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Design Modification and Analysis of Disc Brake

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***Abstract*— Many difficulties surround the heating characteristics of brakes when it comes to their creation, including contact region features, material choice, development of hot spots, associated physical geometry, and deformations, as brakes are subjected to continuous operation. Therefore, it is must for all vehicles to have proper brake system. In this report there is the modification of the disc and that results in the design are used to carry out analysis on it. The analysis of standard disc brake model and new design using in Ansys is done the Thermal analysis and Modal analysis also calculate the deflection and Heat flux, Temperature of disc brake model. Understanding the different forces (action and friction) which are acting on the disc brake, as well as how the disc brake operates more efficiently, will assist to reduce the number of accidents that occur each day. The primary goal of this research is to examine the brake disc's thermo-mechanical behavior during braking. The disc material is changed to carbon-ceramic, and the results of the FEA of the new design disc are used. This study presents the findings and the disc's future prospects.**

***Keywords*—** Disc Brakes, rotor, friction, ANSYS.

I. Introduction

Brakes are mechanical or sometimes electrical devices or components that help to decelerate the vehicle and eventually stop the vehicle in a certain time and certain distance called the stopping distance or the braking distance [1-3]. A device that slows or stops a moving item, in this case, the automobile, and so prevents it from moving. [4-6]. Brakes are majorly significant safety systems in any automobile [7-10]. The operation of brakes is dependent on energy saving [11-13]. Frictional brakes are the most prevalent type of brake, in which friction between two objects converts the kinetic energy of a moving vehicle into thermal energy. [14-16].

Friction brakes are the most popular braking mechanism in commercial or special-purpose vehicles [17-20]. They're often rotating devices with a spinning wear surface, such as a disc or drum, and a stationary pad or shoe [21-23].

Disc brakes: On the outer surface of a revolving Disc, shoes or pads flex and create compressive frictional force [24-26]. It's a round metal Disc with pads attached to it. It is usually constructed of cast iron [27-30]. The project findings have the modified design of a brake rotor, as well as an analysis of the findings of different analysis [31-33].

Drum brakes: The interior side of a revolving drum expands and rubs against the shoes or lining [34-36]. When braking, the shoe or brake lining expands or moves outward to attach itself to the brake drum, creating friction that slows or stops the drum from rotating. The liner pads are mounted in the wheel hub so that they can adhere to the inner surface of the cast iron brake drum, which is made of material.. Due to the lining and drum, drum brakes are

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frequently heavier and take up significantly more space than disc brakes.

The design of a disc brake rotor and an analysis of the results of structural and thermal analysis are both included in this project report.

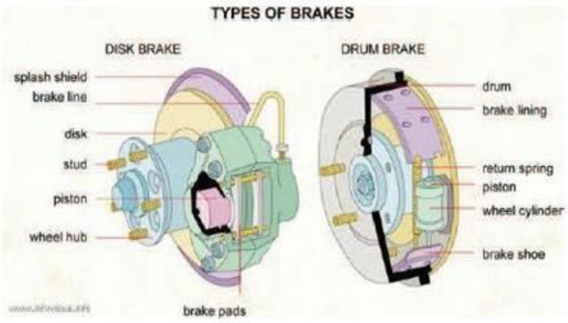

Fig 1: Types of Brakes

Drum brakes: In drum brakes, shoes or lining enlarge and rub against the interior surface of a rotating drum.. The cast iron brake drum is installed in the wheel hub so that the liner pads can be attached to the inner surface of the drum. Additionally, as the brakes are applied, the shoe or brake lining expands or moves outward to attach itself to the brake drum, providing the necessary braking force. friction and causing the drum to slow or stop rotating. Drum brakes are often heavier than disc brakes and take up substantially more space owing to the lining and drum, hence their use in commercial vehicles is limited.

