Design and couple field analysis of Aircraft disc brake rotor

Anudeep.B, Naga Sunil.B

Asst.prof in RGMCET, deepnitw@gmail.com, 9063012368

Abstract— A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of a machine. Braking is a process which converts the kinetic energy of the vehicle into mechanical energy which must be dissipated in the form of heat. Here, the 3D model of aircraft disc brake rotor was created by using CATIAV5R20 with particular dimensions. The structural and thermal analysis of aircraft disc rotor was done in ANSYS 14.5.The materials used for aircraft disc rotor are aluminium metal matrix and ceramic coating. The main aim of this project is validate the mathematical result with ansys results. The maximum stress developed is 26.87MPa for aluminium metal matrix composite (AMMC) and 21.47MPa for ceramic coated aircraft disc brake rotor. Finally, the analysis suggests that Mechanical and thermal properties of aluminium alloy may be improved through the addition of ceramic coatings on the surface which in contact with the brake pad.

Keywords— Aircraft disc brake rotor, Catia V5R20, Ansys 14.5, aluminium metal matrix composite(AMMC), ceramic coating, von-mises stress, total deformation.

INTRODUCTION

Very early aircraft have no brake system to slow and stop the aircraft while it is on the ground. Instead, they rely on slow speeds, soft airfield surfaces, and the friction developed by the tail skid to reduce speed during ground operation. Brake systems designed for aircraft became common after World War I as the speed and complexity of aircraft increased and the use of smooth, paved runway surfaces proliferated. All modern aircraft are equipped with brakes. Their proper functioning is relied upon for safe operation of the aircraft on the ground. The brakes slow the aircraft and stop it in a reasonable amount of time. They hold the aircraft stationary during engine run-up and, in many cases, steer the aircraft during taxi. On most aircraft, each of the main wheels is equipped with a brake unit. The nose wheel or tail wheel does not have a brake.

Fig 1: Aircraft disc brake and exploded view

In the typical brake system, mechanical and/or hydraulic linkages to the rudder pedals allow the pilot to control the brakes. Pushing on the top of the right rudder pedal activates the brake on the right main wheel(s) and pushing on the top of the left rudder pedal operates the brake on the left main wheel(s). The basic operation of brakes involves converting the kinetic energy of motion into heat energy through the creation of friction. A great amount of heat is developed and forces on the brake system components are demanding. Proper adjustment, inspection, and maintenance of the brakes are essential for effective operation.

Fig 2: Aircraft disc rotor housing assembly

The disk brake has to exhibit excellent thermal properties in order to withstand extreme temperatures, such as in a case of aborted takeoff in an aero plane. In order to meet these property requirements, composite materials are used.

This paper deals with the use of a Metal Matrix Composite (MMC) in order to find out if the material can satisfy the requirements for a high- performance disk rotor. A structural-thermal analysis is done over the model of the disk brake using ANSYS 14.5, by applying pressure over the disk rotor.

MATERIALS

Aluminium-Metal matrix composites have lower density and high thermal conductivity. But, repeated braking causes lowering of friction coefficient and significant wear of brake pad. An addition of abrasive particles can help prevent the decrease in friction coefficient. Silicon Carbide (SiC), also known as Carborundum, is a compound of silicon and carbon with chemical formula SiC. It occurs in nature as the extremely rare mineral, Moissanite. Silicon Carbide powder has been mass-produced since 1893 for use as an abrasive. Grains of silicon carbide can be bonded together by sintering to form very hard ceramics that are widely used in applications requiring high endurance, such as brakes, clutches and ceramic plates in bulletproof vests. Silicon carbide is also used as a reinforcement to provide high strength to the resultant material. It has high thermal conductivity and high strength. Aluminium Metal matrix composite reinforced with Silicon carbide in the required volume can be used to get the desired properties to withstand high temperatures in a disk brake and to overcome the drawbacks of conventionally used disk brake materials. The zirconia-based ceramic coatings are used as thermal barrier coatings owing to their low conductivity and their relatively high coefficients of thermal expansion, which reduce the detrimental interfacial stresses. The material properties of Aluminium metal matrix and zirconia based ceramic material as shown in table 1 and 2.

