamadam – 614701, Tamilnadu, India.

Email: elatharasan@yahoo.co.in; Contact +9109791940476

Copyright © 2017 by authors and American-Eurasian Network for Scientific Information (AENSI Publication). This work is licensed under the Creative Commons Attribution International License (CC BY).

http://creativecommons.org/licenses/by/4.0/

Abstract

This paper investigates the effect of fatigue behavior of aluminium reinforced metal matrix composites. Composites made by the powder metallurgy route were studied. Mechanical behavior of metal matrix composites (MMC's) subjected to fully reversed loading conditions. Based on the cyclic loading conditions, fatigue properties of Al6061 reinforced composites were investigated. Now-a-days the traditional materials like steel, plastic, iron, aluminium based materials etc. Recently more number of researches, the mechanical and metallurgical characteristics of different metal alloys was tested. This research paper deals with investigation of stress intensity factor and fatigue behavior of magnesium Al6061 alloys. In modern engineering most of the failure occur in fatigue behavior of the materials for a static loading conditions. A finite element method of a flat specimen subjected to axial loading conditions is developed under the stress state analysis. This analysis of a model deformation well suited for the fatigue behavior. The fatigue strength of 10⁻⁶ cycles and alternating stress around 97 MPa for axial loading conditions. The specimen design and fatigue behavior was done by the finite element method in ANSYS. This simulation result good agreement with the theoretical results.

Keywords: Fatigue, metal matrix composites, SN-curve.

Introduction

Aluminium is a light weight material widely used in several of industrial application, such as automobile, shipbuilding and aerospace applications [1]. However the composite materials having high corrosion resistance and good fatigue performance of some reinforced composites. Metal matrix Composites reinforcement composite particles to improved hardness, fatigue strength and good yield strength. And other thermal properties also improved due reinforcing composites [13-14]. Fatigue is an important characteristic of the material failure. It becomes used to achieve the robust performance [2-6]. Some of the factors to affecting by the fatigue cycles such as surface finish, reverse loading and fluctuations, and stress concentration factors and residual stress etc. and also S-N curve to integrate the alternating stress life of the composite materials. For measuring fatigue analysis of a stress cycle, alternating stress has analysed and calculate the life and over a damages.

Mathematical modelling of aluminium metal matrix composites (MMC’s) have been investigated by the lot of researchers. From the literature survey any material will fail due to the low cycle (<10⁵) and high cycle...
fatigue (>10^5)[7-9]. This paper mainly investigates and designed a new life of a various proportions of composite materials.

Table 1: Chemical properties of composite materials

<table>
<thead>
<tr>
<th>Element</th>
<th>Mg</th>
<th>Mn</th>
<th>Zn</th>
<th>Fe</th>
<th>Cu</th>
<th>Si</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA6061-T6</td>
<td>0.84</td>
<td>0.01</td>
<td>0.06</td>
<td>0.40</td>
<td>0.24</td>
<td>0.54</td>
<td>0.18</td>
<td>bal</td>
</tr>
</tbody>
</table>

Table 2: Mechanical properties of composite materials

<table>
<thead>
<tr>
<th>Element</th>
<th>Yield strength (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA6061-T6</td>
<td>306</td>
<td>342</td>
<td>17</td>
</tr>
</tbody>
</table>

II. Theoretical formulation:

While composites of increased their life time under the failure due to the fully reversed loading conditions. This material will fail under the static and dynamic loading conditions. Characterization by the material serviceability over an expected and calculated design life its importance in fatigue analysis. Stress and strain life both are used to predict a life time survival of composites. Reinforcing composites as different percentage ratios and increasing their density and also it will leads to increase the life time and reduce the damage of the model. Formulating fatigue behavior using three methods are Soderberg, Goodman and Gerber parabola. Soderberg equations mostly used in a recent traditional engineering solutions. This phenomena constant amplitude and proportional loading conditions used to formulate the life cycle calculations. Along with the alternating stress and mean stress value calculated by the FEA results.

