Study of Design and Analysis of Composite Brake Disk

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Abstract

The purpose of friction brakes is to decelerate a vehicle by transforming the kinetic energy of the vehicle to heat via friction and dissipating the heat to the surroundings. Automobile brake materials have additional requirements like resistance to corrosion, light weight, long life, low noise, stable friction, low wear rate and acceptable cost versus performance. So, we can use composite materials for braking system. In this paper the simulation of temperature distribution in aluminium metal matrix composite brake Disk and existing cast iron brake Disk will be carried out for the single stop braking, repeated braking and continuous braking conditions. The simulated temperature distributions and stresses are found out in aluminium metal matrix composite brake Disk and cast iron brake Disk to be compared using finite element method. The results are optimized between aluminum metal matrix brake Disk and Cast iron brake Disk for passenger vehicle.

1. Introduction

In the current scenario, Due to the high power engines the vehicle speeds are too high providing more work for brakes. Due to high speed, the brakes are subjected to high temperatures during braking. In some brake tests, the vehicle is braked at maximum to zero speed repeatedly to check the brake performance at higher Disk temperature. The brake Disks need to be selected that the Disk temperature does not exceed 500°C during the above test. If the cooling characteristic of the Disk known, the Disk thickness can be designed optimally over designing. The project aims to derive the cooling characteristic of the Disk theoretically. To confirm the derived value, he derived cooling characteristic of Disk will be useful for calculating the Disk temperature in above said repeated braking tests.

2. Methodology and Importance of the work

Modelling is done using solid works software and thermal analysis is done using ANSYS 11 FEA software. The main objective of this project is simulation of temperature distribution of passenger car brake Disk and Aluminium metal matrix composite (Al-MMC) brake Disk using analysis software. For checking brake performance variations during frequent applications analysis of the Disk temperature with time is needed. While applying the brake, the major share of the thermal energy (about 95%) is dissipated through the Disk while the rest of it through the brake pads. In this project simulation of temperature distribution in an Aluminium metal matrix composite Brake Disk and existing Cast iron Brake Disk will be carried out for the single stop braking, repeated braking and continuous braking conditions.

3. Manufacturing of Aluminum Metal Matrix Brake Disks

In the earlier days, the brake Disks were made from the conventional brittle aluminum metal matrix materials would have disintegrated into a thousand pieces under slightest pressure. The research division of Daimler Chrysler has developed techniques to make carbon fiber reinforced brake Disks which avoid the brittleness problem. In the earlier days, long carbon fibers were used. Later the use of short carbon fibers increased the efficiency. The composites for producing fiber reinforced aluminum
metal matrix brake Disks are short carbon fibers, carbon powder, and resin mix. The process involves first compressing the carbon fibers, carbon powder, and the resin mix together and then sintering at 1000 degree Celsius. In the furnace a stable carbon frame work created. This consists of carbon fibers in a carbon matrix. Once cooled this material can be ground like wood and the brake disk obtains its final shape. Together with silicon the ground brake disk blank is then inserted into the furnace a second time. The pores in the carbon framework absorb the silicon melt like a sponge; the fibers themselves remain unaffected by this process.

The aluminum metal matrix material is created when the matrix carbon combines with liquid silicon. This fiber reinforced aluminum metal matrix material cools overnight and the gleaming dark grey break disk is ready. Resin is a binder, which holds the different constituents together. Resins are of two types, they are thermosetting resins and thermoplastic resins. Thermoplastic resins are those, which can be softened on heating harden on cooling. Repeated heating and cooling does not affect their chemical nature of materials. These are formed by addition polymerization and have long chain molecular structure. Thermosetting resins are those resins which, during molding process (by heating) get hardened and once they have solidified, they cannot be softened i.e. they are permanent setting resins. Such resins during moldings, acquire three dimensional cross linked structures with predominantly strong covalent bonds. They are formed by condensation polymerization and are stronger and harder than thermoplastic resins. They are hard, rigid, water resistant and scratch resistant.

3.1 Layer by Layer Pasting of Aluminum Metal Matrices on Conventional Brake Disk

Earlier brake Disk have been made of grey cast iron, but these are heavy which reduces acceleration, uses more fuel, etc. The new technology developed by Freno Ltd uses metal matrix composite for the disk, basically an alloy of aluminum for lightness and silicon carbide for strength. However it was found that, the aluminum metal matrix additive made the disk highly abrasive and gave a low and unstable coefficient of friction. So it was realized that the surface had to be engineered in some way to overcome this problem. After experiments, Sulzer Metco Ltd found an answer in the form of a special aluminum metal matrix layer by layer pasting. They developed thermal spray technology as well as manufacturing plasma surface engineering machinery used for the task and layer by layer pasting materials.

