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Design and Analysis of Different Materials in a Disk Brake Rotor for Maximum Heat Transfer Using Finite Element Method(FEA)

Pranay Dawne [1], Ruchika Saini [2]

1. Research Scholar, Department of Mechanical Engineering, JEC Jabalpur (M.P.)
2. Associate Professor, Department of Mechanical Engineering, JEC Jabalpur (M.P.)

Abstract: The Braking systems is most important part in automobile industries. It is used to maintaining and controlling the speed of the vehicle. So it is important to find the best suited material, which can maintain the heat generation and sustain the other mechanical loading. In this paper the study of maximum heat transfer for different materials (Structural Steel, Titanium Alloy, Copper Alloy, MagnesiumAlloy and for the Aluminium Alloy) on the basis of Static structural and thermal analysis performed in the disk brake using the finite element simulation software ANSYS was investigated. This research shows comparison between Brake disc materials namely, Structural Steel, Titanium Alloy, Copper Alloy, MagnesiumAlloy and for the Aluminium Alloy. The results were compared on the basis of Heat flux, Total Deformation, Stress, Strain and thermal behaviour of materials. we can see that, maximum temperature variation comes in Titanium alloy disk is 100 °C to 89.173°C and minimum in Copper Alloy is 100°C to 99.315°C. In the case of heat flux maximum value obtained in Copper Alloy based disc which is 0.010974 W/mm^2 and minimum in Titanium alloy which is 0.0099397 W/mm^2 based disc. Structural Steel gives maximum value of Equivalent stress which is 493.37 Mpa and Titanium alloy gives minimum value of Equivalent stress which is 186.93 Mpa based disc as compare to other materials. The MagnesiumAlloy material gives maximum deformation which is 0.21693 mm and the Titanium alloy material gives minimum deformation which is 0.077834 mm comparatively others. MagnesiumAlloy gives maximum value of Equivalent strain which is 0.0058711 mm/mm and Titanium alloy gives minimum value of Equivalent strain which is 0.0019476 mm/mm based disc as compare to other materials. And Titanium alloy, Structural steel made rotor disk give better heat dissipation results.

Keywords: Disk brake Thermal analysis, Heat flux, Static Structural, Stress, Strain, Deformation Finite element analysis etc.

1. Introduction

Generally Brakes are most important safety parts in the vehicles. Brakes function is to slow down and stop the rotation of the wheel. To stop the wheel, braking pads are forced mechanically against the rotor disc on both surfaces. They are compulsory for all of the modern vehicles and the safe operation of vehicles. In short, brakes transform the kinetic energy of the car into heat energy, thus slowing its speed. The disk brakes are a two parts system, One being the rotating plate called the Disk and the other being the caliper assembly which is clamped on the periphery of the rotor which has a friction material. When the caliper is pressed against the rotating Disk, causes the generation of heat, converting kinetic energy of the rotor is high speed into heat energy which gets accumulated in the rotating Disk. So if the pressure applied by the caliper on the rotor is large, then the heat generated in the rotor is large. The action of caliper to press against the rotating Disk is made possible by implementing one or more hydraulic pistons. Thus the design of the Disk brake rotor is based on some of the crucial factors such as heat generation, heat dissipation, mechanical loading etc.

2. Literature Review

Pandya Nakul Amrish et al; presents, The Computer Aided Design and Analysis of Disc Brake Rotors [1]. Vishvajeet, Faraz Ahmad, Muneesh Sethi, R.K. Tripathi, et al; presented the study on the Thermo-mechanical analysis of disk brake using finite element analysis [2]. Sung-Soo Kang, and Seong-Keun Cho, et al; presented the study on the Thermal deformation and stress analysis of disk brakes by finite element method [3]. Zhang Jian Xia Changgao, et al; reports an study on the Research of the Transient Temperature Field and Friction Properties on Disc Brakes [4]. Ali Belhocine, Mostefa Bouchetara, et al; presents an study on the Structural and Thermal Analysis of Automotive Disc Brake Rotor [5]. Bangaru Bharath Kumar, et al; presents an study on the Thermal Analysis of Disc Brake Rotor [6]. Tanuj Joshi, Sharang Kaul, et al; gives the Performance investigation of Design and Optimization of Perimetric Disc Brake Rotor [7]. M.H. Pranta, M.S. Rabbi, S.C. Banik, M.G. Hafez, Yu-Ming Chu, et al; presents in this study on the computational study on structural and thermal behavior of modified disk brake rotors [8]. Challa Balaji Naga Sai Abhishikt, Balaji Ramachandran, Ganti Naga Alekhya, et al; reports the Design and analysis of disk rotor brake under tribological behaviour of materials [9]. Ashish Kumar Shrivastava and Rohit Pandey et al; presented the study on the Thermal analysis on car brake rotor using cast iron material with different geometries [10]. Adama Coulibaly and Nadjet Zioui et al; presents this study investigated use of thermoelectric generators to harvest energy from motor vehicle brake discs [11]. Leta Tesfaye Jule et al; gives the numerical study on evaluation the structural and thermal analysis of solid and cross drilled rotor by using finite element analysis [12]. Anders Söderberg et al; reports of this work is Simulation of wear and contact pressure distribution at the pad-to-rotor interface in a disc brake using general purpose finite element analysis software [13]. Gabriele Riva and Giorgio Valota, et al; study the an FEA approach to simulate disc brake wear and airborne particle emissions [14]. K. Harshavardhan et al; Investigates the effect of reinforcing SiC and graphite on aluminium alloy brake rotor using plasma spray process [15]. V. Sai Naga Kishore et al; presents this study theTemperature evolution in disc brakes during braking of train using finite element analysis [16]. K. Vinoth Babu and S. Marichamy et al; study the processing of functionally graded aluminum composite brake disc and machining parameters optimization [17].

