Transient Thermal Analysis of Tungsten Carbide and Hafnium Carbide Disc Brake Rotor

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Abstract. Disc brakes are used in vehicles to slow down or stop the angular and linear velocity of the wheels that uses calipers to squish a set of two similar pads versus the disc. During this process, the disc or rotor gets heated up due to friction from the pads. Frequent braking will cause abundant heating of the disc or rotor. Therefore, it is crucial in quick dissipation of heat from the rotor disc. Keeping this in mind, a comparison between the different materials is modelled in Creo parametric and it is analyzed in ANSYS 2019 R3, in this paper transient analysis of Cast Iron, Tungsten carbide and Hafnium carbide is modelled and analyzed using Creo and ANSYS 2019 R3 respectively. The best among them is selected as a material for the disc rotor.

1. INTRODUCTION

Disc brakes are generally used in nontraditional bikes for higher powered stop compared to conventionally used drum brakes. The form of heat is dissipated to surrounding atmosphere by what energy absorbed by the brake. Any disk brake materials should contain properties of high coefficient of friction, low weight, high compressive strength, less wear, great thermal conductivity. Kinetic energy of the vehicles transferred to mechanical energy by braking process. Weight reduction in braking system has been examined for further research area. Braking energy method is useful for improving brake disc life and minimizes the weight of rotor and reduces brake pad wear for any optimized vehicle. The design modification of current research with radial grooves on brake disc performance and its temperature behavior done by using 3D printing additive manufacturing steel. Drum brakes has lower performance than the disc brakes in braking efficiency, also it has maximum heat dissipation than the disc brakes. Disc brake heat generation and dissipation easily spread to the atmosphere. However, the biggest problem we are facing in the disc brake is material. In this research the problem of rotary disc brake material is analyzed by ANSYS17.1 software. Solid and cross drilled disc brake rotor is studied in terms of their thermal behavior during the braking force. Deformation and vonmises stress of disc brake materials place major roles in braking efficiency. The objective of this current research is creating FEA model of every part of the disc brake for understanding the importance of material properties on the disc brake with experimental analysis. Thermal Fatigue will be continuously minimizing when maintaining constant temperature of the disk brake material. Aluminum, Grey cast Iron and High-speed steel are used to solve the above problems faced by
thermal fatigue in disc brake materials. By using this ANSYS and CFD solver methods we can use different types of brake rotor materials those are common in automobile field. New braking rotor designed and analyzed by structural and thermal analyzed with Ansys software for better performance. Von misses stress and deformation is calculated for grey cast iron and steel disc brake materials for two wheeler models using Ansys and calculates stress, deformation, heat dissipation. Audi A6 cross drilled disc brake rotor is analyzed at faster rate with structurally safe, Stainless steel, Aluminum metal matrix composite Titanium alloy, like Grey cast iron, Aluminum alloy, carbon ceramic matrix, Aluminum silicon carbide MMC E-Glass fiber. The unchanged two-wheeler brake disc rotor was elected and transient thermal analysis is conducted on heat flux and temperature distribution at cast iron, hafnium carbide, tungsten carbide respectively.

2. MATERIAL SELECTION

Material selection is very important consideration to improve the performance and life of the disc brakes. In this research work, Cast Iron, Tungsten Carbide and Hafnium Carbide materials was selected to establish the thermal behaviour of the disc brakes under the applied loading conditions by using ANSYS 2019 R3 software. Selected materials for this study were assumed to be an isotropic, homogeneous and temperature-dependent. Due to the equivalent thermal properties of the Tungsten Carbide and Hafnium Carbide materials, the existing Cast Iron disc brake is analyzed with the above said materials. The following physical and thermal properties were taken into account during the transient thermal analysis in ANSYS 2019 R3 software to establish the total heat flux and temperature distribution over the disc brake under the applied loading conditions. A different physical and thermal property of the disc brake materials, which is used in transient thermal analysis, is shown in table 1.

