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Thermo-Structural Analysis of Ventilated and Non – Ventilated Disc Brake using Different Materials.

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Abstract*: Every year Automobile industry is evolving. Significant inventions and improvements are occurring day by day. One of the important inventions in an automobile industry is the braking system. Disc brakes are widely used for maintaining and controlling speed of the vehicle by hindering the rotation of the shaft or any mechanical member. Material selection and design are one of the important factors, which plays an important role in the dissipation of heat generated. This paper compares three different materials i.e. C/C-SiC ceramic, Titanium grade 5 alloy, Tungsten Carbide, with two of the popular designs i.e. Ventilated disc and Solid disc (non-ventilated disc)

Keywords: **Disc brakes, Ventilated disc, Solid disc, heat dissipation**

I. INTRODUCTION

A brake is a device which is used to stop or slow down a vehicle by means of artificially added friction to the rotating mechanical member. Disc brakes are commonly used in modern vehicles as it possesses higher stopping power than the traditional Drum brakes. The disc brakes generally use caliper which squeezes or applies pressure on the brake pads on to the rotating disc rotor which in turn creates friction between them. This results in slowing of rotation of the shaft which reduces the speed of the vehicle. This energy is absorbed by the disc which then converts it into waste heat and dispersed into atmosphere. Some of the materials which are typically used in manufacturing of a disc rotor are Grey Cast Iron, Aluminum composites. These materials possess the properties like high coefficient of friction, high compressive strength, low wear and tear properties, lighter in weight and high thermal conductivity.

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Heat dissipation from the brake disc is an important factor which plays a significant influence on the thermal deformation in the disc.

Thermal and Structural analysis can be done using various softwares such as Solidworks, Ansys etc. In this paper Thermal and Structural analysis is done to analyze the extreme cases of heat distribution in the braking system i.e. Disc rotor.

Numerical interpretations were also used to calculate the thermal behavior of the design. In this paper the materials considered for the analysis are Tungsten Carbide, C/C-SiC ceramic, Titanium Grade-5 alloy.

Two of the popular designs were considered and designed in attempts to increase the maximum heat dispersion of a disc brake.

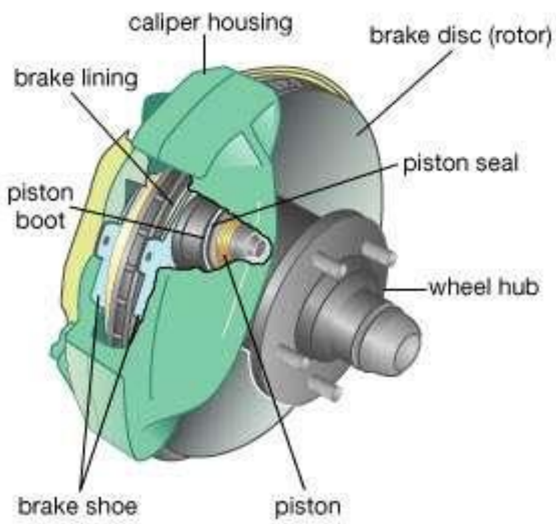


Fig 1: Disc Brake System

II. WORKING PRINCIPLE

The brake system generally consists of brake lever, master cylinder, hydraulic lines, disc rotor, and caliper unit.
When brake is applied, the brake lever pushes the piston in the master cylinder, which develops a fluid pressure.
Hydraulic lines transfer this pressure to the caliper unit which obeys the pascal law. The fluid pressure gets multiplied in the caliper cylinder. This forces the brake pads on to the disc rotor which generates friction and slows the vehicle.

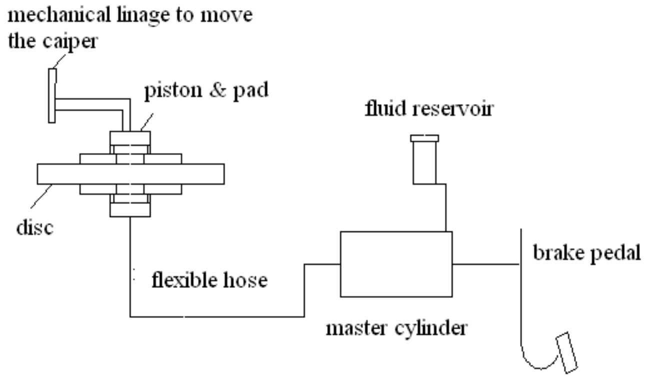


Fig 2: Brake mechanism.