The following is the most typical hydraulic braking configuration:

(i) A lever or a brake pedal
(ii) Pushrod or actuating rod
(iii) Master cylinder assembly
(iv) Hydraulic lines
(v) Brake caliper assembly

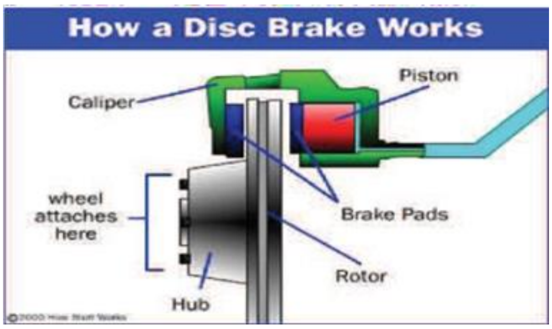

Fig 2: Working of disc brakes

A. Material structure of carbon-ceramic brakes

The ceramic composite material used to make carbon-ceramic brake discs is a unique property. Carbon fiber-reinforced silicon carbide is used to make the carbon-ceramic brake disc body and the friction layers on either side. The major matrix components are silicon carbide (SiC) and elemental silicon (Si). Carbon fibres give reinforcement for the material (C). The major matrix component silicon carbide is responsible for the composite material's high hardness. Carbon fibres have a high mechanical strength and the fracture toughness that is required in technological applications. The ceramic composite material's quasi-ductile characteristics ensure its endurance to high thermal and mechanical loads. As a result, carbon fiberreinforced silicon carbide materials combine the benefits of both carbon fiberreinforced carbon (C/C) and polycrystalline silicon carbide ceramics. C/SiC materials have elongation at break ranging from 0.1 to 0.3 percent. Fiber-reinforced silicon carbide has a unique profile that makes it a first-choice material for high-performance braking systems. The low weight, hardness, and stable characteristics even at high pressure and temperature, not to mention the resistance to thermal shock and quasi-ductility properties, ensure that the brake disc lasts a long time and avoids all of the problems associated with loading that are typical of traditional brake discs made of grey cast iron. The table one lists the characteristics and distinctions between grey cast iron and carbon ceramic discs C/SiC for brake discs made of carbon ceramic grey cast iron (GG-20) Density (g cm-3)

Brake disc operating temperature maximum (°C) 900 700 coefficient of linear thermal expansion (K-1) 2.6 - 3.0 9 - 12 Temperature sensitivity (W m-1K -1) 40 54 cp, or specific heat capacity (kJkg-1K -1) 0.8 0.5.

TABLE 1
PROPERTIES OF CARBON CERAMIC

Properties	C/SiC for carbon ceramic brakedisc
Density (g cm-3)	2,45
Tensile strength(MPa)	20-40

Modulus Of elasticity (GPa)	30
Flexural strength (MPa)	50-80
Break Elongation (%)	0.3
Thermal stability (°C)	1350
Maximum operating temperature (Brake disc) (°C)	900
Linear coefficientof thermal expansion (K-1)	2.6-3.0
Thermal conductivity ($Wm^{-1}K^{-1}$)	40

Carbon-ceramic brake disc benefits Although there are many different types of carbon ceramic brake rotors available today, they all have benefits over iron rotors.

B. Weight Reduction

One of the most significant performance benefits of carbon ceramic materials is weight reduction. Carbon ceramic discs are 50% lighter than cast-iron discs of the same size due to their low densities. Because of the decrease in the car's unsprung weight and spinning mass, the handling and driving dynamics of the vehicle when braking, accelerating, and turning were improved.

C. High degree of hardness and low rate of wear

Another important characteristic of ceramics is its hardness. Compared to conventional grey cast-iron brake discs, ceramic composite brake discs are more robustly built. The discs' lifespan is increased by this function, which stops wear and waste. The lifespan of this material is four times greater than that of steel. Ceramic discs can last up to 300,000 kilometres and have a strong abrasion resistance. The material's excessive surface hardness is also a hint that it should be held to higher friction levels. It implies that more braking capacity is available, allowing heavier weights to be handled with the same size disc.