Table 1: Properties of Aluminium Metal Matrix composite

Density(kg/m^3)	2670
Specific heat(J/kg K)	910
Thermal conductivity(W/mK)	250
Elastic modulus (GPa)	71
Bulk modulus (Pa)	6.96E+10
Shear modulus (Pa)	2.66E+10
Poisson ratio	0.33
Co efficient of thermal expansion(10^{-6}/K)	0.22

Table 2: Properties of zirconia-based ceramic coating (Mgzr03)

Property	Value
Density(Kg/m3)	5600
Young's modulus (Pa)	4.60E+10
Poisson ratio	0.2
Bulk modulus (Pa)	2.56E+10
Shear modulus (Pa)	1.92E+10
Thermal conductivity(W/mK)	0.8

AIRCRAFT DISC BRAKE ROTOR DATA:

- Mass of the aircraft vehicle = 57749 kg
- Initial velocity (u) = 69.44m/s
- Vehicle speed at the end of the braking application (v) = 0 m/s
- Brake rotor diameter = 0.3m
- Axle weight distribution 30% on each side (γ)=0.3
- Percentage of kinetic energy that disc absorbs (90%) k=0.9
- Acceleration due to gravity g =9.81m/s2
- Coefficient of friction for dry pavement μ=0.7

MODELING OF AIRCRAFT DISC BRAKE ROTOR IN CATIA V5R20

The solid modeling of the aircraft disc brake was made with the help of CAD tools CATIA v5 as shown in Figure 1. By using the following dimensions, we can prepare the aircraft disc brake. Fig 1 and 2 shows the 2d model and CATIA 3D model of aircraft disc brake with the particular dimensions.
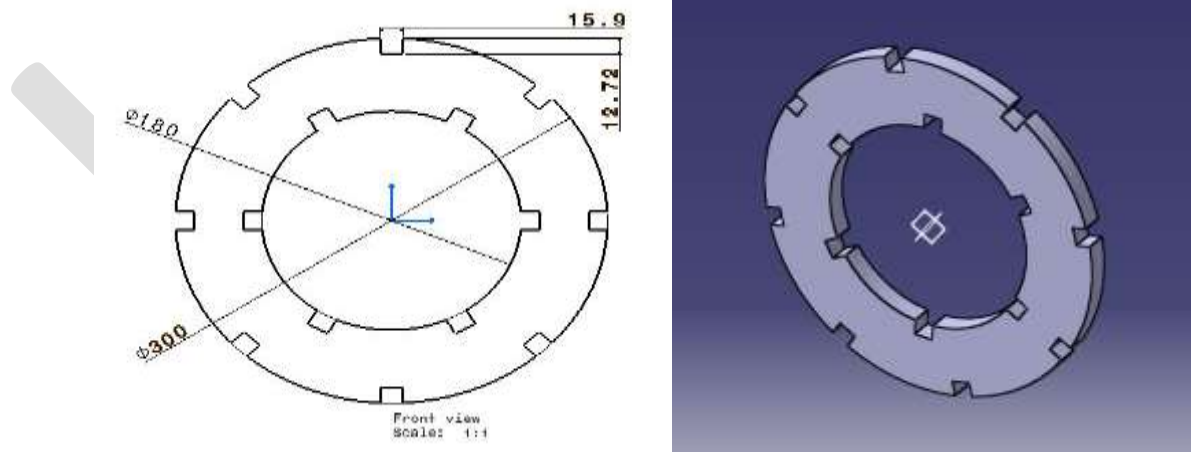

Fig 3: Aircraft disc rotor 2D and 3D model

MATHEMATICAL CALCULATIONS:

Energy generated during braking

$$KE = k\frac{1}{2}\gamma\frac{m(u-v)^2}{2}$$

$$KE = 0.9 \times 0.5 \times 0.3 \times 57749 \times \frac{(69.44-0)^2}{2}$$

KE=18796096.47 joules

Braking Power: Braking power during continued braking is obtained by differentiating energy with respect to time (t=65sec).

$$P_b = \frac{K.E}{t} = \frac{18796096.47}{65} = 289170.71 \; watts$$

Calculate the Heat Flux (Q): Heat Flux is defined as the amount of heat transferred per unit area per unit time, from or to a surface.

$$Q = \frac{P_b}{A}$$

$$A = \frac{\pi}{4} \times (D^2 - d^2) = \frac{\pi}{4} \times (0.3^2 - 0.18^2)$$

$$A = 0.04523 \text{ m}^2$$

$$Q = \frac{289170.71}{0.04523} = 6393338.82 \; W/m^2$$

ANALYTICAL TEMPERATURE RISE CALCULATIONS

Single stop temperature rise is the temperature rise due to single braking condition.