The discussed literature review study demonstrated that the existing literature it was found most of the work is dedicated to thermal analysis, which provides the material heat dissipation result, where as structural analysis provides the deformation, stress result. But during braking operation the rotor disk and pad are subjected to thermal as well as mechanical loading. So in present study a disk rotor plate was analyzed under thermal and mechanical loading condition. The complete study is divided into sections, first describe the introduction and existing literature of disk brake, second present the disk brake design and material properties details, third section shows the finite element analysis procedure, fourth section provide simulation results, and fifth section conclude the complete study.

Thus, The objective of this work is ***"To determine the Maximum heat transfer performance of different Materials in a Disk Brake Rotor Using Finite Element Method(FEA)".***

3. Research Methodology

3.1. Design and Specification of disc break:

The various researchers have been studying the maximum heat dissipation of the Disk Brake Rotor. The analysis has been divided into two sections comprising: Model validation, using different Materials of Disk Brake Rotor for maximum heat dissipation. The heat transfer takes place between Hot Disk Rotor to the surrounding air. Thermo-mechanical analysis enable the temperature loading in static structural by making coupling between steady state thermal and static structural module. During the operation of disk brake the rotor disk was subjected to temperature and mechanical loading. So in present study the temperature of 100 ºC was applied and convection surface area which will convict the heat to surrounding air which can be seen in Fig. 2(a). And Figs. 2(b) shows the fixed support and other mechanical loading (disk pad pressure and rotational velocity) respectively. After applying all the boundary condition the simulation was performed with coupled analysis. The study is carried out i.e.,Finite Element Analysis (FEA) for different Materials. The design specification of Disc Brake Rotor are presented in Table 1. The dimensions of Disc Brake Rotor are presented in Table 1.

Table1. The Specification of Disc Brake Rotor.

Sr. No.	Description	Unit	Value
1.	Outer diameter of Disc brake rotor	mm	280
2.	Inner diameter of Disc brake rotor	mm	225
3.	Hub diameter	mm	130
4.	Thickness of rotor	mm	5

3.2. Finite Element Analysis (FEA):

ANSYS Workbench 15.0 is used for Finite element analysis (FEA). In ANSYS software the Thermo-mechanical analysis enable the temperature loading in static structural by making coupling between steady state thermal and static structural module is used as platform for the study.

3.3. Steady State Thermal and Static Structural Analysis:

The structure of a disk brake can be divided into the flange and hub, bridge parts. To reduce the weight of the disk, there are punches in bridge parts. Also, vents are made in part of the flange in order to dissipate high-temperature heat between the disk and pad. Mounting of the disk is entered into primarily by bolts screwed into the hub part which is also for punching. In this study, analysis has been performed for the front wheel disk brakes. Ventilated brake disks are used. The brake disc consumes the major part of the heat, usually greater than 90% by means of the the effective contact surface of the friction coupling. Considering the complexity of the problem and the limitation in the average data processing, one identifies the pads by their effect, represented by an entering heat flux.

3.4. Geometry and Meshing of Disc Brake:

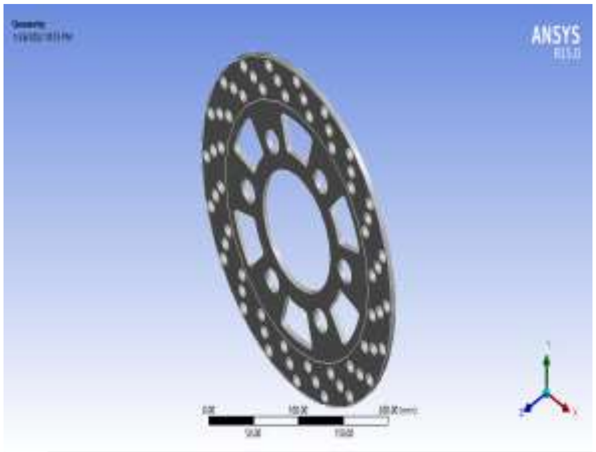


Fig. 1.(a) Geometry of the Disc Brake Rotor.

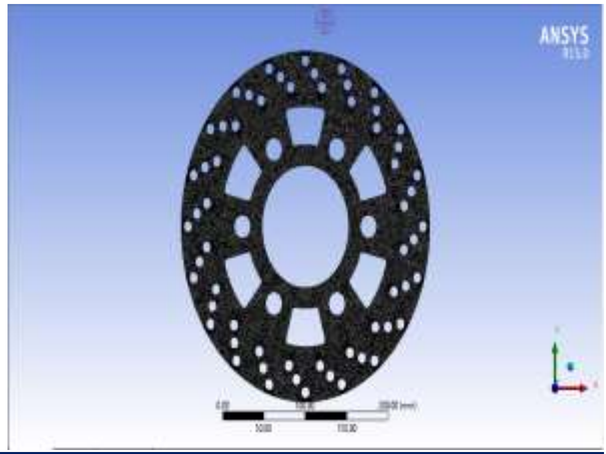


Fig. 1.(b) Meshing of the Disc Brake Rotor.