Table 2: Carbon ceramic vs. grey cast iron discs differences

	C/SiC for carbon-ceramic brake disc	Gray cast iron (GG-20)
Density (g cm^{-3})	2,45	7,25
Tensile strength(MPa)	20 - 40	200 - 250
Modulus of elasticity (GPa)	30	90 - 110
Flexural strength(MPa)	50 - 80	150 - 250
Elongation at break(%)	0.3	0.3 - 0.8
Thermal shock resistance (second thermal coefficient K') (W m^{-1})	> 27.000	< 5.400
Thermal stability(°C)	1350	approx. 700
Maximum operating temperature (brakedisc) (°C)	900	700
Linear coefficientof thermal expansion (K^{-1})	2.6 - 3.0	9 - 12
Thermal conductivity (W $m^{-1}K^{-1}$)	40	54
Specific heat capacity (cp) ($kJkg^{-1}K^{-1}$)	0.8	0.5

The ceramic composite brake discs' non-metallic construction, which renders them resistant to corrosion and rust as well as to both liquid and solid road salts, is another benefit of their design.

D. Deformation resistance

Carbon ceramic materials are more resistant to distortion or warping at high temperatures because of their high thermal stability values (1350°C for carbon ceramic vs. 700°C for cast iron).

E. Brake fade Reduction

High heat stability, heat capacity, and heat dissipation are advantages of carbon ceramic brake discs.

Over a wider (and higher) temperature range, carbon ceramic maintains a constant coefficient of friction. In numerical terms, this indicates that they have roughly twice the thermal stability of cast irons. As temperatures rise, they maintain their braking performance longer in extreme circumstances, such as racing. Cast iron has a 60% lower specific heat capacity than carbon ceramic, meaning it can absorb 60% more heat for a given increase in rotor temperature. Thermal conductivity and heat dissipation within the carbon-ceramic composite material are a function of fibre length. Cast iron rotors take longer to cool down than long carbon fibre rotors do.

II. Literature Review

Faramarz Talati et al [1] extracted the governing heat equations for the disc and the pad in the form of transient heat equations with heat generation that is dependent on time and space. According to the paper, in order to prevent a reduction in the friction coefficient between the disc and the pad, temperature increases in different brake components, and brake fluid vaporisation as a result of excessive heating, the heat produced by friction between the disc and the pad should be dissipated to the environment as much as possible.

J Hari Narayana Rao et al [2] when combined with another field Study of the rotor disc's thermal structure that took into account a variety of disc rotor materials, including cast iron, stainless steel, and aluminium alloy Cross drilling holes in the rotor disc for greater heat dissipation is part of the work, which involves a comparison between a real solid disc and other design discs.

A.Belhocine and M. Bouchetara [3] The thermal behaviour of the full and vented brake discs of the cars was investigated using ANSYS, taking into account elements like braking type, disc geometry, and material

Dr Sanjay Chikalthankar et al [4] After creating a solid model in ProE, the model was exported to Hypermesh for meshing. The natural frequency of the component was discovered using ANSYS vibration analysis.

Prashant Sharma et al [5] Researchers have offered an analytical model for calculating the contact temperature distribution on a brake's working surface. The temperature distribution in a perforated model is significantly better than that of a simple disc because there is less temperature differential. After analysing both models, it was discovered that the minimum temperature obtained by both bodies after a given time instant was almost comparable.

Manjunath T V and Dr Suresh P M [6] A team from

For both solid and vented discs, Ford Motor Company (FEM) did a coupled thermal structural study to evaluate the disc's deformation and Von Mises stress were established.The article determined that the vented type disc brake is superior to the previous one for the current application.

Yathish K.O et al [7] The performance check cast iron and aluminium made rotor discs 6061-SiC-red mud composite was investigated. Using software tools such as ANSYS and Hypermesh, the material's influence on displacement, stress, contact pressure, contact status, and contact sliding distance of the disc and pad assembly may be determined.

Chetan T. Jadav and K. R. Gawande [8] did a disc brake examination on a Bajaj Pulsar 150cc. The cost of a pulsar disc rotor was estimated to be roughly 900 dollars, while the cost of a friction pad was estimated to be around 150 dollars. The cost and disc weight of the assembly were decreased by 28% and 44%, respectively, by keeping the braking torque constant, lowering the diameter of the rotor disc, and increasing the friction pad area.