$$T_{max} = \frac{0.527 \times q \times \sqrt{t}}{\sqrt{\rho c k}} + T_{amb}$$

T_{max} = maximum disc temperature (^{0}C)

q   = Heat flux (W/m^2)

t   = Break on time (sec)

ρ = Density of disc brake material (Kg/m^3)

C   = Brake disc specific heat capacity (J/Kg/K)

K   = Brake disc thermal conductivity (W/mK)

T$_{amb}$ = Ambient temperature (^{0}C)

$$T_{max} = \frac{0.527 \times 6393338.82 \times \sqrt{65}}{\sqrt{2670 \times 910 \times 250}} + 20 \; ^\circ C \quad T_{max} = 1122.17 \; ^\circ C$$

Fade Stop Temperature Rise: The temperature rise after repeated stopping can also be approximated, although so many variables exist it is suggested this is only used for basic optimization work.

$$\Delta T = \frac{Pt}{\rho c v}$$

Where: ΔT = Average temperature increase per stop (^{0}C)

P   = Average power (Watts)

t   = time taking to take maximum temperature rise when brake applied

ρ = Density of disc brake material (Kg/m^3)

C = Brake disc specific heat capacity (J/Kg/K)

V = Disc volume (m^3)

$$\Delta T = \frac{289170.71 \times 4}{2670 \times 910 \times 0.04523 \times 0.019}$$
$$\Delta T = 553.96 \,℃$$

The compressive stresses 'σ'developed in the surface of a disc from sudden temperature increases is

$$\sigma = \frac{E}{1 - 2\mu} \times \alpha \times \Delta T$$

$$\sigma = \frac{71 \times 10^9}{1 - (2 \times 0.33)} \times 0.22 \times 10^{-6} \times 553.96$$

Compressive stresses $\sigma = 25.04 \, MPa$

INTRODUCTION TO ANSYS

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

Coupled-field analysis of AMMC aircraft disc brake rotor in ANSYS 14.5

1. First, Prepared aircraft disc brake model in CATIA V5 and Save as this part as IGES for Exporting into Ansys Workbench 14.5 Environment. Import .IGES Model in ANSYS Workbench Simulation Module.

2. Apply Material for aircraft disc brake

   Material Details: Aluminium Metal Matrix composite (Table 1) material and coated with ceramic coating (Table2)

   The zirconia-based ceramic coatings are used as thermal barrier coatings owing to their low conductivity and their relatively high coefficients of thermal expansion, which reduce the detrimental interfacial stresses.

3. Mesh the aircraft disc brake

4. Define boundary condition for Analysis Boundary conditions play an important role in   finite element calculation here, rotor supports are fixed. Pressure 13MPa and rotational velocity 60 rad/sec

5. Define type of Analysis for both AMMC and ceramic material (Mgzr03)

   Type of Analysis:-Static Structural and steady state thermal

6. Apply the pressure on aircraft disc brake

7. Run the Analysis

8. Get the Results

Structural analysis of AMMC aircraft disc brake rotor: A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can, however.

Include steady inertia loads (such as gravity and rotational velocity), and time varying loads that can be approximated as static equivalent loads. Static analysis determines the displacements, stresses, strains and forces in structures and components caused by loads that do not induce significant inertia and damping effect. Steady loading and response conditions are assumed; that is, the loads and structures response are assumed to vary slowly with respect to time.
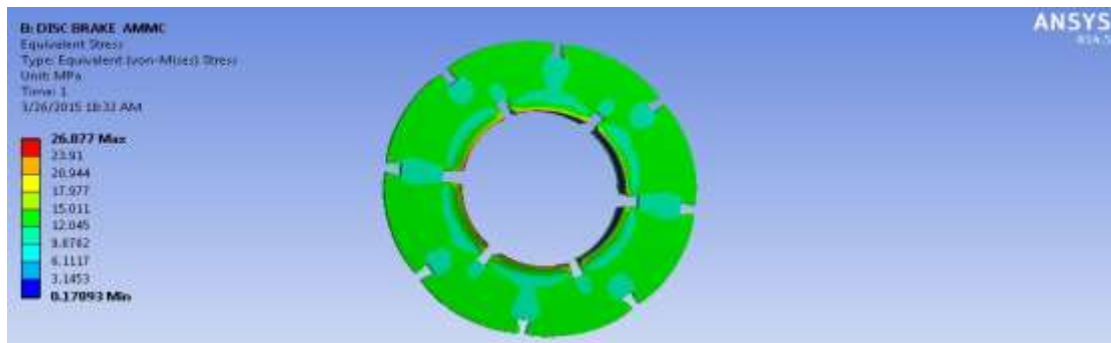