The Disc Brake Rotor geometry is built in the ANSYS workbench 15.0 and thus it is Analysis in the ANSYS workbench design module. The disk was design with circular holes which increase the heat dissipation from disk and maintain the temperature. To perform the analysis five different materials was selected which generally used in making the rotor disk. Table. 3 shows the material properties of selected materials. Fig. 1(a) and (b) shows the Geometry and meshing of rotor disk. Meshing has 2 mm mesh size and its number of Elements and nodes are 325381 and 505662 respectively. Initially a relatively medium mesh is generated. This mesh contains mixed cells having both triangular and quadrilateral faces at the boundaries. All the boundary condition were shown in the Fig.2(a) and (b) and also in Table 2.

3.5. Boundary Conditions:

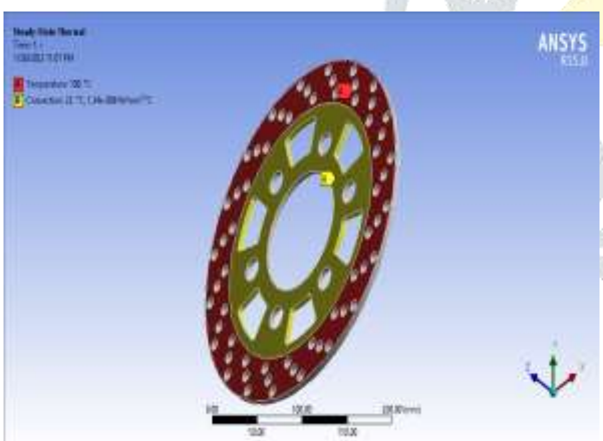


Fig. 2.(a) Steady State Thermal of the Disc Brake Rotor.

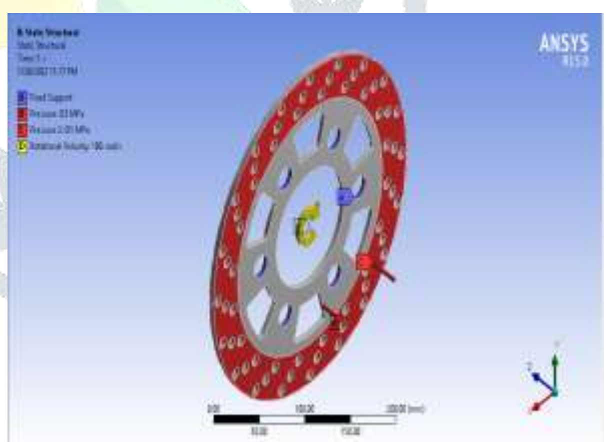


Fig. 2.(b) Static Structural of the Disc Brake Rotor.

Table 2. Boundary Conditions.

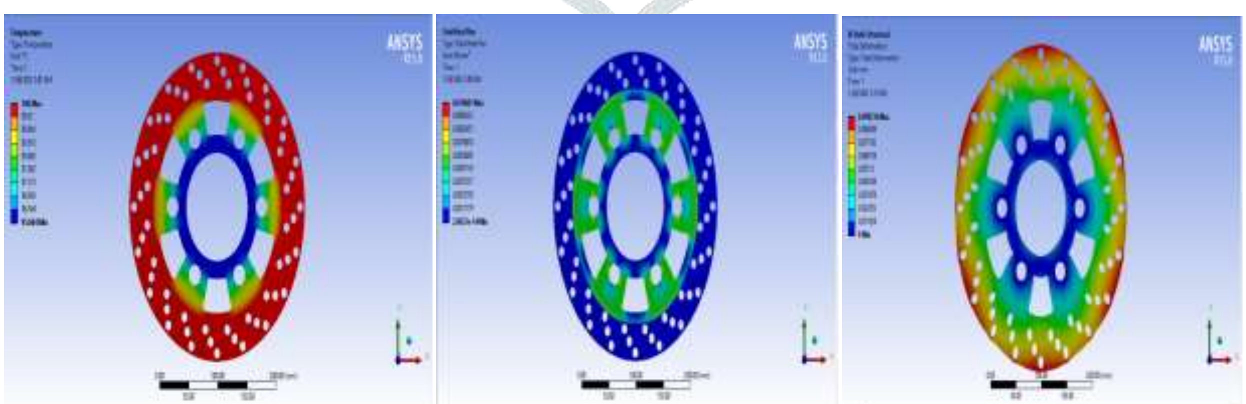
Sr. No.	Steady State Thermal	Static Structural
1.	Temperature (100º C)	Fixed Support
2.	Convection (W/mm^2)	Pressure (1 MPa)
3.		Rotational Velocity (100 rad/s)

Table 3. Material Property used for the study.

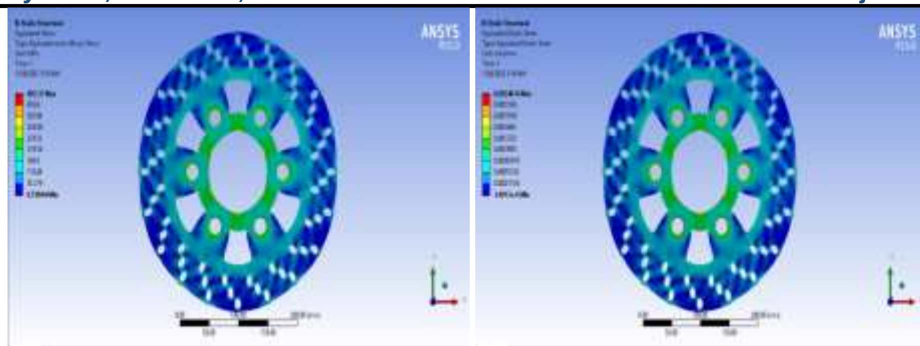
Material Property					
Materials	**Density (kg/m^3)**	**Young's modulus (MPa)**	**Tensile strength (MPa)**	**Compressive strength (MPa)**	**Poisson's ratio**
Structural Steel	7850	$2*10^5$	250	250	0.3
Titanium Alloy	4620	$9.6*10^4$	930	930	0.36
Copper Alloy	8300	$1.1*10^5$	280	280	0.34
MagnesiumAlloy	1800	$4.5*10^4$	193	193	0.35
Aluminium Alloy	2770	$7.1*10^4$	280	280	0.33