| Material properties          | Unit | Cast iron | Tungsten Carbide | Hafnium Carbide |
|-----------------------------|------|-----------|-----------------|-----------------|
| Thermal conductivity        | W/mK | 50        | 110             | 29283           |
| Density                     | kg/m³ | 6600      | 15630           | 12206           |
| Specific heat capacity      | J/Kg°C | 380       | 187             | 188             |
| Coefficient of thermal expansion | 10⁻⁶/K | 0.16   | 5.5             | 6.59            |
| Elastic modulus             | GPa  | 110       | 700             | 510             |

3. THREE-DIMENSIONAL MODEL GENERATION

Three-dimensional model generation of an existing disc brake has started with the collection of basic dimensions from the physically available disc brake by reverse engineering concept. The standard specifications of an unmodified existing disc brake were measured with the help of standard measuring instruments with tolerances and clearances, in order to get the exact three-dimensional model of the disc brake. A commercial modeling software (CREO) is used to create the two-dimensional views of the disc brake by means of the measured value with proper specifications. Different two-dimensional views are created with the help of the measured dimensions through the modeling software. Entire two-dimensional views are checked for the conversion of three-dimensional model. The complete three-dimensional model of an unmodified existing disc brake was created with the help of the same modeling software through the two-dimensional sketches. Comprehensive three-dimensional model of an unmodified disc brake that is modeled by the commercially available software is shown in figure 1. In order to understand the disc brake architecture the entire three-dimensional model of the disc brake has converted also a wire frame model. Different orientations have applied on the disc brake model to obtain the various configuration views for the better understanding of disc brake architecture. The three-dimensional model that was created by using the commercially available software is ready of the finite element analysis to establish the total heat flux and total heat transfer over the disc brake surface for the three different materials like, Cast
Iron, Tungsten Carbide and Hafnium Carbide materials respectively.

![Figure 1. Complete three-dimensional model of a disc brake rotor](image)

4. TRANSIENT THERMAL ANALYSIS

In this finite element analysis through the ANSYS 2019 R3 software, comprehensive three-dimensional model of an unmodified existing disc brake rotor was undergone the transient thermal analysis by applying the thermal loads on the different surfaces of the disc brake rotor. Before the transient thermal analysis on the disc brake rotor, the complete comprehensive three-dimensional model of the disc brake rotor has converted as IGES file through the modeling software for the analysis process in ANSYS 2019 R3 software. The converted IGES model of disc brake rotor has imported in ANSYS workbench through import module of external geometry file and the imported IGES model of disc brake rotor has generated as per the requirements for the ANSYS 2019 R3 software to carry out the transient thermal analysis in the new geometry creation module. In mesh creation module, the entire imported geometry of the disc brake rotor has selected and the different meshing parameters like, physical preference, type of mesh, number of mesh elements and element size has assigned on the mesh model of the disc brake rotor. By using the mesh generation option, the entire disc brake rotor model has converted as mesh model through the simulation conversion option under the predefined meshing parameters. By using the solid geometry tree menu, the material for meshed wheel model has assigned by means of the new material definition option. The required disc brake rotor material properties like, capacity thermal conductivity, density specific heat, coefficient of thermal expansion and elastic modulus were fed into the ANSYS 2019 R3 software by means of the new material menu. After the material properties assignment on the mesh model of disc brake rotor, new analysis option has selected in the software to fix the support for the disc brake rotor to apply the load. In new analysis menu, middle portion of the disc brake rotor part has constrained with zero degrees of freedom, in order to arrest the all movements in that point. The zero degrees of freedom have applied on the mesh geometry of the disc brake rotor. Transient thermal analysis option has opted to apply the thermal load on the disc brake rotors axis. The complete loaded disc brake rotor geometry has selected to interleave the total heat flux and total temperature distribution attained by the disc brake rotor model in the load applied directions. Finally, by using the solve icon option, the entire analysis was computed for the given inputs and for the selected outputs from the ANSYS 2019 R3 software. After the solver command execution process, the required results for the disc brake rotor has obtained from the software in the form of color counter plots for the specific inputs. In this research, the specific outputs like total heat flux attained by an unmodified existing disc brake rotor and the total temperature distribution of the same disc brake rotor has obtained in the form of color plots with minimum and maximum magnitudes accordingly.

