FABRICATION AND COMPUTATIONAL ANALYSIS OF CENOSPHERE REINFORCED ALUMINUM METAL MATRIX COMPOSITE DISC BRAKES

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ABSTRACT

The disc brakes which replaced drum brakes, has found great performance in the automobile industries and also found a prominent role in the aeronautical/aerospace industries. In recent research, composites are used because of low weight and high thermal performances. To moderate the structural weight and progress in fuel efficiency, the aeronautical/automobile industry has melodramatically increased the use of aluminium composites in the current years. Aluminium alloy based metal matrix composites (MMCs) reinforced with ceramic particulates have publicized great usage for such applications. Moreover, these advanced materials have the potential to perform better under severe conditions like higher speed, higher load etc. which are increasingly being encountered. In this study an effort, has been made to investigate a new composite material called cenosphere reinforced aluminium alloy. The Aluminium-Cenosphere composite material which has low thermal expansion and greater performance in hot and cold conditions can be used in the disc brake. Repetitive braking of the vehicle leads to wear on both brake pad & disc surface during each braking event. The resulting wear has very significant role in the performance of the braking system. The objective of this study is to analyze disc brake system, to simulate disc brake assembly and to prepare the FEM model for contact analysis. A three-dimensional finite element model of the brake pad and the disc is
developed to calculate static state analysis and transient state analysis. Properties of numerical model are set from properties of cenosphere reinforced aluminium matrix composite. The major FEM analysis like stress and thermal analysis is performed.

**Key words:** Aluminium-Cenosphere composite material, Stress Analysis, Thermal Analysis.


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1. **INTRODUCTION**

Conventional monolithic materials have limitations with respect to achievable combinations of strength, stiffness and density. In order to overcome these shortcomings and to meet the ever-increasing engineering demands of modern technology, metal matrix composites are gaining importance. In recent years, discontinuously reinforced aluminium based metal matrix composites have attracted worldwide attention as a result of their potential to replace their monolithic and counterparts primarily in aerospace, automobiles energy sector. [1]

The present investigation has been focused on utilization of waste fly ash particle in useful manner by dispersing it in aluminium matrix to produce composite. In the present work, fly ash particle which mainly consists of refractory oxides like silica, alumina and iron oxides will be used as the reinforcing phase and to increase the wettability, magnesium or silicon were added. Fly ash particle used in current work is called as cenosphere or micro balloon. It is a hollow sphere made up of ceramic outer surface. Cenospheres as a filler in Al casting reduces cost, decreases density and increase hardness, stiffness, wear and abrasion resistance. It also improves the maintainability, damping capacity, coefficient of friction etc, which are needed in various industries like aerospace, automotive etc.

The basic idea is that continuous fiber reinforced composite has better strength but the processing methods is highly expensive which hinders their adoption. The continuous fiber reinforced composites do not allow secondary forming such as rolling, forging and extrusion. As a result of these limitations new efforts on the research of discontinuous reinforcements have been used at early stages of development of metal matrix composite emphasis on the preparation of fiber reinforced composite only. But due to the high cost associated with the process of production, anisotropic properties of the resultant composite and difficulties associated with the fabrication process, production of this type of composite has been limited. Now-a-days the particulate reinforced Aluminium matrix composite are gaining importance because of their low cost with advantage like isotropic properties. The strengthening of Aluminium alloys with dispersion of fine ceramic particulate composite materials were developed as an alternative of unreinforced alloy for obtaining materials with high stiffness (high strength/modulus and low density) with special interest for the structural applications. The dispersion strengthened alloys can be classified, based on the size and volume percentage of particles uniformly dispersed in the matrix. [2-5]

The braking capacity of the disc brakes is more efficient than the ordinary drum brakes. So, the aircraft requires a halt on the runway which may be shorter at some times at high velocity approaching the ground. In recent criteria, composites are used because of low weight and high thermal performances. CMC-Ceramic Matrix Composites are used in the disc brake rotors which has low density with increased strength and tribological characteristics.
Due to its low coefficient of thermal expansion and high thermal conductivity, this CMC can retain its strength at high temperature. [6]

The CMC disc brakes are very expensive and they become inefficient and much weaker if used in cold conditions. The weakness is a result of thermal expansion of the composite and ceramic matrix. As the material expands at different rates under different temperatures cracking can occur on the surface. It was found that with this ceramic composite certain area wouldn’t dissipate heat resulting in “hot spots”. This is due to the materials ability to conduct heat in axial and transverse directions. Since the fibers are placed perpendicular to the friction surface they are unable to transfer heat in other directions. The simplest solution is to make the material with a higher ceramic content. This sacrifices the strength of the brake and while adding excess mass, since the density of ceramic is far greater than the composite fiber. Another solution is to use a more thermally conductive fiber in the ceramic matrix. This results in a higher cost of production. [7-8]

Instead of this CMC brakes, brakes made out of AMC has better performances compared with CMC. The Aluminium-Cenosphere composite material can be used in the disc brake rotors and the performance can be analyzed, which has low thermal expansion and greater performances in hot and cold conditions.

