ISSN (e): 2250 – 3005 || Volume, 07 || Issue, 02|| February – 2017 ||
International Journal of Computational Engineering Research (IJCER)

Transient Thermal Analysis of AlSiCp Composite Disc Brake

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ABSTRACT
Disc brakes are devices which will slow down or stop the heading vehicle. During the process of braking the brakes get heated up. Repeated braking will cause the excessive heating of the disc and braking action becomes less effective when the disc is over heated. So it is very much necessary that the heat generated is dissipated faster or the disc material gets less heated. In this paper we have considered a metal Matrix Composite $AlSiC_p$ which will satisfy these criteria. An analysis of composite and CI disc brakes over a repeated braking is done and the results are analyzed. The current paper deals with transient thermal analysis of composite disc brake. Transient analysis is generally made on systems where the forces acting are varied with respect to time. Model of the disc brake is done in Creo. Here temperature distribution in composite disc brake and CI disc brake under dynamic conditions are compared and analyzed using Ansys workbench 15.0. The composite material selected is $AlSiC_p$, as it has good mechanical properties, wear resistance and high thermal conductivity. The project aims at reducing the heat generated during repeated braking with the use of an $AlSiC_p$ composite disc brake
Keywords: *AlSiC Composite, Ansys workbench 15.0, Creo, Disc brake, Thermal Analysis, Transient Thermal Analysis.*

I. INTRODUCTION

Composites are materials that have been obtained by the combination of two or more materials which will give raise to a material possessing better physical and mechanical properties than individual materials. Metal matrix composites (MMCs) are composed of a metal matrix and a reinforcement or filler material, which confers excellent mechanical performance. The reinforcement provides the strength and stiffness to the matrix. The reinforcement is usually a fiber or a particulate. Particulate reinforced composites usually constitute about 40 to 50 percentage volume of the composite. The principal matrix materials for MMCs are aluminum and its alloys. The major advantage of Aluminum matrix composites compared to unreinforced materials like steel are increased strength, increased stiffness, increased elevated temperature, improved wear resistance, lower weight, improved damping capabilities, lesser thermal expansion and good corrosion resistance. Aluminum Silicon Carbide (AlSiC) is a metal matrix composite with SiC particle reinforcement. AlSiC is finding its application extensively in automotive and aerospace industries owing to its light weight and high temperatures sustainability. Several automotive parts such as piston, cylinder liner, engine valves, brake discs, brake drums, clutch discs, connecting rods are replaced with this composite. Owing to its light weight, high wear resistance and less thermal expansion and less conductivity it acts as a better disc brake material.

Types of Thermal analysis

Ansys supports two types of thermal analysis:

1. A steady thermal analysis determines the temperature distribution and other thermal quantities under steady-state loading conditions. A steady-state loading condition is a situation where temperature effects varying over a period of time can be ignored.
2. A transient thermal analysis determines the temperature distribution and other thermal quantities under conditions that vary over a period of time.

II. EXPERIMENTAL PROCEDURE

Disc brake is wheel brake which slows or stops rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of pushing brake pads against a brake disc with a set of calipers hydraulically or mechanically. Braking action converts motion into heat. If the brakes get too hot, they become less effective. This phenomenon where the brakes fail due to the excessive heating up is called brake fade. Hence an $AlSiC_p$ composite material has been chosen for the brake material replacing the present material which is Cast Iron and analysis was carried over two different designs one is solid disc other is ventilated disc. Transient Analysis for an applied brake for 6 seconds in a time period of 150 seconds, temperature gradient was observed on a CI disc brake and $AlSiC_p$ composite disc brake.

Modeling of disc brake in Creo.
A 3D model of disc brake was done in Creo.