In use, the aluminum metal matrix face requires a special carbon metallic friction pad, which deposits a layer of material on the brake Disk. This coupling provides the required conditions of exceptional wear resistance, high and stable coefficient of friction. The coated matrix composite Disks were first used on high performance motor cycles, where the reduced gyroscopic effect had the additional advantage of making the cycles easier to turn. Another company named Lanxide used aluminium as the Disk material. To provide necessary abrasion resistance, aluminium Disks have to be reinforced with aluminum metal matrix material, hence metal composite. They used silicon carbide also to increase the strength.

3.2. Porsche Aluminum Metal Matrix Disk Brakes

After a long period of research and tests Porsche has developed new high performance Disk brakes, PCCB (Porsche Aluminium metal matrix composite Brakes). Porsche has succeeded as the first car manufacturer in the world to develop aluminum metal matrix brake Disks with involute cooling ducts for an efficient cooling. The new brake system offers a substantial improvement in the car braking technology and sets entirely new standards in terms of decisive criteria such as braking response, fading stability, and weight and service life.
4. Properties

Rule of Mixture

\[ P_r = P_m V_m + P_r V_r \]

Where \( P \) = Property, \( V \) = Volume fraction

Subscript \( c \), \( m \) and \( r \) indicate respective composite material, matrix and reinforcement.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m(^3))</th>
<th>Thermal conductivity (W/mK)</th>
<th>Specific Heat (J/kg/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>7228</td>
<td>48.4</td>
<td>419</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2700</td>
<td>180</td>
<td>896</td>
</tr>
<tr>
<td>Sic</td>
<td>3100</td>
<td>120</td>
<td>750</td>
</tr>
<tr>
<td>Al-MMC</td>
<td>2820</td>
<td>162</td>
<td>852.2</td>
</tr>
</tbody>
</table>

**Table 1 Materials and their properties**

The surface temperature as a function of time [Ref (6)]

\[
T (L, t) - T_i = \left( \frac{5}{4} \right)^{1/2} \left( \frac{q(0)}{k} \right) (at)^{1/2} \left[ 1 - \left( \frac{2t}{3t_s} \right) \right], \quad K
\]

Where
- \( a \) = Thermal diffusivity, m\(^2\)/h,
- \( k \) = Thermal conductivity, Nm/hm\(^2\)
- \( q(0) \) = heat flux, Nm/hm\(^2\)
- \( t \) = braking time, h
- \( T_i \) = initial temperature, K
- \( t_s \) = time to stop vehicle, h
5. Flow Chart

Assumption
Mass of the vehicle (m) = 1500Kg
Deceleration (a) = 0.9g
Speed of the vehicle (v) = 90Km/hr
Correction factor for rotating masses (k) = 1

The average braking power (P) = (kmaV)/2, Nm/s
= (1*1500*0.9*9.81*25)/2 = 170625 Nm/s
Pb (Avg) = Pb/4 = 170625/4 = 42656.25 Nm/s

Stopping Time (ts) = V/a, sec = 25/ (0.9*9.81)

Swept Area (A) = \( \pi r^2 \), m² = \( \pi*(0.12^2)-(0.072^2) \) = 0.027554 m²

Heat flux (q (0)) = Pb (avg)/A = 42656.25/0.027554 = 1548125 Nm/sm²

5.1. Temperature Analysis for Repeated Braking

Increasing temperature
\[ \Delta T = \frac{q_o t_s}{\rho CV} \]

Brake temperature before the nth brake application is
\[ [T(t) - T_\infty]_b = \left( 1 - e^{-\left[ -(n_a-1)\frac{h A t}{\rho CV}\right]} \right) \frac{e^{-\left[ h A t\right]/\rho CV}}{1 - e^{-\left[ h A t\right]/\rho CV}} \]

Brake temperature after the nth brake application is
\[ [T(t) - T_\infty]_b = \left( 1 - e^{-\left[ n_a h A t\right]/\rho CV}\right) \frac{\Delta T}{1 - e^{-\left[ h A t\right]/\rho CV}} \]
5.2. Temperature Analysis for Continued Braking

\[ T(t) = T_i - T_\infty - \frac{q_o}{hA} e^{-\frac{hAt}{\rho c_v}} + T_\infty + \frac{q_o}{hA} \]

where \( q_o \) = braking power absorbed by the drum, Nm/h
\( t \) = time during which brakes are applied

5.3. Design and analysis

5.3.1. Dimensions of the brake Disk

![Diagram of brake disk dimensions](image1)

Figure 3 Dimensions of the Composite Disk

![Graph showing temperature analysis for repeated braking](image2)

Figure 4 Temperature Analysis for Repeated Braking

![Graph showing surface temperatures as function of time](image3)

Figure 5 Surface temperatures as function of time
Figure 6 Temperature Analysis for Continued Braking

Figure 7 Disk Brake

Figure 8 Meshing

Figure 9 First step for AL-MMC
6. Conclusion

The conventional cast iron and experimental composite brake Disk were thermal analysed and the results show that the composite brake Disk shows better properties than conventional cast iron brakes like thermal conductivity and reduced weight.

References

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