Soderberg equation

\[ \frac{1}{n} = \frac{\sigma_m + K_f \sigma_{-1}}{\sigma_y} \]  

(1)

Goodman equation

\[ \frac{1}{n} = K_f \left( \frac{1}{n} = \frac{\sigma_m + \sigma_{-1}}{\sigma_y} \right) \]  

(2)

Mean load

\[ \sigma_a = \frac{\sigma_{max} + \sigma_{min}}{2} = 0 \text{ N} \]  

(3)

Variable load

\[ \sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} = 10000 \text{ N} \]

Mean stress

\[ \sigma_m = 0 \text{ N/mm}^2 \]

Most of the traditional engineering applications Soderberg equation preferred for experimental and theoretical formulations. For constant amplitude and proportional loading of endurance limit \( \sigma_{-1} \) to working as a fully reversed cycle can sustain the variable stress for an infinite number of cycles without failure. These all the data predicted by the existing design calculations and implement to the new prepared metal matrix composites.

From the design data approximately the endurance limit of the metal and alloys are \( \sigma_{-1} = 0.45 \sigma_u \) (For tension).

\( \sigma_{-1} = 139.5 \text{ N/mm}^2 \)

\[ \frac{D}{d} = 1.4 \quad \frac{r}{d} = 2.08 \]

From the design datebook PSGDB

Stress concentration factor (Kt) = 1.52

Fatigue factor Kt = 1 + q (Kt - 1) = 1.416

Modified endurance limit \( \sigma_{-1m} = \frac{\sigma_{-1} \times K_R}{K_f} \)

= 78.81 N/mm^2

For completely reversed loading condition
\[ \sigma_m = 0 \text{ N/mm}^2 A = \frac{\pi}{4} (d^2) \]

\( A = 28.86 \text{ mm}^2 \)

Using Soderberg equation

\[ \frac{1}{n} = \frac{\sigma_m}{\sigma_y} + K_f \frac{\sigma_e}{\sigma_s} \]

\[ P = \sigma_a = 2227.17 \text{ N} \]

Load for infinite life = 22.27 KN

To increasing load gradually \( \sigma_e = 2 \times 78.81 = 157.62 \text{ N/mm}^2 \)

Endurance strength for \( N = 10^3 \) cycles = 0.75 \( \sigma_u = 232.5 \text{ N/mm}^2 \)

Endurance strength for \( N = 10^6 \) cycles = 78.8 \text{ N/mm}^2

\( N \) cycles can be found in S-N curve respectively to form a triangle.

Taking logarithmic value for the above load cycles using triangle law to found the value of load cycles.

\[ \log (232.5) = 2.36, \log (78.8) = 1.89, \log (157.62) = 2.18 \]

\[ \frac{2.36 - 2.18}{2.36 - 1.89} = \frac{\log N - 3}{6 - 3} \]

\( N = 35850 \) cycles.

III. Numerical simulations:

Numerical simulation of static analysis and fully reversed loading conditions and constant amplitude, it causes the failure under the repeated loading conditions. And predicted stress life based on the S-N curve. It concerned with stress life as total life. The aluminium 6061 of fatigue strength 97MPa of 5X8 cycles. This limit >10^6 Represents the high cycle fatigue behavior. For the system mean stress value 0. Calculating alternate stress less than the predicting stress is maximum to the life at the end point of the material. Higher value of constant amplitude predicts the damage of the model in low stress values. From the analysis to shows the available life of the tensile cycles.

RESULT AND DISCUSSIONS

The Constant amplitude of number of cycles under the loading, the part will fail due to high alternating stress. Form the theoretical analysis alternating stress less than the alternating stress of the S-N curve will be used at the last fatigue point. Fatigue damage of the loading histories is the design life to the available life and greater than one it is reached a failure. Fully reversed loading conditions the fatigue behaviour of composite materials as various reinforcement volume fractions compared with the life behaviour, Biaxiality indication, alternating stress and damage factor. The volume reinforcement 0%, 3%, 6%, 9% particle reinforcement compared with the variable material. The factor of safety less then one the material will fail and below figure 2.