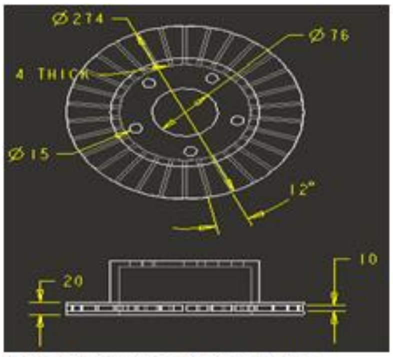


Fig.1 Dimensions of a disc brake

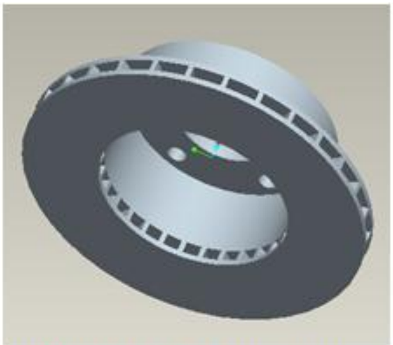


Fig.2 3D Model of a disc brake in Creo

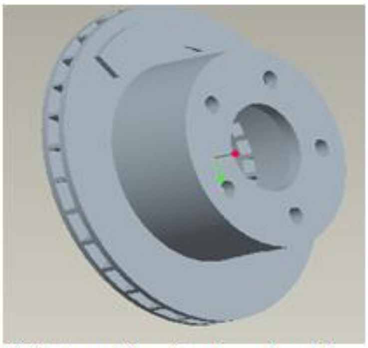


Fig.3 Assembly of brake pad and disc brake

Inputs for Thermal Analysis.
Kinetic Energy of the moving vehicle is converted into heat when brakes are applied. So heat generated when brakes are applied is equal to the change of kinetic energy.
In this study, we make an assumption that the vehicle is moving at a speed of 50KMPH and total kinetic energy of the vehicle is converted into heat energy.
Heat generated = $\frac{1}{2} * mv^2$
$= \frac{1}{2} * 1000 * 27.72 = 383645$ J
Total KE = heat generated/second/rubbing area
Area of rubbing surface = $\pi/4(0.260^2-0.140^2) = 0.037699m^2$
Area of the rubbing surface as this will act on both sides of friction pad= 2*.037699
$=0.07539m^2$
Considering 6 seconds of brake application,
Heat flux = heat generated/second/rubbing area = 383645/6/0.07539
The analysis is done by taking the braking torque distribution between front and rear as 70:30
Heat flux on each front wheel = 296.846 KW/m^2

Transient Thermal Analysis:
Due to the application of brakes to the car, heat generation takes place on the disc brake rotor due to friction. And this temperature so generated has to be conducted away and dispersed across the disc brake cross section. The condition of braking is very severe and thus thermal analysis is carried out and with the above calculated heat flux, thermal gradient of the composite and CI disc brakes are analyzed.

In this study, transient thermal analysis was carried out on the disk brake rotors since braking a wheel is a dynamic event. When brake pad is pressed against the rotor, friction between rotor and brake pads produces heat. Ideally, the applied pressure and heat generated occurs in a nonlinear fashion. Modeling such a system is complex and computationally challenging. Hence, in this study, an assumption is made that the applied pressure and heat generated is constant throughout the braking process. With this assumption, a constant heat flux of 297Kw/m2 is provided to the rotor in the region that contacts the brake pad.

The analysis is carried out on both solid and vented rotors made out of cast iron and $AlSiC_p$ to study how aluminum matrix composite material impacts the heat conduction. For this purpose, the assembly is meshed with SOLID70 3D solid elements with a thermal conduction capability. The element has eight nodes with a single degree of freedom, temperature, at each node. The element is applicable to a three-dimensional, steady-state or transient thermal analysis. After meshing with suitable elements, thermal loads such as heat flux due to friction, convection between rotor and moving air and radiation are provided to the finite element model to perform transient thermal analysis. From the results, temperature in the rotor is obtained as a function of time and space.