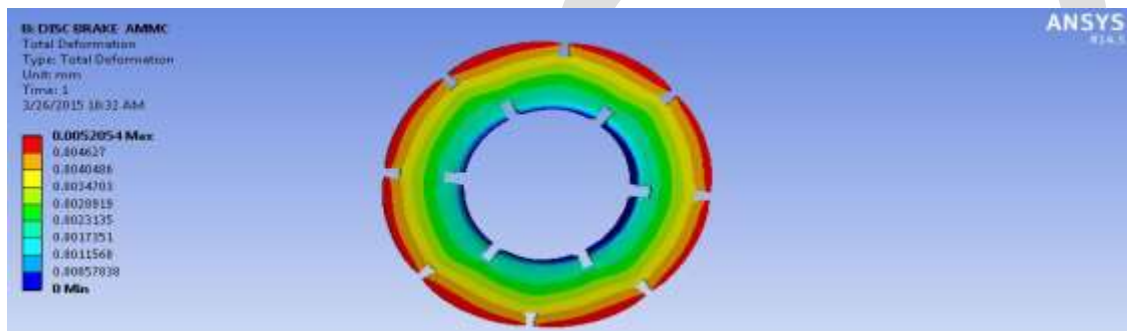Fig 3: Von-Mises stresses of AMMC aircraft disc brake rotor

Fig 4: Total deformation of AMMC aircraft disc brake

Steady state thermal analysis of AMMC aircraft disc brake: The analysis is a coupled type analysis as the thermal analysis is done and the residual thermal stress are imported to the static structural analysis. For thermal analysis, boundary condition, convection heat coefficient is applied along with the heat flow throughout the body, and then it is solved in terms of temperature and heat flux. The thermal stress is imported to static structural analysis. The boundary condition and loading condition were set following conditions for testing purpose in one automotive manufacturing company. The boundary conditions were defined by fixing all the surfaces. The force is applied to the patch where the brake pad touches the instant when brake is applied. It is solved in terms of total deformation, equivalent stress and equivalent strain.

Structural analysis of aircraft disc brake rotor with ceramic coating (MgZr03):
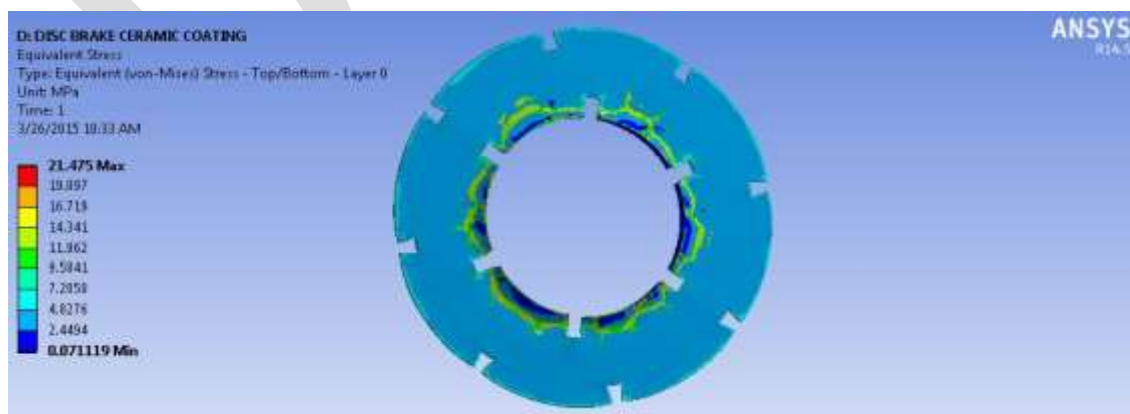