4.1 Heating calculations

While applying brake on the vehicle kinetic energy converted into heat. Therefore, heat generated
when brakes are applied is equal to that of the kinetic energy. In this paper, we assume that the vehicle is moving at a speed of 100 kmph and the total kinetic energy of the vehicle is converted into heat energy.

- Heat generated \((Q) = \frac{1}{2} \times mv^2 = \frac{1}{2} \times 1000 \times (27.77)^2 = 385586.45\) Joules.

- Total Kinetic Energy \((\text{K.E}) = \) heat generated / second / rubbing area.

- Area of rubbing surface \((A)= \pi/4 (0.260^2-0.150^2) = 0.03542\) m².

- Area of the rubbing surface (both sides of friction pad) = 2×0.03542 =0.07084 m².

- Torque distribution of braking is done by analysis between front and rear as 50:50.

- Heat flux of the wheel = 226792.7725 W/m².

### 5. RESULTS AND DISCUSSIONS

The following results and discussions were established based on the numerical results that are obtained from the transient thermal analysis on the existing and unmodified disc brake rotor using the ANSYS 2019 R3 software by changing the disc brake rotor materials (Cast Iron, Tungsten Carbide and Hafnium Carbide). The minimum and maximum temperature distributions and the total heat flux distributions over the disc brake rotor surface that are obtained from the transient thermal analysis for three different materials were discussed in this chapter.

**A. Maximum and minimum temperature distribution over the Cast Iron disc brake rotor surface**

Distribution of temperature over the Cast Iron disc rotor surface, which is obtained from the transient thermal analysis results, is illustrated in figure 2. The minimum temperature of 21.378°C was observed at the middle portion of the disc brake rotor surface and the maximum temperature of 115.29°C was noticed at the outer portion of the disc brake rotor surface.

![Figure 2. Distribution of temperature over the Cast Iron disc brake rotor surface for time (t) = 6 seconds](image)

**B. Maximum and minimum temperature distribution over the Tungsten Carbide disc brake rotor surface**

Distribution of temperature over the Tungsten Carbide disc rotor surface, which is obtained from the transient thermal analysis results, is illustrated in figure 3. The minimum temperature of 20.994°C was observed at the middle portion of the disc brake rotor surface and the maximum temperature of 69.391°C was noticed at the outer portion of the disc brake rotor surface.
C. Maximum and minimum temperature distribution over the Hafnium Carbide disc brake rotor surface

Distribution of temperature over the Hafnium Carbide disc rotor surface, which is obtained from the transient thermal analysis results, is illustrated in figure 4. The minimum temperature of 24.172°C was observed at the middle portion of the disc brake rotor surface and the maximum temperature of 67.537°C was noticed at the outer portion of the disc brake rotor surface.

D. Variation on minimum temperature distribution for all disc brake rotor materials

Variation on minimum temperature distribution over the different disc brake rotor materials were shown in figure 5. It was observed from the figure 5, disc brake rotor that was analyzed with the cast iron material exhibits the temperature distribution 21.378°C, and the minimum temperature distribution of 20.994°C were noticed in the disc brake rotor material, which was analyzed with Tungsten Carbide material. The distribution of temperature with 24.172°C magnitude was noticed in the transient thermal analysis over the disc brake rotor material that was analyzed with Hafnium Carbide material.
Figure 5. Variation on minimum temperature distribution over the different disc brake rotor materials

E. Variation on maximum temperature distribution for all disc brake rotor materials

Variation on maximum temperature distribution over the different disc brake rotor materials were shown in figure 6. It was observed from the figure 6, disc brake rotor that was analyzed with the cast iron material exhibits the maximum temperature distribution of 115.29°C, and the maximum temperature distribution of 69.391°C were noticed in the disc brake rotor material, which was analyzed with Tungsten Carbide material. The distribution of maximum temperature with 67.537°C magnitude was noticed in the transient thermal analysis over the disc brake rotor material that was analyzed with Hafnium Carbide material.