2. METHODOLOGY

2.1. Stir Casting of Aluminium Metal Matrix Composite

Stir casting is a unique and prominent technique for the development of reinforced aluminium matrix composite materials. This technique is utilized as a result of its simple process and ability to overcome the problem of expensive processing method which has restricted the widespread application of metal matrix composite which are considered potential material candidate for various structural and nonstructural applications in the field of aerospace, automotive, biomedical, military defence and sports industries. The development of this promising technique evolved as a result of modern technological advancement in material application and the demand for lightweight materials with improved mechanical and thermal properties. This process involves a liquid state fabrication technique which requires the incorporation of reinforcing phase (discontinuous form) into a molten matrix metal (continuous form) to obtain a uniform distribution through stirring as shown in Fig.1.

![General Stir Casting Setup](image)

**Figure 1** General Stir Casting Setup
2.2. Procedure for Stir Casting
Aluminium alloys reinforced with ceramic particles exhibit superior mechanical properties to unreinforced aluminium alloys and hence are candidates for engineering applications. The aluminium metal matrix composites are produced either by casting route or by powder metallurgy. The former has the advantage of producing the component at lower cost and possibility of producing larger components. However, the inherent difficulties of casting difficulties are non-wettability of ceramic particles by liquid aluminium, segregation of particles higher porosity level and extensive inter - facial reaction due to higher processing temperature. Wettability of the particles can be improved by coating the particles with metals such as Ni and Cu, addition of active elements such as Si and Mg into liquid Al or preheating of the particles before addition into liquid aluminium. The most conventional method of production of composites by casting route is vortex method where the liquid aluminium is stirred with an impeller and ceramic particles are incorporated into vortex formed by stirring of the liquid metals. Addition of Si or Mg into the liquid metal reduces the surface tension and there by avoids the rejection of the particles from the melts. Hence 2% - 6% of Si or Mg is generally added into the Al melts before incorporation of the particles. [9-10]

2.3. Simple Casting Setup
The casting setup used in the process of casting aluminium – cenosphere composite material is based upon the Stir casting technique. The Stir casting method is the process of implementing an impeller at a specified rpm for the fine dispersion of the cenosphere in the molten metal of aluminium alloy.[11-13] The main equipment used in fabricating aluminum – cenosphere composites specimen are: Stirrer, Temperature controller, Pre-heater and Furnace. The total assembly is shown in the Fig.2.

2.4. Modeling and Analysis of the Composite Disc Brakes
The design of the composite disc brake carries the following specifications Diameter = 357mm and Overall Thickness = 40mm.
2.5. Analysis of the Composite Disc Brake Rotor
The basic types of analysis are of two types, they are,
1) Steady state analysis which determines all the loading conditions under steady state. In a steady state loading conditions is a situation where the loading effects varying over a time period of time can be ignored.
2) Transient Analysis which determines all the loading conditions over a period of time. [14-17]

The finite elemental analysis method for the analysis of the aluminium cenosphere composite disc brake is carried out in the following ways [18],
1. Thermal Analysis
2. Structural Analysis
3. Coupled thermal-structural Analysis
4. Contact analysis

2.6. Material Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Al10ceno</th>
<th>Pad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2124</td>
<td>1400</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (MPa)</td>
<td>125</td>
<td>-</td>
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<tr>
<td>Poisson ratio</td>
<td>-</td>
<td>0.25</td>
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<tr>
<td>Thermal Conductivity (W/m·k)</td>
<td>159.3</td>
<td>5</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion (C-1)</td>
<td>12.1×10⁶</td>
<td>10×10⁶</td>
</tr>
</tbody>
</table>

Notes: Al10ceno - Since, Aluminium with 10% cenosphere has enhanced mechanical and tribological properties when compared with other aluminium-cenosphere composites. So, it is chosen as the perfect material for the current application.[19-23]