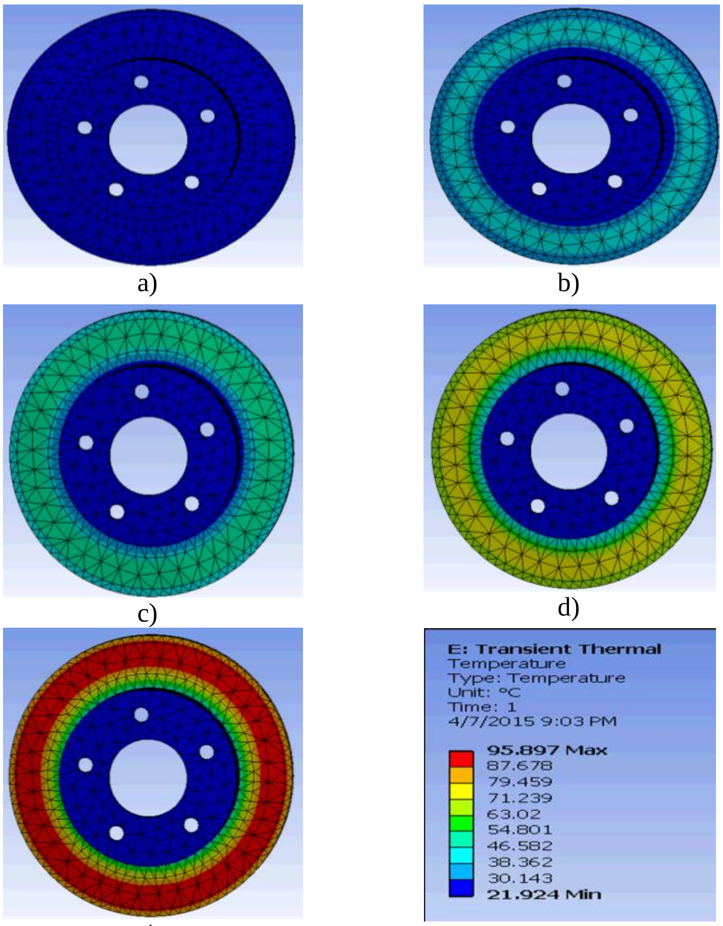


Fig.4 Temperature (^{0}C) distribution inside a solid disc rotor made of $AlSiC_p$ at the instant (a) t=0s, (b) t=1s, (c) t=2s, (d) t=4s, (e) t=6s and (f) temperature scale for Figures 5 (a)-(e)

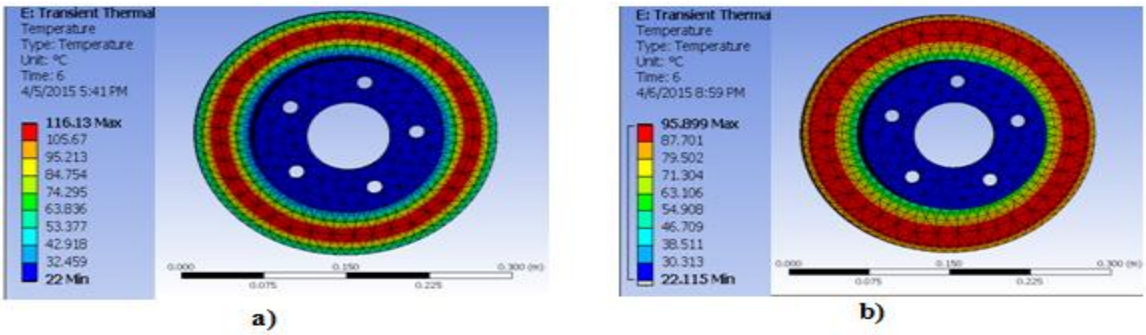


Fig.5 Temperature(^{0}C) distribution of solid disc rotor made of **(a)** cast iron, and **(b)** $AlSiC_p$ at the instant t=6s.

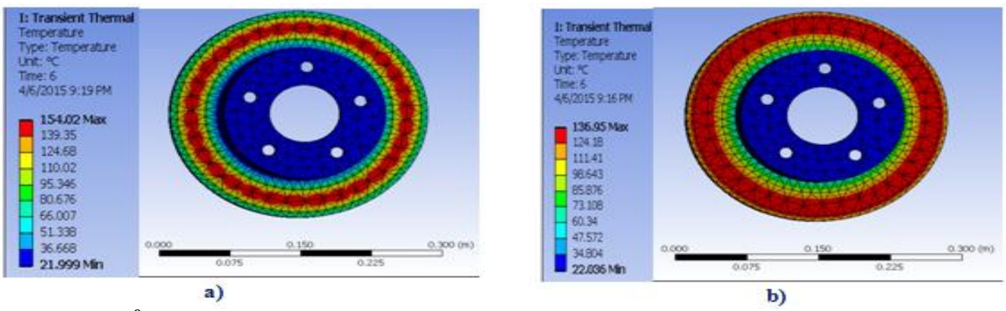
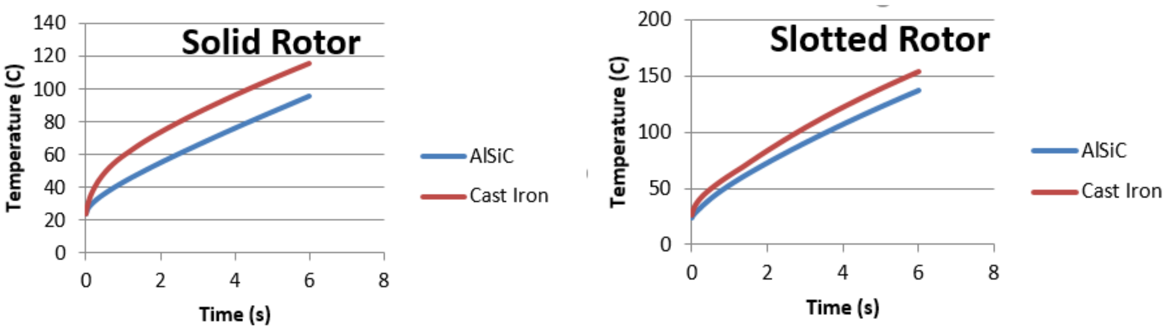