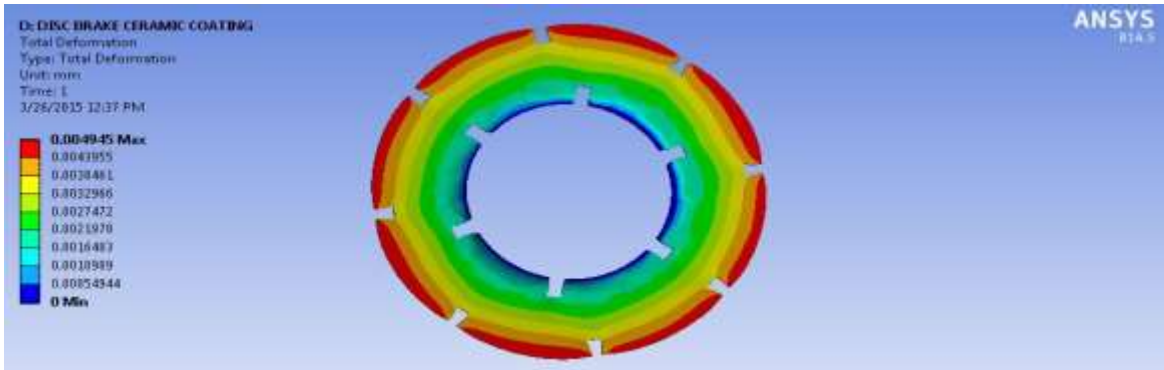Fig 6: Von-Mises stresses of ceramic coated aircraft disc brake

Fig 7: Total deformation of ceramic coated aircraft disc brake

Steady state thermal analysis of Aircraft disc brake with ceramic coating (MgZr03):
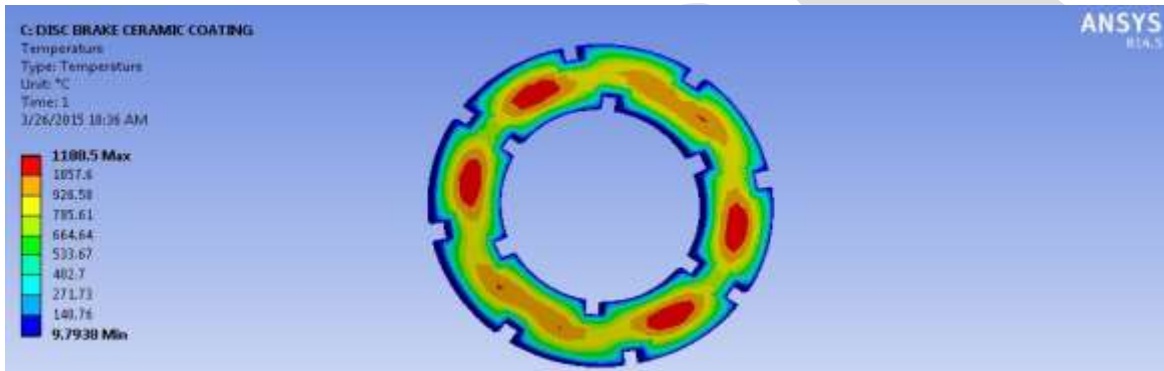

Fig 8: Temperature distribution on ceramic coated aircraft disc brake

COMPARISON THE RESULTS OF AIRCRAFT DISCBRAKE:

Table 3: Comparison of analytical and FEM results of AMMC

Table 4: Comparison of AMMC and ceramic coated disc brakes

Property	AMMC	Ceramic coated
Von misses stress (Mpa)	26.87	21.475
Total deformation(mm)	0.0052	0.0049
Maximum temperature (^{0}C)	1166.2	1188.5

CONCLUSION

Property	Analytical	FEM
Von misses stress (Mpa)	25.04	26.87
Maximum temperature (^{0}C)	1122.7	1166.2

- In this aircraft disc research, the rotor model was created by CATIA V5 R20 software. Then, the model created by CATIA was imported to ANSYS software.

- Validation is done through finite element solver with the initial model and checked that maximum stress and displacement are within control.

- Above Results Shows that FEA Results Conformal matches with the theoretical calculation so we can say that FEA is a good tool to reduce time consuming theoretical Work.

- The maximum temperature 1166.2^0c appears at the brake padding surface as shown in the fig5. The maximum stress 26.87MPa appears at the edge of fixed supports as shown in fig3.

- From coupled field analysis of ceramic coated disc brake, it is observed that the maximum temperature 1188.5^0C appears at the padding area and the maximum stress (21.47MPa) developed at the supports of edges.

- From table 4, we observed that by using of ceramic coating less deformation was developed compared to AMMC.

- From table 4, we observed that by using of ceramic coating less von misses stress was developed compared to AMMC.

- Finally, the analysis suggests that Mechanical and thermal properties of aluminium alloy may be improved through the addition of ceramic coatings on the surface which in contact with the brake pad.

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