2.7. Boundary Conditions and Loading

<table>
<thead>
<tr>
<th>Object Name</th>
<th>Convection</th>
<th>Heat Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope</td>
<td>Geometry Selection</td>
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</tr>
<tr>
<td>Geometry</td>
<td>235 faces</td>
<td>2 faces</td>
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<tr>
<td>Definition</td>
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<tr>
<td>Type</td>
<td>Convection</td>
<td>Heat flux</td>
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<tr>
<td>Ambient Temperature</td>
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<tr>
<td>Magnitude</td>
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<td>3.7691e+005 W/m²</td>
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Table 3 Structural Load Input Conditions

<table>
<thead>
<tr>
<th>Object Name</th>
<th>Rotational Speed</th>
<th>Pressure</th>
<th>Fixed Support</th>
<th>Remote Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope</td>
<td></td>
<td>2 faces (PAD)</td>
<td>24 Faces</td>
<td></td>
</tr>
<tr>
<td>Definition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Rotational Speed</td>
<td>Pressure</td>
<td>Fixed Support</td>
<td>Remote Displacement</td>
</tr>
<tr>
<td>Define By</td>
<td>Component</td>
<td>Normal To</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>-</td>
<td>0. m</td>
<td></td>
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<tr>
<td>X Component</td>
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<td></td>
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<tr>
<td>Y Component</td>
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<td></td>
<td></td>
<td>0. °</td>
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<tr>
<td>Z Component</td>
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<tr>
<td>Rotation Y</td>
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<td>-</td>
<td></td>
<td>0. °</td>
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<tr>
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<td>-</td>
<td>-</td>
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</table>

Table 4 Structural Contact Input Conditions

<table>
<thead>
<tr>
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</thead>
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<td>Contact</td>
<td>2 Bodies</td>
</tr>
<tr>
<td>Target</td>
<td>1 Body</td>
</tr>
<tr>
<td>Contact Bodies</td>
<td>Multiple</td>
</tr>
<tr>
<td>Target Bodies</td>
<td>Part 3 (Rotor)</td>
</tr>
<tr>
<td>Definition</td>
<td>Frictional</td>
</tr>
<tr>
<td>Type</td>
<td>Frictional</td>
</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Figure 4 Rotational Velocity with respect to Time
3. RESULTS AND DISCUSSION

3.1. Steady State Thermal Conditions
The temperature distribution and Heat flux distribution of the steady state thermal analysis is shown in the following Fig.5.

![Figure 5](image-url)

**Figure 5** Temperature Distribution and Total Heat Flux over the Disc Brake Rotor

3.2. Steady State Structural Conditions
The total deformation of the steady state structural analysis is shown in the following Fig.6

![Figure 6](image-url)

**Figure 6** Total Deformation of the Disc Brake Rotor

3.3. Steady State Contact Conditions
The penetration and frictional stress of the steady state contact analysis is shown in the following

3.4. Steady State Coupled Thermal-Structural Conditions
The total deformation of the steady state coupled thermal-structural analysis are shown in the following Fig.7
3.5. Transient State Thermal Conditions
The temperature and heat flux distribution of the transient state thermal analysis is shown in the following Fig. 8.

3.6. Transient State Structural Analysis
The total deformation of the transient state structural analysis is shown in the following Fig. 9.

Figure 7 Total Deformation of the Disc Brake Rotor

Figure 8 Temperature Distribution and Total Heat Flux (Transient) over the Disc Brake Rotor

Figure 9 Total Deformation (Transient) of the Disc Brake Rotor
3.7. Transient State Contact Conditions
The penetration and frictional stress of the transient state contact analysis is shown in the following Fig.10.

![Figure 10 Penetration & Frictional Stress (Transient) of the Disc Brake Rotor](image)

3.8. Transient State Coupled Thermal-Structural Conditions
The total deformation of the transient state coupled thermal-structural analysis is shown in the following Fig.11.

![Figure 11 Total Deformation (Transient) of the Disc Brake Rotor](image)

The results are analyzed and found some enhancement in the performance of the aluminium-cenosphere composite material in the disc brake rotor. The composite material used in the disc brakes is light weight and has better wear resistance than the monolithic element because of the presence of cenospheres. Also, the cenospheres which are present in 10% of volume in aluminium is having better thermal resistance properties and they will resist the heat penetration deep inside the material. The heat generated due to friction can be dissipated through disc brake fins at the center, this makes the life cycle of the disc brake efficient.

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