III. MATERIAL SELECTION

The material should possess mechanical properties such as good compressive strength, high thermal conductivity, low thermal expansion, light weight and high friction coefficient.

The thermal storage capacity of the material should be high to prevent any deformation or distortion by the thermal stress till the heat dissipates.

In this paper we are considering materials such as C/C-SiC ceramics, Titanium grade 5 alloy and Tungsten Carbide. These materials are considered because they have all the necessary mechanical properties for designing a disc brake.

The properties of these materials are listed below in the following table.

	C/C-SiC	Ti -5	WC
Thermal conductivity (K) W/mK	40	6.7	88
Specific heat(Cp) J/Kg-K	800	526	292
Density (ᶅ) Kg/m^3	2450	4650	15630
Thermal expansion (α) K^{-1}	2.8 X 10^{-6}	1 X10^{-5}	7.1 X 10^{-6}
Poisson's ratio	0.27	0.33	0.31
Modulus of elasticity (E) GPa	30	109.9	53.8

Table 1: Properties of materials

IV. MODELING AND DESIGN

This paper attempts to compare the maximum heat dissipation between a Solid disc and a Ventilated disc using the above three materials i.e. Tungsten Carbide, Titanium -5 and C/C-SiC ceramic.

For analysis purpose the geometric parameters such as the outer and inner diameter are fixed for both ventilated disc and solid disc which are 286 mm and 161 mm respectively.

The disc brakes are modelled and simulated using Solidworks 2019.

A. Design calculations:

Mass of the vehicle: 1500 Kg.
Top Speed (u): 160 Kmph = 44.44 ms^{-1}
Coefficient of friction: 0.7

1. Kinetic Energy:

$$KE = \frac{m(u^2 - v^2)}{2} = 0.5 \text{ x } 1500 \text{ x } 44.44^2 = 33330 \text{ J}$$

2. Stopping Distance:
   i. Frictional force:
   F = µmg = 0.7 x 1500 x 9.81 = 10300.5 N
   ii. Deceleration of vehicle:
   a_{dec} = Fm^{-1} = 10300.5/1500 = 6.867 ms^{-1}
   iii. Stopping distance:
   $$SD = \frac{u^2}{2a_{dec}} = 44.44^2/2 \text{ x } 6.87 = 141.065 \text{ m}$$
   iv. Time taken:
   $$t = \frac{u}{a_{dec}} = 44.44/6.87 = 6.34 \text{ sec}$$
3. Brake power:
   $$P = \frac{KE}{t} = 33330/6.34 = 5257.0977 \text{ W}$$
   When sudden brake is applied, about 60% of the weight of the vehicle shifts towards the front axles or on the front wheels.
   Therefore, 5257.0977 x 0.6 = 3124.25 W.
   Brake power on single wheel:
   P_{sw} = 1577.129 W.
4. Heat flux:
   $$q = \frac{4P}{\pi(D^2 - d^2)}$$
   = 35935.48 Wm^{-2}

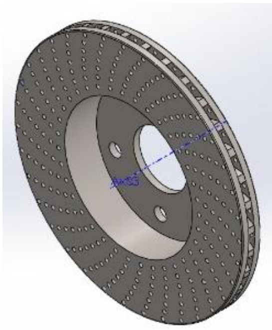


Fig 3: Ventilated Disc

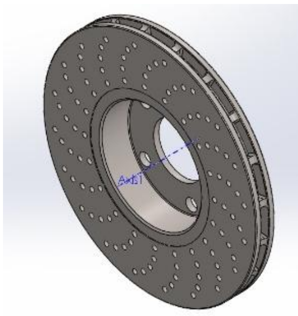
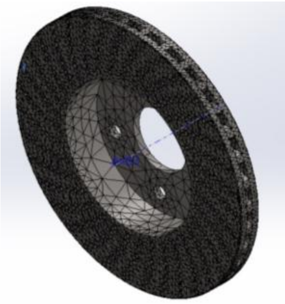


Fig 4: Solid Disc

V. MESHING

The models of the disc brake shown in the above figures are meshed using curvature-based mesh in Solidworks simulations with total number of nodes varying till 16000.