Figure 6. Variation on maximum temperature distribution over the different disc brake rotor materials

F. Maximum and minimum heat flux distribution over the Cast Iron disc brake rotor surface

Distribution of heat flux over the Cast Iron disc rotor surface, which is obtained from the transient thermal analysis results, is illustrated in figure 7. The minimum heat flux of 398.95 W/m² was observed at the middle portion of the disc brake rotor surface and the maximum heat flux of 3.4331×10⁷ W/m² was noticed at the outer portion of the disc brake rotor surface.
Figure 7. Total heat flux exhibited by the Cast Iron disc brake rotor material

G. Maximum and minimum heat flux distribution over the Tungsten Carbide disc brake rotor surface

Distribution of heat flux over the Tungsten Carbide disc rotor surface, which is obtained from the transient thermal analysis results, is illustrated in figure 8. The minimum heat flux of 3.3474 W/m² was observed at the middle portion of the disc brake rotor surface and the maximum heat flux of $2.4533\times10^5$ W/m² was noticed at the outer portion of the disc brake rotor surface.

H. Maximum and minimum heat flux distribution over the Hafnium Carbide disc brake rotor surface

Distribution of heat flux over the Hafnium Carbide disc rotor surface, which is obtained from the transient thermal analysis results, is illustrated in figure 9. The minimum heat flux of 428.1 W/m² was observed at the middle portion of the disc brake rotor surface and the maximum heat flux of $4.5069\times10^5$ W/m² was noticed at the outer portion of the disc brake rotor surface.

Figure 8. Total heat flux exhibited by the Tungsten Carbide disc brake rotor material
I. Variation on minimum heat flux distribution for all disc brake rotor materials

Variation on minimum heat flux distribution over the different disc brake rotor materials were shown in figure 10. It was observed from the figure 10, disc brake rotor that was analyzed with the cast iron material exhibits the heat flux distribution of 398.95 W/m², and the minimum heat flux distribution of 3.3474 W/m² were noticed in the disc brake rotor material, which was analyzed with Tungsten Carbide material. The heat flux distribution of 428.1 W/m² magnitudes was noticed in the transient thermal analysis over the disc brake rotor material that was analyzed with Hafnium Carbide material.

![Figure 9. Total heat flux exhibited by the Hafnium Carbide disc brake rotor material](image)

J. Variation on maximum heat flux distribution for all disc brake rotor materials

Variation on maximum heat flux distribution over the different disc brake rotor materials were shown in figure 11. It was observed from the figure 11, disc brake rotor that was analyzed with the cast iron material exhibits the heat flux distribution of $3.4331 \times 10^5$ W/m², and the minimum heat flux distribution of $2.4533 \times 10^5$ W/m² were noticed in the disc brake rotor material, which was analyzed with Tungsten Carbide material. The heat flux distribution of $4.5069 \times 10^5$ W/m² magnitudes was noticed in the transient thermal analysis over the disc brake rotor material that was analyzed with Hafnium Carbide material.

![Figure 10. Variation on maximum heat flux induced by the different disc brake rotor materials](image)
Figure 11. Variation on minimum heat flux induced by the different disc brake rotor materials

6. CONCLUSIONS

An unmodified existing two-wheeler disc brake rotor has modeled using modeling software and the transient thermal analysis has been conceded on the disc brake rotor by changing its material such as Cast Iron, Tungsten carbide and Hafnium carbide materials to evaluate the temperature distribution as a function of time (6 seconds). From this analysis, it is found that Tungsten carbide has better temperature dissipation performance over the both cast iron and Hafnium carbide under repeated braking conditions. Coating of these materials on conventional disc brake has thermal advantages. It has concluded that, Tungsten carbide material can be used to two-wheeler disc brake material for the replacement of existing rotor materials.

REFERENCES

[1] Amar Ambekar, Amit Bharti, Shashank Shekhar, Anushtup Biswas, Thermo-structural analysis of disc brake for maximum heat dissipation Conference on Electronics, Computer and Manufacturing Engineering (ICECME/2017).

