STATIC STRUCTURAL ANALYSIS OF BORON CARBIDE (B₄C) PARTICULATE REINFORCEMENT WITH ALUMINIUM ALLOY (LM25) MATRIX

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Abstract

This analysis deals with the investigation on aluminium alloy (LM25) and boron carbide particulate (B₄C) reinforcement which were cross linked to each other. Aluminium alloy LM 25 is the matrix metal possessing mechanical properties such as low weight, high strength and good machinability. Experimental tests were performed before the static structural analysis, the results obtained from the experiments were used as input data for the software analysis which was performed on ANSYS 17.0 fluent software. Finally, after the stress analysis it was concluded that as the increase of B₄C in the composite will result good strength and 10% B₄C is the best composition with aluminum matrix taken.

Keywords: aluminum alloy (LM25); boron carbide particulate (B₄C); static structural analysis; ANSYS 17.0 fluent software; stress analysis

1. INTRODUCTION:

A composite is a material fabricated with the help of two or more different materials with various different chemical and physical properties. The discrete components remain distinct with in the fabricated and completed structure. The new material may be preferred for many reasons: common examples include materials which are harder, less in weight and in expensive when contrasted to conventional materials.

More lately, investigators have also started sensing, actuation, computation and communication of different types of composites. Sudershankumar et al. [1] conducted FEM analysis on connecting rod by implementing on two materials such as aluminum 360 and aluminum reinforced with boron carbide. The best combination of parameters like von misses stress and strain, deformation, factor of safety and weight reduction for two wheeler piston were done in ansys software. Idrisi et al. [2] has developed the metal matrix composite materials by combining the desirable attributes of metals and ceramics. Aluminium 5083 used as the matrix material in which SiC added as the reinforced material. This work was concentrated on the study of behavior of Aluminium 5083 with SiC as
reinforcement produced by stir casting method and ultrasonic assisted stir casting method. The results show that the mechanical properties i.e., tensile and compressive properties improved. Priyanka et al. [3] has performed analysis to calculate the von Misses stress, total deformation, elastic strain in the current design of the connecting rod with different loading conditions utilizing the FEM software ansys 12.1. Rahmani et al. [4] has conducted broad load analysis on connecting rod along with finite element method in Ansys software. In regard to this method and to calculate stress in different part of connecting rod, the total forces exerted connecting rod were calculated and then it was modeled, meshed and loaded in ansys software. Rama rao et al. [5] made an aluminum alloy boron carbide composites utilizing liquid metallurgy approach with particulates weight fraction of 2.5, 5 and 7.5 %. Observation was done by uniform distribution of boron carbide particulates in aluminum matrix. Herakal & Goud [6] carry out study in order to analyze the rod under the fatigue load by using the fully reversed loading condition. From the analysis it was concluded that the stress analysis, the stress was maximum at the small region and also was maximum stress is at the tiny region.

2. DESIGN AND MODELING:
A pre modelled composite test specimen is taken and imported to ANSYS workbench. The model is meshed using a tetrahedral element and is subjected to boundary conditions i.e. forces, contacts, supports etc. The obtained results are imported to the material library and are applied to the model for obtaining the results.

![Systematic representation of the steps in finite element analysis](image)

The composite specimen is designed according to the procedure and specification which are given in ASTM standards [7]. The dimensions are calculated in terms of SI Units. Length, diameter etc., parameters are taken into consideration. Here, CATIA software is used to design the model. Thus, the dimensions for the specimen are calculated and these
are used for modelling the object in CATIA-3D Model. Model was created using CATIA software which is shown in figure 3 and the drawing of specimen as per ASTM Specification for static structural analysis is shown in the figure 2.

![Figure 3: 3D – Design of the specimen in CATIA software](image)

After modelling is done, mode is under gone to analysis using ANSYS 17.0 fluent software.

### 2.1 Meshing of Model

Firstly, Automatic meshing method is used to mesh the model. Element used is 4 node Tetrahedron (Solid 285). The element size is taken as 3. The mesh grid is as shown in figure 3 below.
In the present analysis, the boundary conditions were applied on nodes at one end of the model that are activated by fixing the displacement in “All DOF” as Zero. And the other end is loaded by tensile force in –Fx direction.

The material properties are considered from the experimental tests results which was performed before performing static structural analysis.

Table 1: Test results obtained from experiments and which was used as input data for static structural analysis

<table>
<thead>
<tr>
<th>S.N o</th>
<th>Test Parameter</th>
<th>Pure Al Alloy</th>
<th>Al + 6% B₄C</th>
<th>Al + 7.5% B₄C</th>
<th>Al + 10% B₄C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hardness</td>
<td>97</td>
<td>106</td>
<td>112</td>
<td>123</td>
</tr>
<tr>
<td>2</td>
<td>Tensile strength (MPa)</td>
<td>263</td>
<td>278</td>
<td>287</td>
<td>294</td>
</tr>
<tr>
<td>3</td>
<td>Modulus of elasticity (GPa)</td>
<td>70.9</td>
<td>71.3</td>
<td>71.5</td>
<td>71.6</td>
</tr>
<tr>
<td>4</td>
<td>Density (Kg/m³)</td>
<td>2677</td>
<td>2674</td>
<td>2663</td>
<td>2667</td>
</tr>
</tbody>
</table>
3. STATIC STRUCTURAL ANALYSIS