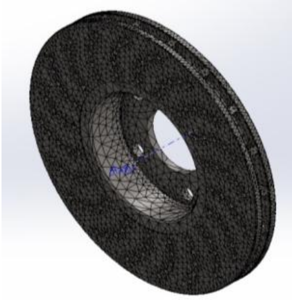


Fig 5: Ventilated disc mesh **Fig 6: Solid disc mesh**

VI. BOUNDARY CONDITIONS

A. Boundary conditions for structural analysis:

Rotational speed, ω = 72.9 rad/s is applied on the disc brake. Pressure, P = 1.2 MPa is applied on both sides of the brake pads.

B. Boundary conditions for thermal analysis:

Heat flux, q = 35938.48 Wm^{-2} is applied to the both discs. Convective film coefficient of 300 W/m^2 K is applied to all the surfaces of the disc. Internal temperature is set to 298K..

VII. RESULT AND DISCUSSION

A transient thermal analysis was carried out by applying the values of heat flux; for hard braking on different models of disc brakes and on different materials of the disc brake.

i. Titanium grade 5 alloy:

a. .

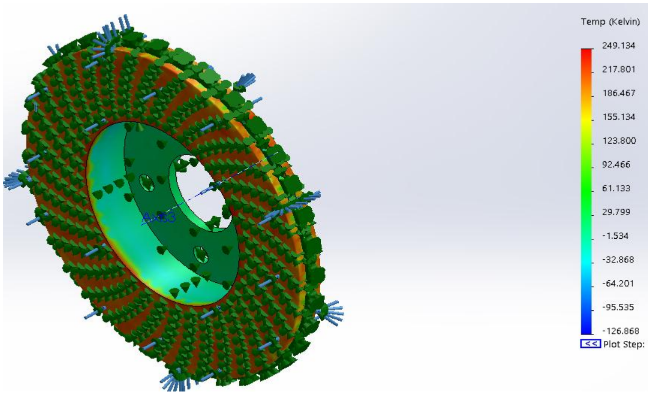


Fig 7: Temperature contour of Ti -5 ventilated disc.

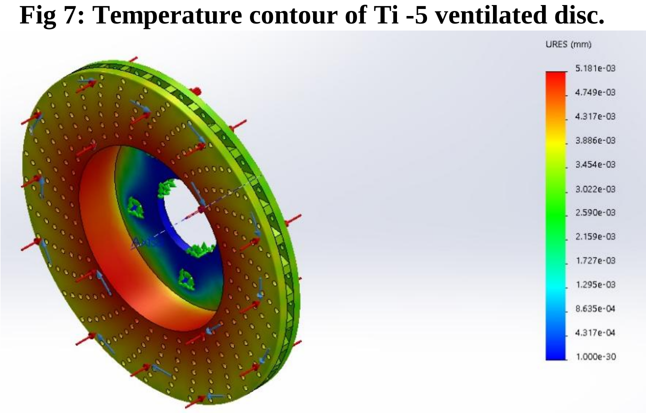


Fig 8: Deformation contour of Ti -5 ventilated disc.

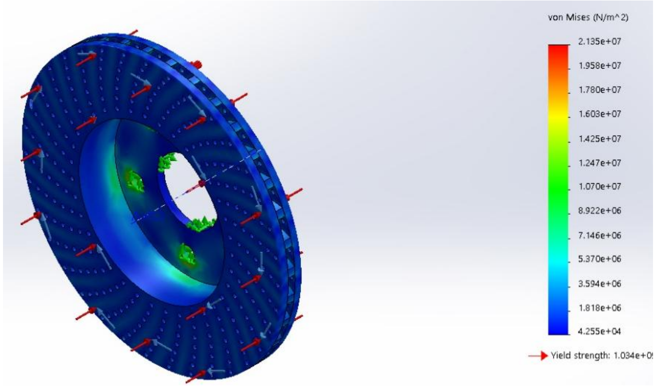


Fig 9: Von mises stress contour of Ti-5 ventilated disc.

b. .