4. Result and Discussions

The Finite Element Analysis (FEA) results for different Materials namely, Structural Steel, Titanium Alloy, Copper Alloy, MagnesiumAlloy and for the Aluminium Alloy, to find out the best suited material which can sustain the deformation under thermal loading in a Disc Brake Rotor. The materials were simulated for temperature, heat flux, total deformation and Equivalent stress and Equivalent Strain, for result comparison. The results of selected materials were shown in the figures. In this section the brake disk was analyzed for different Materials to find out the maximum heat dissipation. The some variables have been considering constant i.e Applied Temperature (100º C), Pressure (1 MPa) and Rotational Velocity (100 rad/s). Firstly, The results is obtained for Structural Steel Material (a) Temperature variation, (b) Heat flux, (c) Total deformation, (d) Equivalent Stress, (e) Equivalent Strain were shown in the Fig.3. Similarly the results are obtained for Titanium Alloy, Copper Alloy, MagnesiumAlloy and the Aluminium Alloy materials were shown in the Fig.4,Fig.5,Fig.6 and Fig.7. Figure depicts the Finite Element Analysis results for different Materials in a Disc Brake Rotor.

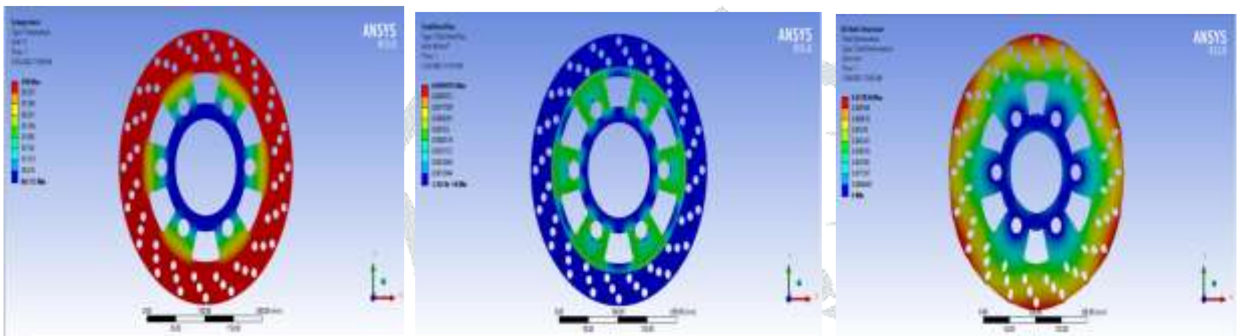


(a) (b) (c)

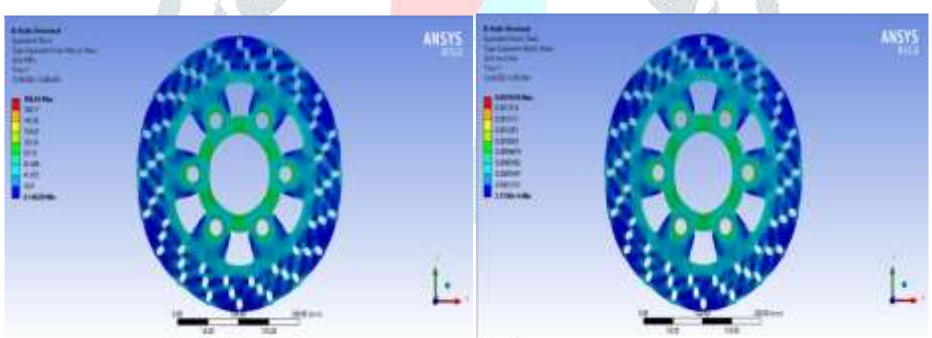


(d) (e)

Fig. 3. For Structural Steel Material (a) Temperature variation, (b) Heat flux, (c) Total deformation, (d) Equivalent Stress, (e) Equivalent Strain.

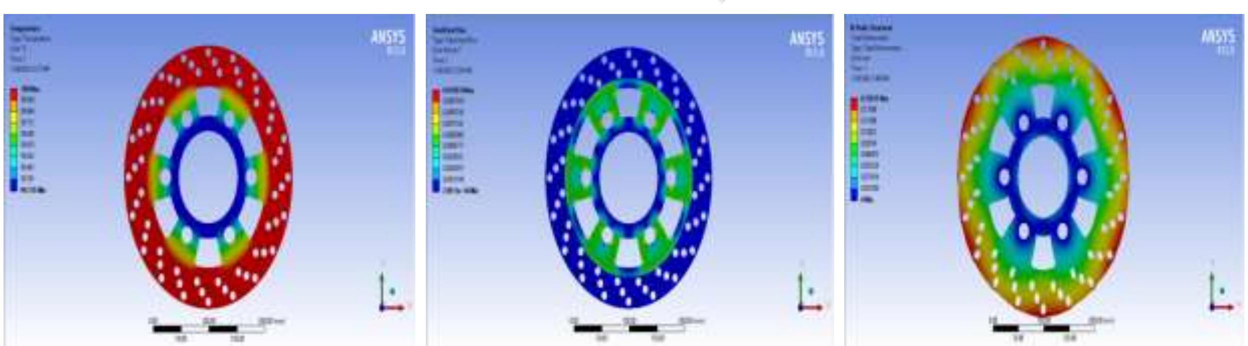


(a) (b) (c)