The minimum value of factor of safety for 3% reinforcement composites is 1.0131. The composite with 6%\% and 9% volume fraction of particle reinforcement with the aluminium 6061 of the value nearest to one. So, that indicates failure before the design life is reached for 6% and 9% reinforcement. Fatigue material properties are based on uniaxial stresses but real world stress states are usually multiaxial. This result gives the user some idea of the stress state over the model and how to interpret the results.

Biaxiality indication is defined as the principal stress smaller in magnitude divided by the larger principal stress with the principal stress nearest zero ignored. A Biaxiality of zero corresponds to uniaxial stress, a value of -1 corresponds to pure shear, and a value of 1 corresponds to a pure biaxial state. The values for the composites are shown in Figure. Here all the three volume fraction of particle reinforcement of composites has the value of almost nearer to zero at the area of gauge length. This indicates that uniaxial stress acting at that point. One end of the gripping area showed the value of -0.4 and the other shows the value of +0.4. This indicates that one end is partially subjected to shear state and the other end partially subjected to the biaxial state.

Fatigue Life can be analysed over the whole model or can have scope to interested areas just like any other contour result in Workbench. The contour plot shows the available life for the given fatigue analysis. If loading is of constant amplitude, this represents the number of cycles until the part will fail due to fatigue. If loading is non-constant, this represents the number of loading blocks until failure. Thus if the given load value represents one hour of loading and the life is found to be 24,000, the expected model life would be 1,000 days. Ina Stress
Life analysis with constant amplitude, if the equivalent alternating stress is lower than the lowest alternating stress defined in the S-N curve, the life at that point will be used. Fatigue life diagram for three different volume fraction of particles reinforcement with aluminium alloy are shown in Figure 8. Here the fatigue life for the 9% reinforcement is high, when compared to the base material.

Fig. 1: Fatigue life of Pure Al 6061

Fig. 2: Factor of safety (a) Al6061 (b) Al6061+1% Sic + 1% TiO2 + 3% Mg (c) (b) Al6061+1% Sic + 1% TiO2 + 6% Mg (d)(b) Al6061+1% Sic + 1% TiO2 + 9% Mg
Fig. 3: Load: Deformation (a) Al6061 (b) Al6061+1% Sic + 1% TiO$_2$ + 3% Mg (c) (b) Al6061+1% Sic + 1% TiO$_2$ + 6% Mg

Fig. 4: alternating stress (a) Al6061 (b) Al6061+1% Sic + 1% TiO$_2$ + 3% Mg (c) (b) Al6061+1% Sic + 1% TiO$_2$ + 6% Mg
Conclusion:
Aluminium reinforced metal matrix composites were studied powder metallurgy route. The combinations of composites’ made various proportions such as 0%, 5%, 10%, and 15%. This investigated mechanical characterization to prevent the material in reliability of working condition. This reinforcement influenced good dispersive strength and good bonding agreement. Increased weight fraction improves their mechanical properties of fatigue for the new composite material. The uniform distribution of Sic particles to create an oxide layer. Finite element analysis used to investigate the fatigue behaviour of new composite materials. This numerical simulation of fatigue life behaviour clearly observed, reinforcement of composite particle evenly spreads with the aluminium matrix composites. From the fatigue behaviour characteristics of numerical simulation the life increased and damage will decreased. It is important evident that Sic, TiO$_2$, and Mg adding the base material of life time service ability also increased. The load applied gradually 2000-6000N respectively. From the theoretical the infinite load number 22.24KN and design life 35850 cycles. And the fatigue sensitivity of applied load will fail in 5XE8 cycles. Instead of increasing load beyond the limit material will fail 1.3XE8 respectively.

REFERENCES
9. Qing, H., 2013. of 2D micromechanical analysis of Sic/Al matrix composites under the tensile, shear and combined tensile & Design, 51(0): 909-923.