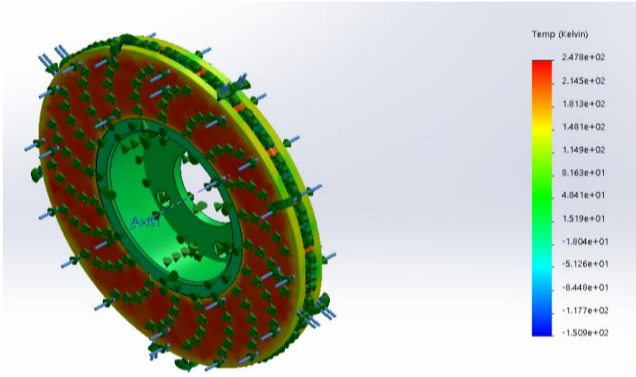


Fig 10: Temperature contour of Ti-5 solid disc.

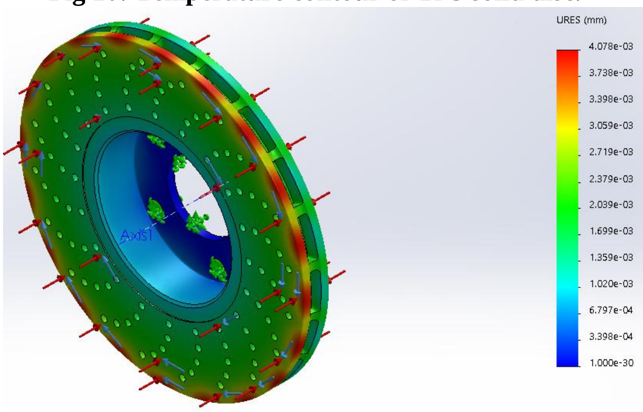


Fig 11: Deformation contour of Ti-5 solid disc.

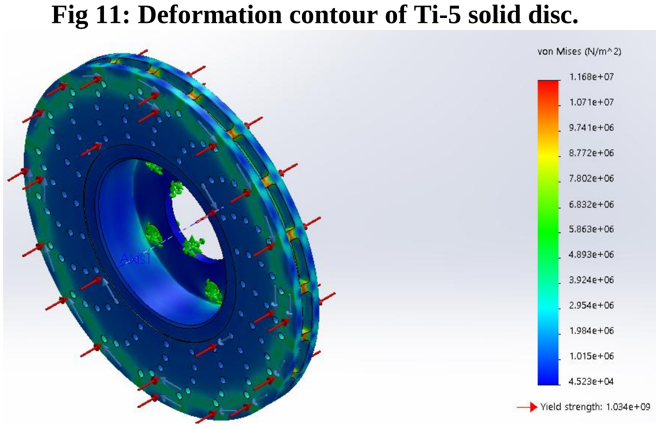


Fig 12: von Mises stress contour of Ti-5 solid disc.

The above figures 7-12 represents the temperature, displacement, von Mises stress of Ti-5 material were the maximum values of a. ventilated disc (249.134 K, 5.181 e^{-3} mm, 2.135 e^{7} N/m^2) b. solid disc (247.8 K, 4.078 e^{-3} mm, 1.168 e^{7} N/m^2) respectively.

ii. C/C-SiC composite:

a. .

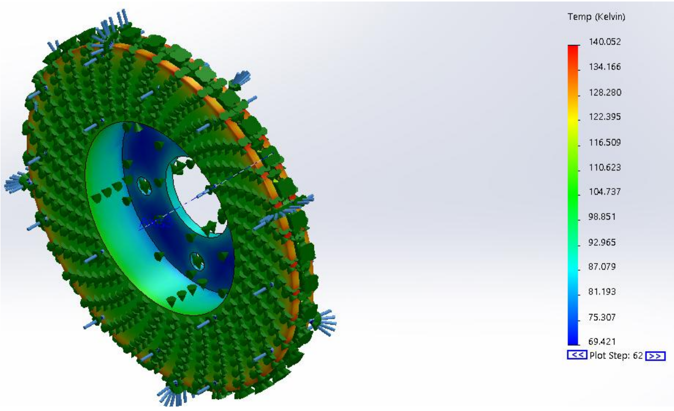


Fig 13: Temperature contour of C/C-SiC ventilated disc.