Fig.6 Temperature (^{0}C) distribution of ventilated disc rotor made of **(a)** cast iron, and **(b)** $AlSiC_p$ at the instant t=6s.

III. RESULTS

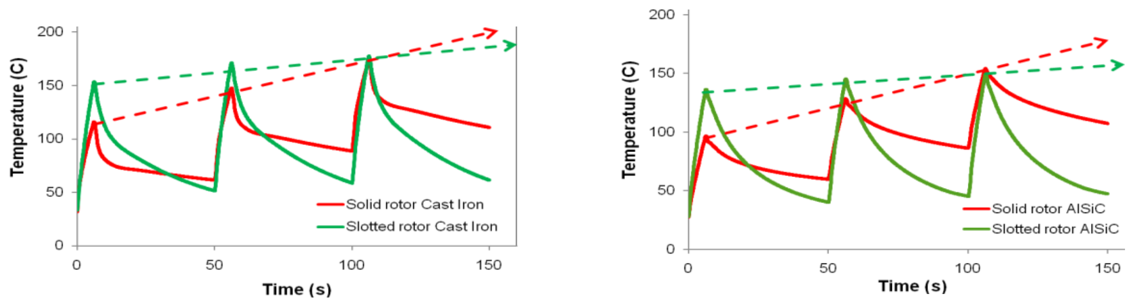
A transient analysis of the brake disc for 6 secs of application of brake was carried out and the temperature distribution on the solid and ventilated disc were tabulated and plotted as below.

	Solid Disc		**Ventilated Disc**	
	$AlSiC_p$	**Cast Iron**	**$AlSiC_p$**	**Cast Iron**
Temperature distribution in ^0C	**95.89**	**116.13**	**136.95**	**154**



Graph1 Temperature vs time for ventilated and solid rotor

The above graphs shows the temperature vs time graph plotted for a braking time of 6 secs in ventilated disc brake rotor. It can be seen from the above graph that when a brake is applied for 6secs the temperature raise in cast iron is more than that of the $AlSiC_p$ solid rotor. Disc brakes in racing cars and heavy vehicles almost get red hot and need a lot of air to cool down during hard and severe braking conditions. In such conditions $AlSiC_p$ ventilated disc brake provides better cooling and dissipates more heat as compared to the solid disc. A transient analysis performed for 150 seconds with 3 brake cycles of 6 seconds each shows the temperature distribution at each second. Graph-2 indicates the temperature raise with respect to time for repeated braking conditions(for three brakes applied at intervals of 50 seconds). It can be noted that though the ventilated disc gets more heated in the first cycle, the temperature slope tends to be less steep than solid rotor. The temperature at the end of 150 secs for solid rotor is 100^0c whereas for the ventilated rotor it is 40^0c. This shows that under repeated braking conditions, $AlSiC_p$ has better performance than a solid brake.



Graph 2 Temperature vs Time for Ventilated and solid rotor for 3 brake cycles and 150secs time.

IV. CONCLUSION.

Transient thermal analysis of the brake disc was performed to see the temperature distribution as a function of time (6 seconds). From transient analysis, it can be concluded that ventilated composite disc has a better performance over the Cast Iron disc, under repeated braking conditions by dissipating more heat than that of the solid disc.

V. FUTURE WORK.

CFD analysis of the disc brake can be performed to optimize the heat transfer. Optimization of disc thickness can be done to minimize the stresses and deformation. Cut patterns and drilled rotor can be analysed for a better heat transfer using. The effect of parameters like disc radius, thickness can be optimized. Modal analysis can also be performed to find the frequency and resonance of the disc.

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