[2] Ali Belhocine, MostefaBouchetara, Thermal analysis of a solid brake disc, Applied Thermal Engineering, 2012, 32, pp.59.

[3] P.BaskaraSetupathi, A.Muthuvel, N.Prakash, Stanly Wilson Louis, Numerical analysis of a rotor disc for optimization of the disc materials, Journal of Mechanical Engineering and Automation, 2015, 05 (3B), pp.05-14.

[4] Deekshith Ch, C.Udayakiran, Y.Vijayakumar, Design, analysis and manufacturing of disc brake rotor, International Journal of Engineering Research and Development, 2017, 13 (11), pp.15-23.

[5] Daanvir Karan Dhir, Thermo-mechanical performance of automotive disc brakes, Materials Today: Proceedings, 2018, 05, pp.1864–1871.

[6] Gulam Mohammed Sayeed Ahmed, Salem Algarni Design, Development and FE thermal analysis of a radially grooved brake disc developed through direct metal laser sintering, 2018, Materials, 11, pp.01-16.

[7] JanvijayPateriya, Raj Kumar Yadav, Vikas Mukhraiya, Pankaj Singh, Brake disc analysis with the help of Ansys software, International Journal of Mechanical Engineering and Technology, 2015, 06 (11), pp.114-122.
[8] Jimit G. Vyas, M.J. Zinzivadia, M.I. Kathadi, *Design and analysis of solid and cross drilled disc brake rotors*, Kalpa Publications in Engineering, 2017, 01, pp.294-301.

[9] Mit Patel, Mansi Raval, Jenish Patel, *Design of disc brake’s rotor*, International Journal of Engineering Development and Research, 04 (04), pp.919-926.

[10] N.K. Kharatea, S.S. Chaudhari, *Effect of material properties on disc brake squeal and performance using FEM and EMA approach*. Materials Today: Proceedings, 2018, 05, pp.4986–4994.

[11] Nikit Gupta, Mohit Bhandwal, Basant Singh Sikarwar, *Modelling and simulation of brake disc for thermal analysis*, Indian Journal of Science and Technology, 2017, 10 (17), pp.01-05.

[12] Pandya Nakul Amrish, *Computer aided design and analysis of disc brake rotors*, Advances in Automobile Engineering, 2016, 05 (02), pp.01-13.

[13] Pankaj Pathak, Anshul Choudhary, K.K. Jain, *Structure & thermal analysis of disk plate for two wheeler automotive front disk brake*, International Journal of Engineering Sciences & Research Technology, 2017, 06 (11), pp.315-327.

[14] Praharsha Gurram, Shrawan Anand Komakula, G. Vinod Kumar, *Design and analysis of vented disc brake rotor*, International Journal of Applied Engineering Research, 2019, 14 (09), pp.2228-2233.

[15] Prashant P. Suryawanshi, Amol R. Tanpure, Sachin R. Dhatrak, Bhavesh C. Lokhande, Rohan D. Hucche, *Thermal and structural analysis of two wheeler disc brake*, International Journal of Innovative and Emerging Research in Engineering, 2017, 04 (04), pp.175-182.

[16] Rajappan, Magesh, Gurunathan, *Buckling analysis in unidirectional glass epoxy laminated plate*, Journal of Chemical and Pharmaceutical sciences, 2015, Special issue (09), pp.137-139.

[17] G. Gurunathan, P. Paramadhayalan, S. Purushothaman, R. Girimurugan, *An experimental study on mechanical properties of jute fiber reinforced coconut shell particles filled epoxy resin matrix biocomposites*, Journal of Xi’an University of Architecture and Technology, 2020, 12 (04), pp.2773-2783.

[18] S. Vandaarkuzhali, R. Elansezhian, *Performance evaluation of air conditioning system using nanofluids*, Australian journal of basic and applied sciences, 2015, 09 (07), pp.01-10.

[19] Saravanan Paranthaman, Mala Dharmalingam, Godwin Antony Arockiaraj, Vijayan Venkatraman, *An experimental investigation on a low heat rejection diesel engine using waste plastic oil with different injection timing*, Thermal science, 2020, 24 (1B), pp.453-461.