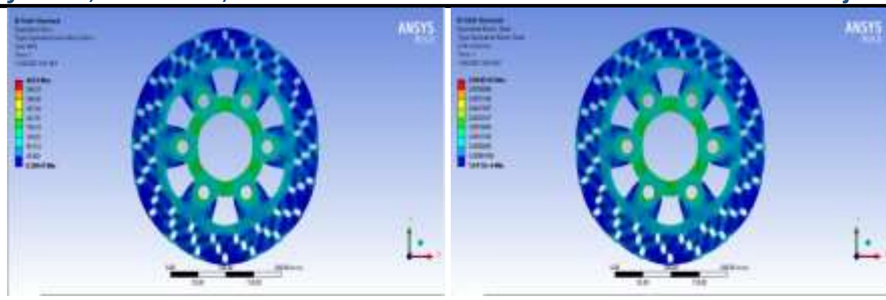


(d) (e)

Fig. 4. For Titanium Alloy Material (a) Temperature variation, (b) Heat flux, (c) Total deformation, (d) Equivalent Stress, (e) Equivalent Strain.

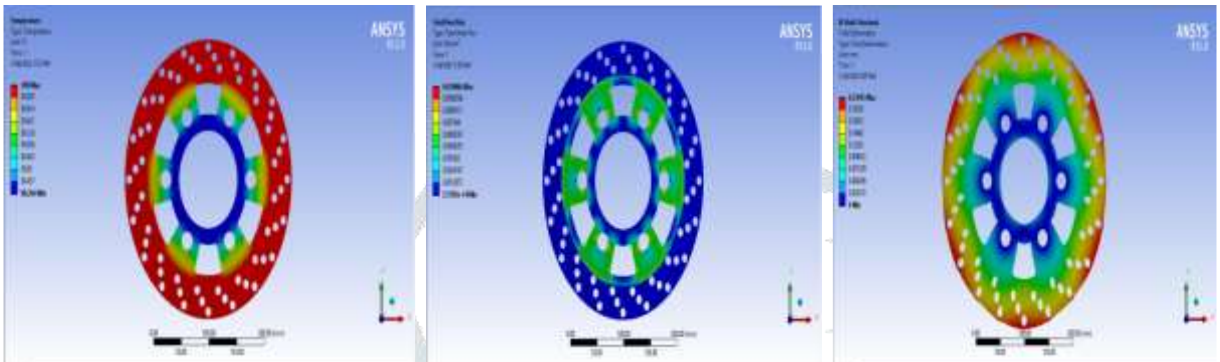


(a) (b) (c)

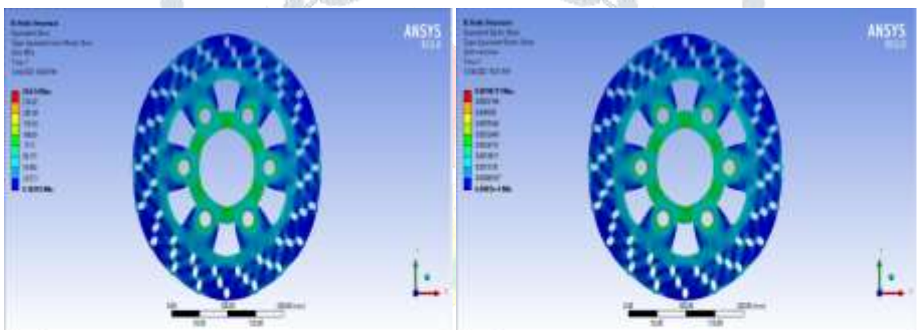


(d) (e)

Fig. 5. For Copper Alloy Material (a) Temperature variation, (b) Heat flux, (c) Total deformation, (d) Equivalent Stress, (e) Equivalent Strain.

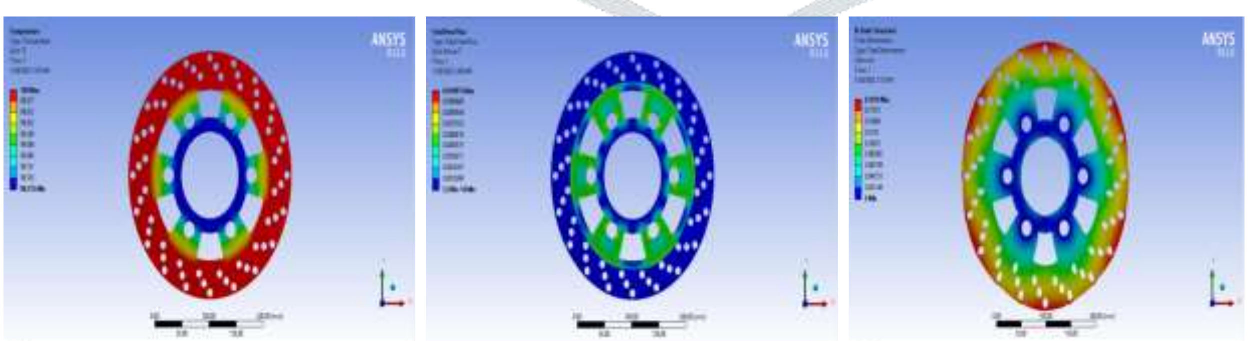


(a) (b) (c)