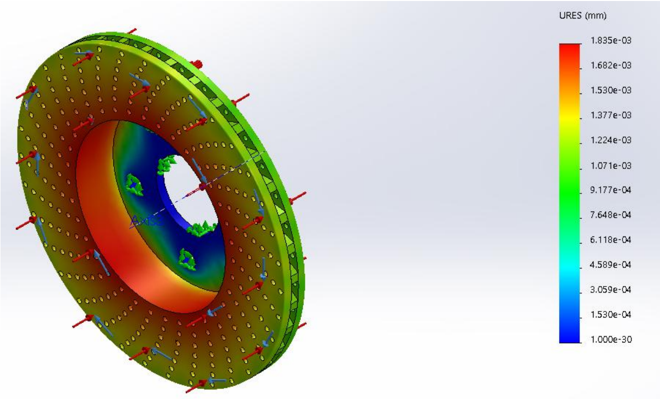


Fig 14: Deformation contour of C/C-SiC ventilated disc.

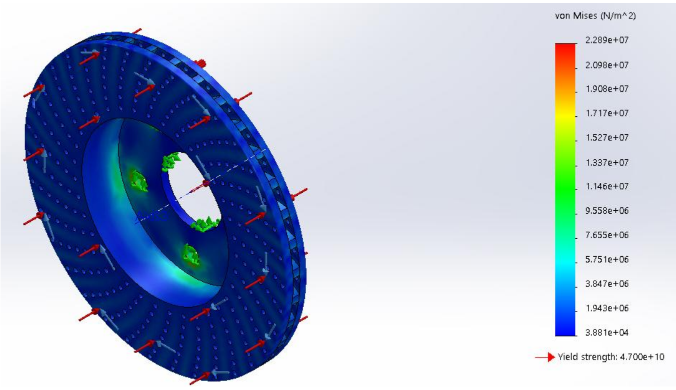


Fig 15: von Mises stress contour of C/C-SiC ventilated disc.

b. .

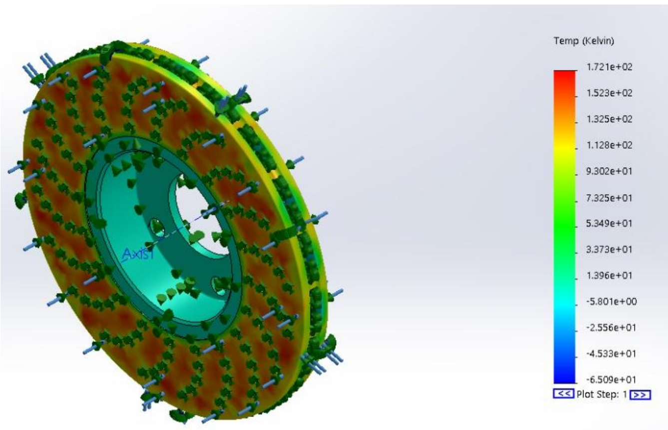


Fig 16: Temperature contour of C/C-SiC solid disc.

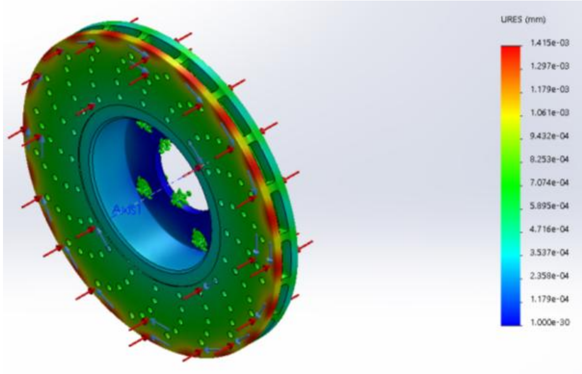


Fig 17: Deformation contour of C/C-SiC solid disc.