3.1 Equivalent (von mises) stress

The equivalent stress is often referred by von mises stress. It is not really a stress, but a number that is used as an index. If the von mises stress exceeds the yield stress, then the material is considered to be at the failure condition. The formula is:

\[ \sigma_v = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}} \]  \hspace{1cm} (1)

Where \( \sigma_1, \sigma_2, \sigma_3 \) are the principal stresses and \( \sigma_v \) is the equivalent stress or "Von mises stress"

To calculate von-mises stress were to find out the principal stress values along x-direction - direction and z-direction. The principal stress along three axis is written as in eq.2:

\[ \sigma^3 - I_1 \sigma^2 + I_2 \sigma - I_3 = 0 \]  \hspace{1cm} (2)

Where,

\[ I_1 = \sigma_x + \sigma_y + \sigma_z \]
\[ I_2 = \sigma_x \sigma_y + \sigma_y \sigma_z + \sigma_z \sigma_x - \tau_{xy}^2 - \tau_{yz}^2 - \tau_{zx}^2 \]
\[ I_3 = \sigma_x \sigma_y \sigma_z + 2 \tau_{xy} \tau_{yz} \tau_{zx} + \sigma_x \tau_{yz}^2 - \sigma_y \tau_{zx}^2 - \sigma_z \tau_{xy}^2 \]

Therefore, the above eq.2 will give three roots, which will be the three principal stresses for the given three normal stresses (\( \sigma_x, \sigma_y \) and \( \sigma_z \)) and the three shear stresses (\( \tau_{xy}, \tau_{yz} \) and \( \tau_{zx} \)).

4. RESULTS AND DISCUSSION:

4.1 Group 1: Pure Aluminium Alloy (LM25 + 0%B\textsubscript{4}C):

For the finite element analysis of the specimen a load of 28KN was implemented along with the input values (test parameters) such as the tensile strength, modulus of elasticity, density as mentioned in the Table 1 above. The analysis is carried out using ANSYS 17.0 fluent software. The force is applied at the one end of model keeping the other end fixed. The maximum and minimum von mises stress, strain and displacement are noted from the ANSYS software.

![Figure 6: Variation of von mises stresses and total deformation for Group 1 (Pure Alloy) (LM25 + 0%B\textsubscript{4}C)](http://ymerdigital.com)
The maximum von mises stress which was developed in group 1 (Pure alloy) is 240.023 kN/m² and minimum von mises stress developed is 70.6172 N/m² and the total deformation in the pure alloy due to load applied was 0.524e⁻³ mm. The deformation found after the stress analysis was constant with no major disturbance in the specimen as observed in the figure 6. When it comes to point of strain, the maximum strain was 0.344e⁻⁵ and the minimum strain was 0.609e⁻⁸ as seen in figure 7.

![Figure 7: Variation of strain for Group 1 (Pure Alloy) (LM25 + 0%B₄C)](image)

### 4.2 Group 2: Aluminium Alloy Composite (LM25 + 6% B₄C)

For the finite element analysis 29KN of force is used. The analysis is carried out using ANSYS software. The force is applied at the one end of model keeping the other end fixed. The maximum and minimum von mises stress, strain and displacement are noted from the ANSYS.

![Figure 8: Variation of von mises stresses and total deformation for Group 2 (LM25 + 6% B₄C)](image)

The maximum von mises stress which was developed is 293.756 kN/m² and minimum von mises stress developed is 159.115 N/m² and the total deformation was 0.708e⁻³ mm. The deformation found after the stress analysis in the specimen as observed in the figure 8 was more, when compared to group 1 (pure alloy). When it comes to point of strain, the maximum strain was 0.418e⁻⁵ and the minimum strain was 0.909e⁻⁸ which is represented by the figure 9 below.
4.3 Group 3: Aluminium Alloy Composite (LM25 + 7.5% B₄C)

For the finite element analysis 32 kN of force is used. The analysis is carried out using ANSYS software. The force is applied at the one end of model keeping the other end fixed. The maximum and minimum von mises stress, strain and displacement are noted from the ANSYS 17.0 fluent software.

The maximum von mises stress developed was 313.845 kN/m² and minimum von mises stress developed was 101.982 N/m² which can be seen in the figure 10 and total deformation which was quite higher than that of both Group 1 and Group 2 and which was 0.7558e⁻³mm in value, when it comes to the point of the amount of strain, the maximum strain was 0.445e⁻⁵ and minimum strain was 0.849e⁻⁸ in the case of the LM25 + 7.5% B₄C alloy as seen in figure 11.
4.4 Group 4: Aluminium Alloy Composite (LM25 + 10% B₄C)

For the finite element analysis 34KN of force is used. The analysis is carried out using Ansys 17.0 software. The force is applied at the one end of model keeping the other end fixed. The maximum and minimum von mises stress, strain and displacement are noted from the Ansys fluent 17.0 software.