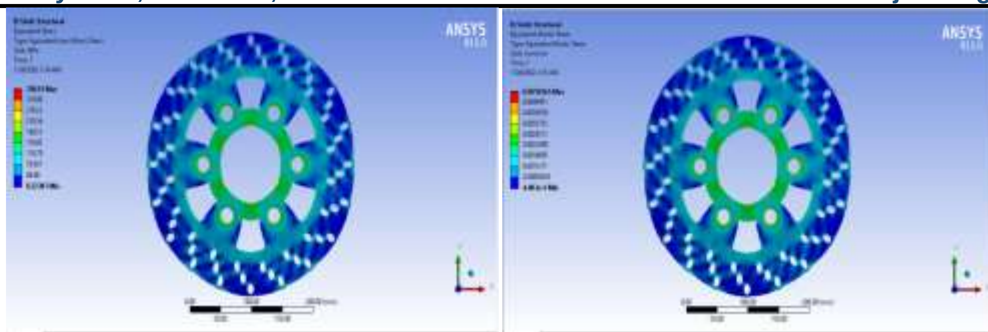


(d) (e)

Fig. 6. For Magnesium Alloy Material (a) Temperature variation, (b) Heat flux, (c) Total deformation, (d) Equivalent Stress, (e) Equivalent Strain.



(a) (b) (c)



(d) (e)

Fig. 7. For Aluminium Alloy Material (a) Temperature variation, (b) Heat flux, (c) Total deformation, (d) Equivalent Stress, (e) Equivalent Strain.

Table 4. Simulation Result comparison for all five materials.

Result						
Materials	**Temperature (°C)**		**Heat Flux (W/mm^2)**	**Total Deformation (mm)**	**Equivalent Stress (MPa)**	**Equivalent Strain (mm/mm)**
	Max.	**Min.**				
Structural Steel	100	95.684	0.010601	0.09923	493.37	0.0024674
Titanium Alloy	100	89.173	0.009939	0.07783	186.93	0.0019476
Copper Alloy	100	99.315	0.010974	0.15037	445.9	0.0040545
MagnesiumAlloy	100	98.264	0.010866	0.21693	264.14	0.0058711
Aluminium Alloy	100	98.355	0.010875	0.19140	358.93	0.0050565

The results of different materials (Structural Steel, Titanium Alloy, Copper Alloy, MagnesiumAlloy and for the Aluminium Alloy), to find out the best suited material which can sustain the deformation under thermal loading. The materials were simulated for temperature, heat flux, deformation, stress and strain, for result comparison. The results of selected materials were shown by Fig.3 to Fig.7. In this section the brake disk was analyzed for Structural Steel, Titanium Alloy, Copper Alloy, MagnesiumAlloy and the Aluminium Alloy materials based disc rotor. Steady-state thermal and static structure analysis was performed to check the material behavior. The results of all five materials are shown in the Table 4.

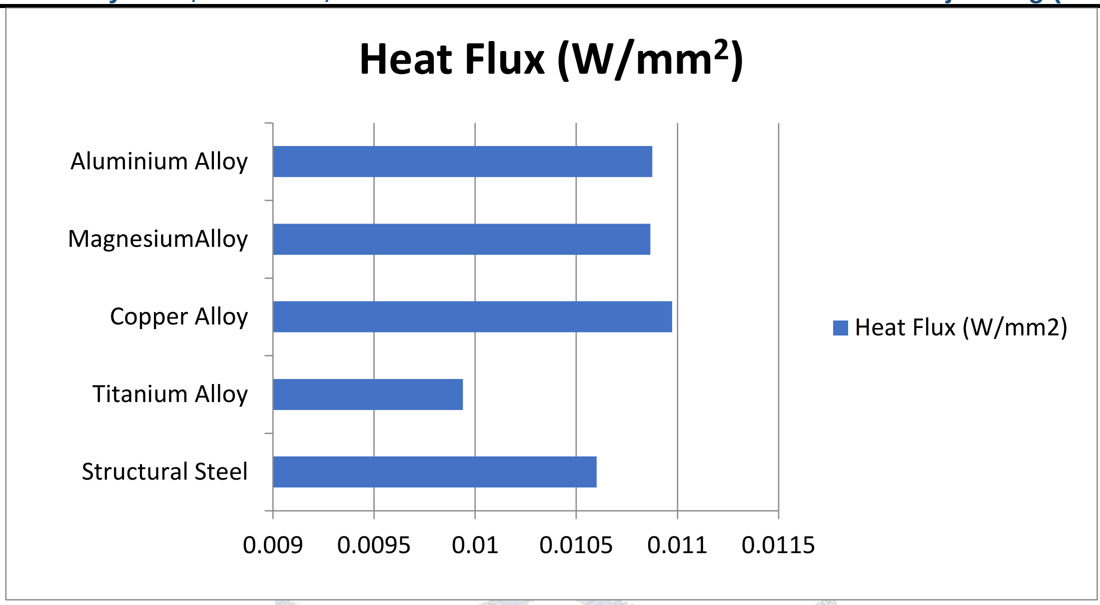


Fig.8. The Variation of the Heat flux for all different Materials.