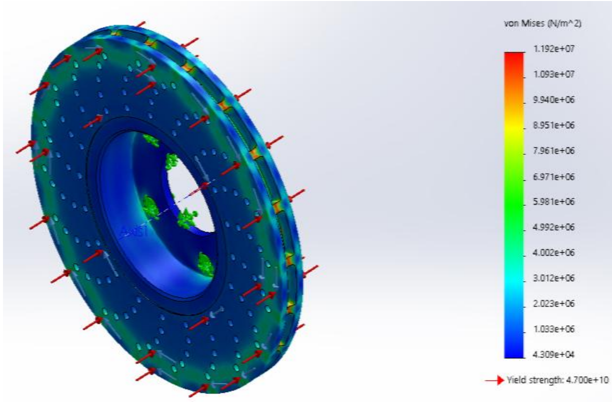


Fig 18: von Mises stress contour of C/C-SiC solid disc.

The above figures 13-18 represents the temperature, displacement, von mises stress of C/C-SiC material were the maximum values of a. ventilated disc (140.052 K, 1.835 e^{-3} mm, 2.289 e^{7} N/m^2) b. solid disc (172.1 K, 1.415 e^{-3} mm,1.192 e^{7} N/m^2) respectively.

iii. Tungsten Carbide

a. .

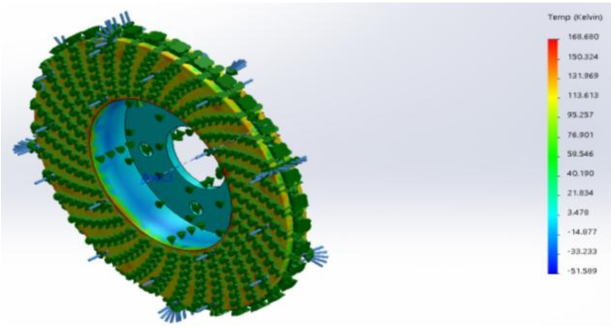


Fig 19: Temperature contour of Tungsten Carbide ventilated disc.

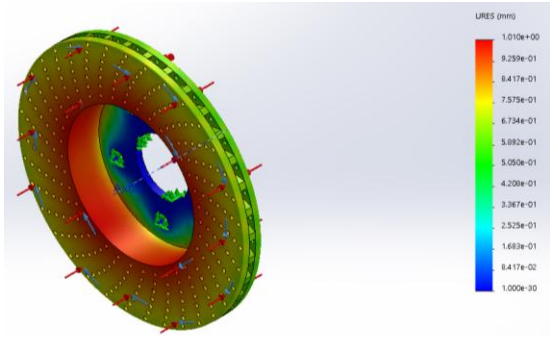


Fig 20: Deformation contour of Tungsten Carbide ventilated disc.

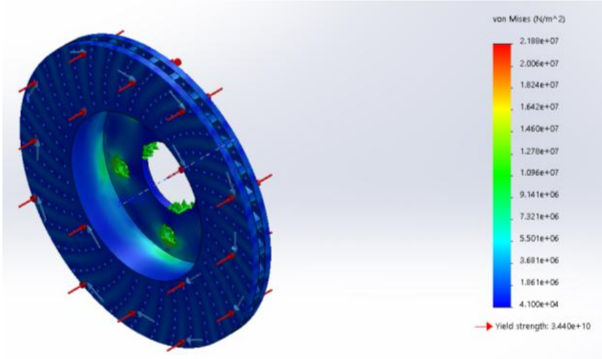


Fig 21: von Mises stress contour of Tungsten Carbide ventilated disc.

b.

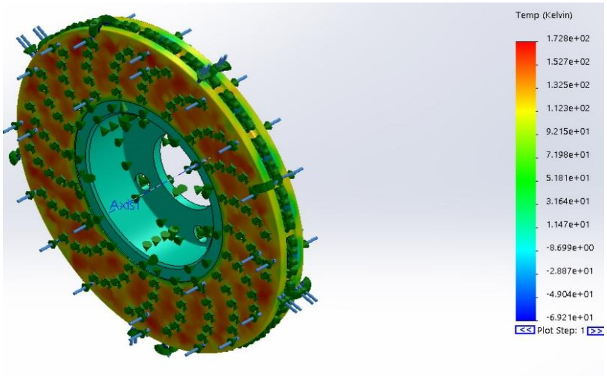


Fig 22: Temperature contour of Tungsten Carbide solid disc.