The maximum von mises stress which was developed in group 4 (LM25 + 10% B₄C) was 351.518 kN/m² and minimum von mises stress developed was 106.881N/m² as shown in the figure 12 and the total deformation was 0.626e⁻³mm which was less than that of group 3 alloy which was more than all the other alloy compositions and finally when it comes to strain in the group 4 alloy, the maximum strain was 0.501e⁻⁵ and minimum strain was 0.631e⁻⁸ as shown in the figure 13 below.
5. COMPARSION WITH RESULT ANALYSIS

5.1 Comparison of total deformation

It can be clearly observed from the figure 14 that, for the given load the maximum total deformation of the model gets increasing with increase of $B_4C$ in the composite. But the increase of total deformation is not varying linearly. The slope of the curve from group 1 to group 2 is steeper than the curve from group 2 to group 3 and the curve comes down from group 3 to group 4.

![Deformation Vs Composition](image-url)
5.2 Comparison of Von mises stresses

From the figure 15, it is cleared that the von mises stresses are increasing as the increase of B₄C reinforcement in aluminum alloy matrix.

5.3 Comparison of strain

From the figure 16, it is cleared that the von mises stresses are increasing as the increase of B₄C reinforcement in aluminum alloy matrix, same as what observed in von- mises it was in the strain values also increase in the strain values from group 1 to group 4. The table 2 below presents the output values of maximum equivalent (von mises) , minimum equivalent (von mises) stress and deformation on B₄C reinforcement with aluminum alloy matrix.
Table 2: Maximum equivalent (Von mises), minimum equivalent (Von mises) stress and deformation of various compositions (groups) on B₄C reinforcement with aluminum alloy matrix

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of composition</th>
<th>Von-mises stress</th>
<th>Deformation(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Group 1 (Pure Al Alloy)</td>
<td>Maximum (kN/m²) 240.023</td>
<td>0.524e⁻³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum (N/m²) 70.6172</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Group 2 (Al + 6% B₄C)</td>
<td>Maximum (kN/m²) 293.756</td>
<td>0.708e⁻³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum (N/m²) 159.115</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Group 3 (Al + 7.5% B₄C)</td>
<td>Maximum (kN/m²) 313.845</td>
<td>0.7558e⁻³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum (N/m²) 101.982</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Group 4 (Al + 10% B₄C)</td>
<td>Maximum (kN/m²) 351.518</td>
<td>0.626e⁻³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum (N/m²) 106.881</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Maximum equivalent, minimum equivalent strain of various compositions (groups) on B₄C reinforcement with aluminum alloy matrix

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of composition</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Group 1 (Pure Al Alloy)</td>
<td>Maximum 0.344e⁻⁵</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum 0.609e⁻⁸</td>
</tr>
<tr>
<td>2</td>
<td>Group 2 (Al + 5% B₄C)</td>
<td>Maximum 0.418e⁻⁵</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum 0.909e⁻⁸</td>
</tr>
<tr>
<td>3</td>
<td>Group 3 (Al + 7.5% B₄C)</td>
<td>Maximum 0.445e⁻⁵</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum 0.849e⁻⁸</td>
</tr>
<tr>
<td>4</td>
<td>Group 4 (Al + 10% B₄C)</td>
<td>Maximum 0.501e⁻⁵</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum 0.631e⁻⁸</td>
</tr>
</tbody>
</table>

Table 2 and Table 3 above present the minimum and maximum values of strain and stress for all the four group of alloy compositions along with the deformation value of those four groups. The maximum von mises stress was 351.518 Kn/m² which was observed in the group 4-Al + 10% B₄C alloy minimum values was 70.6172 N/m² which was observed in the group 1-Pure Al alloy during the stress analysis.

From the stress analysis conducted strain analysis results were also retrieved by using the software, where the maximum strain of 00.501e⁻⁵ was observed in the group 4 (Al + 10% B₄C) alloy and minimum of 909e⁻⁸ in the group 2 (Al + 5% B₄C) alloy composition.
6. CONCLUSIONS

There have been several studies on the failure occurrence in aluminum alloy and their main cause is due to improper combinations of compositions during manufacturing. In the current analysis performed, Aluminium alloy (A356) is selected as matrix while B₄C act as reinforcement. The static analysis of the composite is evaluated using Ansys software.

The analysis has been carried out taken on the composite using Ansys software. The results indicated that the von mises stress, deformation and strains have been increased with the increasing percentage of boron carbide (B₄C) reinforcement in aluminum (LM25) matrix. From the stress and strain results from static structural analysis results, it is concluded that as the increase of B₄C in the composite will result good strength. From the present work, 10% B₄C is the best composition with aluminum matrix. They are also several other compositions for (B₄C) reinforcement in aluminum (LM25) matrix but due to ecological and physical constraints only few results were obtained.

CONFLICTS OF INTEREST

The authors state that there are no conflicts of interest concerning the publication of this paper.

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