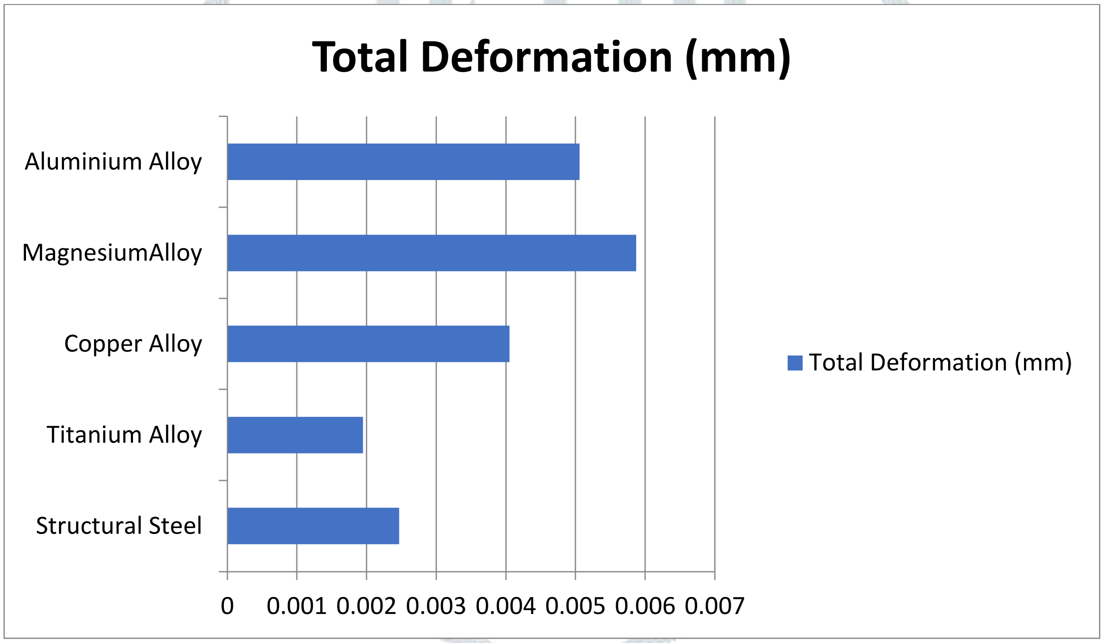


Fig. 9. The Variation of the Total Deformation for all different Materials.

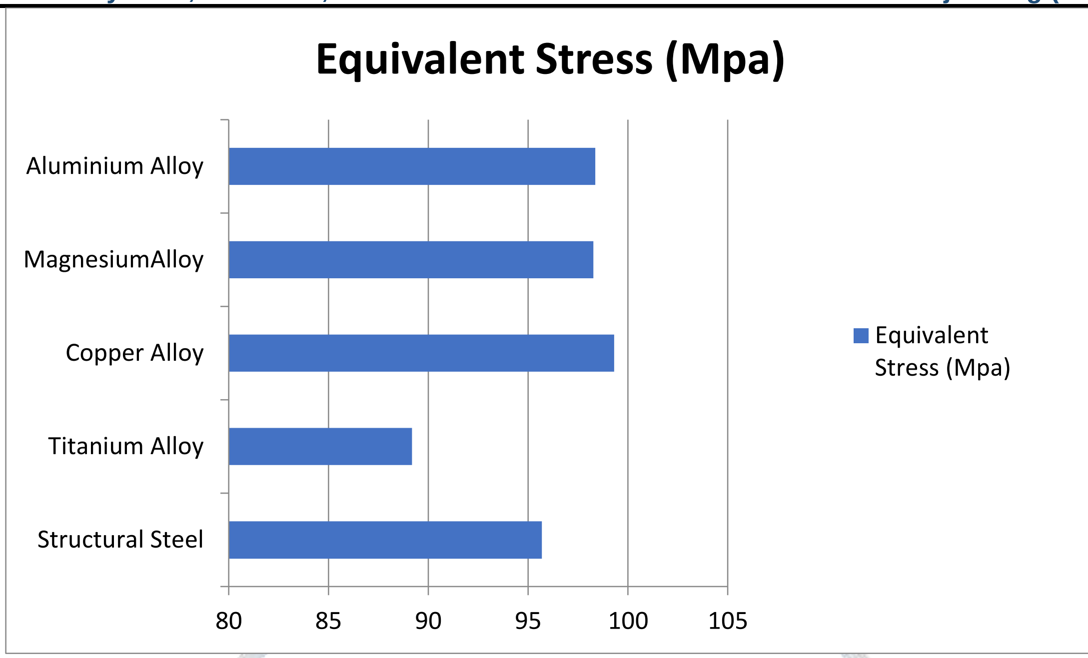


Fig. 10. The Variation of the Equivalent Stress for all different Materials.