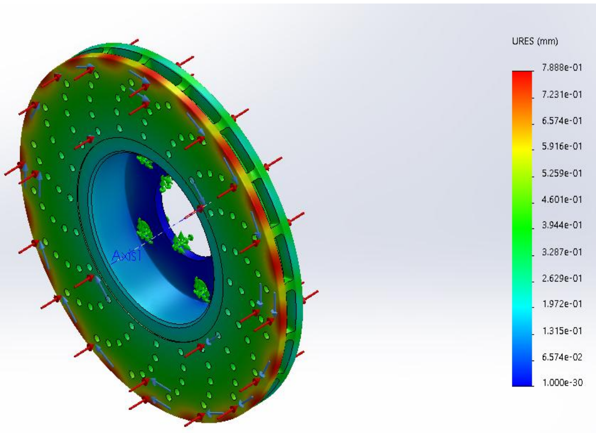


Fig 23: Deformation contour of Tungsten Carbide solid disc.

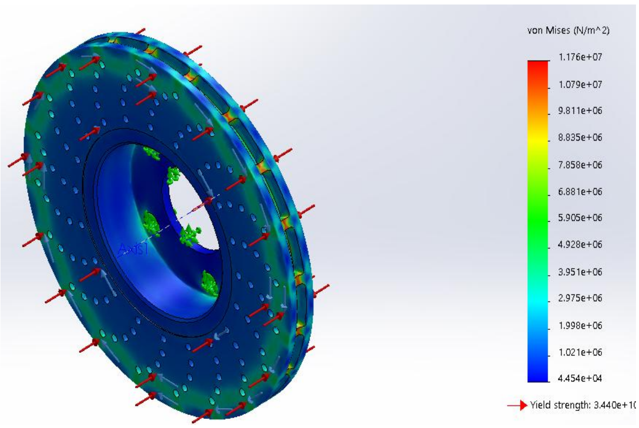


Fig 24: von Mises stress contour of Tungsten Carbide solid disc.

The above figures 19-24 represents the temperature, displacement, von Mises stress of Tungsten Carbide material were the maximum values of a. ventilated disc (168.68 K, 1.010 mm, 2.188 e^7 N/m^2) b. solid disc (172.8 K, 7.88 e^{-1} mm, 1.176 e^7 N/m^2) respectively.

	Ventilated disc			Solid disc		
	Ti -5	C/C-SiC	WC	Ti -5	C/C-SiC	WC
Temperature (K)	249.134	140.052	168.68	247.8	172.1	172.8
Deformation (mm)	0.00518	0.001835	1.010	0.004078	0.001415	0.788
Von Mises Stress (n/m^2)	2.135 x10^7	2.289 x10^7	2.188 x10^7	1.68 x10^7	1.192 x10^7	1.176 x10^7

Table 2: Comparison of results obtained after analysis of various discs

The results obtained for temperature distribution, total deformation i.e. displacement and von Mises stress are tabulated in table 2. It is observed that C/C-SiC Ventilated disc has the least disc temperature with a corresponding stress value of 2.289 x10^7 N/m^2. The reduction in the disc temperature for ventilated C/C-SiC disc is found to be about 18.62% as compared to its other disc model Titanium grade-5 disc has a relatively higher disc temperature. The deformation in the discs are found to be maximum in the tungsten carbide ventilated disc (1.010 mm) and minimum in C/C-SiC Solid disc (0.001415 mm).

VIII. CONCLUSION

- The design and analysis of the disc brakes are done using Solidworks.
- It is observed that the C/C-SiC ceramic ventilated disc has the lowest Temperature of 140.052K with a corresponding maximum stress of 2.289 x 10^7 N/m^2
- The C/C-SiC ceramic solid disc has the lowest displacement of 0.00145 mm with a corresponding temperature of 172.1 K and maximum stress of 1.192 x 10^7 N/m^2
- It can be recommended to use a solid C/C-SiC disc as it has the lowest displacement and has optimal temperature range for normal performance vehicles. And use a ventilated C/C-SiC disc for high performance vehicles.
- It is also observed that Tungsten Carbide disc has the highest displacement of a.solid disc: 0.788 mm b. ventilated disc: 1.010 mm despite having the 2nd lowest disc temperatures of 168.68 K and 172.8 K. All these essential properties can be preserved, if a coating of tungsten carbide is coated on gray cast iron so that Tungsten Carbide will have enough strength to with stand these pressures.

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