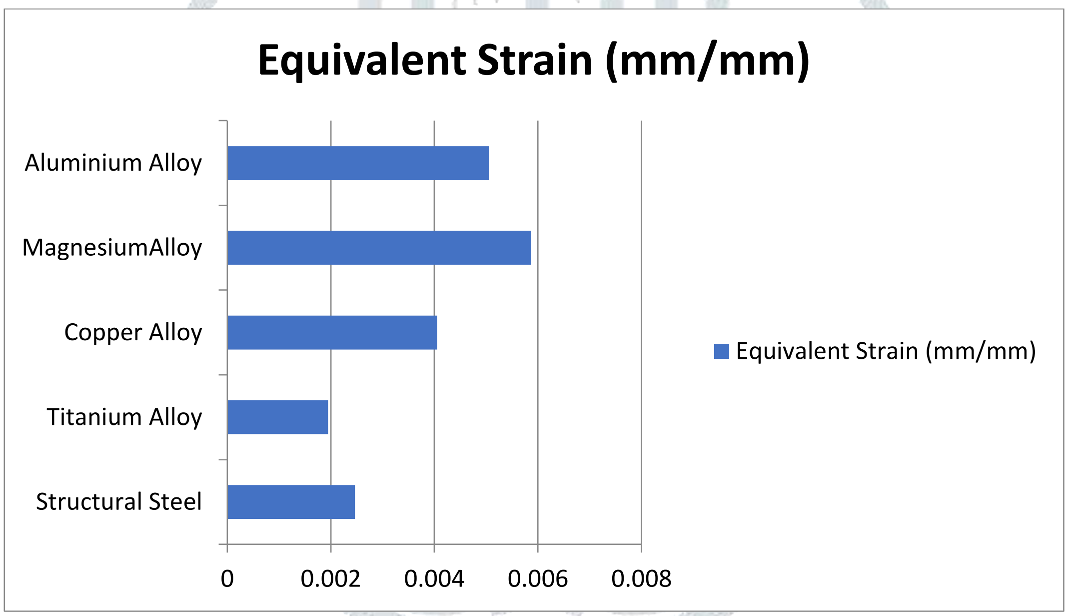


Fig. 11. The Variation of the Equivalent Strain for all different Materials.

5. Conclusion

The present study provides a technique to analyze the material performance under thermal and mechanical loading. In this paper the study of maximum heat transfer for different materials (Structural Steel, Titanium Alloy, Copper Alloy, MagnesiumAlloy and for the Aluminium Alloy) in the disk brake was investigated. A rotor disk was designed and simulated by Ansys workbench using five different materials. The following observation has been made; Firstly the results of Structural Steel material based brake disk can be observed that the maximum temperature is varying from 100 °C to the 95.684 °C. The maximum value of heat flux can be observed is 0.010601 W/mm^2 and a minimum of 2.0927e^{-14} W/mm^2. The maximum deformation obtained is 0.099234 mm. The maximum Von-Mises stress procured is 493.37 MPa and a minimum of 0.51844 MPa and the maximum Von-Mises strain is 0.0024674 mm/mm and a minimum of 3.4917e^{-6} mm/mm. Second the results of Titanium Alloy material based brake disk can be observed that the maximum temperature is varying from 100 °C to the 89.173 °C. The maximum value of heat flux can be observed is 0.0099397 W/mm^2 and a minimum of $3.1674e^{-14}$ W/mm^2. The maximum deformation obtained is 0.077834 mm. The maximum Von-Mises stress procured is 186.93 MPa and a minimum of 0.14628 MPa and the maximum Von-Mises strain is 0.0019476 mm/mm and a minimum of $2.1558e^{-6}$ mm/mm. Third the results of Copper Alloy material based brake disk can be observed that the maximum temperature is varying from 100 °C to the 99.315 °C. The maximum value of heat flux can be observed is 0.010974 W/mm^2 and a minimum of $2.9013e^{-14}$ W/mm^2. The maximum deformation obtained is 0.15037 mm. The maximum Von-Mises stress procured is 445.9 MPa and a minimum of 0.28941 MPa and the maximum Von-Mises strain is 0.0040545 mm/mm and a minimum of $5.0112e^{-6}$ mm/mm. Fourth the results of MagnesiumAlloy material based brake disk can be observed that the maximum temperature is varying from 100 °C to the 98.264 °C. The maximum value of heat flux can be observed is 0.010866 W/mm^2 and a minimum of $2.5192e^{-14}$ W/mm^2. The maximum deformation obtained is 0.21693 mm. The maximum Von-Mises stress procured is 264.14 MPa and a minimum of 0.18393 MPa and the maximum Von-Mises strain is 0.0058711 mm/mm and a minimum of $6.9985e^{-6}$ mm/mm. Fifth the results of Aluminium Alloy material based brake disk can be observed that the maximum temperature is varying from 100 °C to the 98.355 °C. The maximum value of heat flux can be observed is 0.010875 W/mm^2 and a minimum of $2.248e^{-14}$ W/mm^2. The maximum deformation obtained is 0.1914 mm. The maximum Von-Mises stress procured is 358.93 MPa and a minimum of 0.22387 MPa and the maximum Von-Mises strain is 0.0050565 mm/mm and a minimum of $4.483e^{-6}$ mm/mm. we can see that, maximum temperature variation comes in Titanium alloy disk is 100 °C to 89.173°C and minimum in Copper Alloy is 100°C to 99.315°C. In the case of heat flux maximum value obtained in Copper Alloy based disc which is 0.010974 W/mm^2 and minimum in Titanium alloy which is 0.0099397 W/mm^2 based disc. Structural Steel gives maximum value of Equivalent stress which is 493.37 Mpa and Titanium alloy gives minimum value of Equivalent stress which is 186.93 Mpa based disc as compare to other materials. The MagnesiumAlloy material gives maximum deformation which is 0.21693 mm and the Titanium alloy material gives minimum deformation which is 0.077834 mm comparatively others. MagnesiumAlloy gives maximum value of Equivalent strain which is 0.0058711 mm/mm and Titanium alloy gives minimum value of Equivalent strain which is 0.0019476 mm/mm based disc as compare to other materials. And Titanium alloy, Structural steel made rotor disk give better heat dissipation results as compare to other materials made disk.

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