Sreekanth Reddy S et al [9] For the various Aluminium, Grey Cast Iron, HSS M42, and HSS M2, I modelled a disc brake in CATIA and ran stress analysis in ANSYS workbench. Aluminium was shown to be the material with the lowest stress caused when the material characteristics, stress strain, and displacement values derived from the structural analysis were compared.

Daanvir Karan Dhir [10] The aim of this study was to see how the temperature of an automotive disc brake rose while braking and how it affected disc durability. The rotor stiffness was calculated as a result of numerical analysis of the heat flux generated and the heat transfer coefficient considered.

III. Validation using Finite Element Analysis

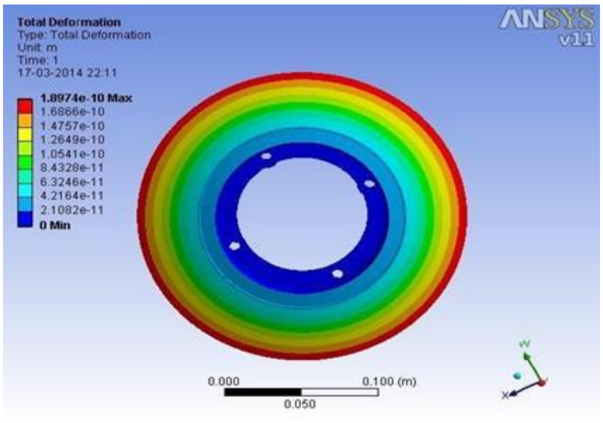

Figure 3: A

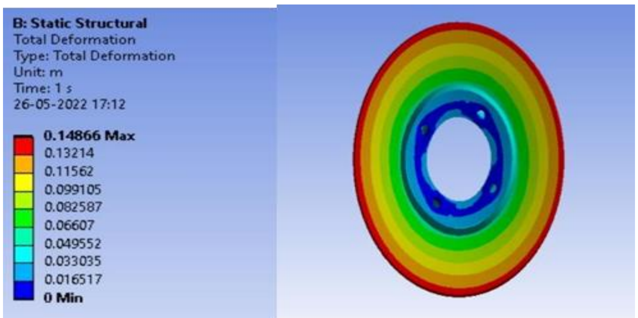

Figure 3: B

Figure 3: A and B shows the total deformation for the disc rotor where figure A is used for Experimental Validation.

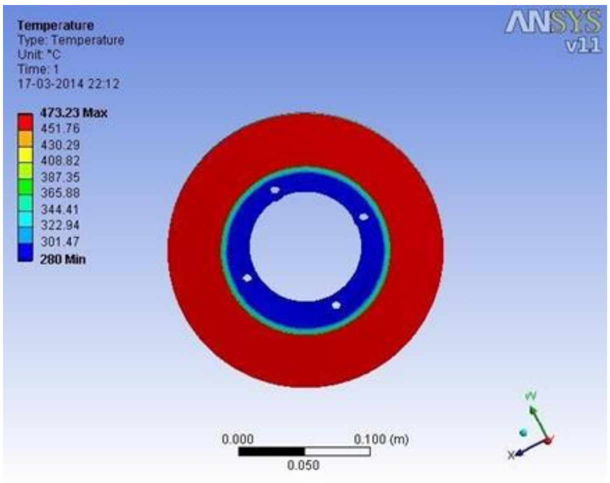

Figure 3: C

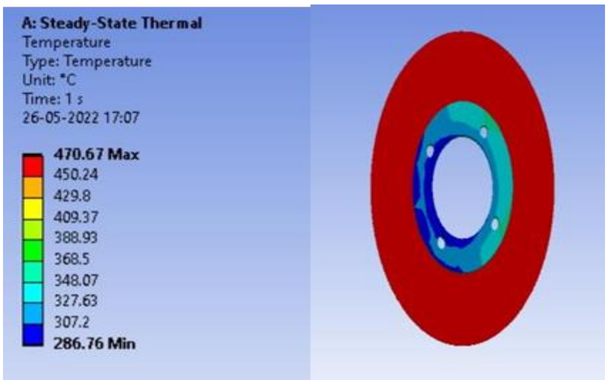

Figure 3: D

Figure3: C and D shows the steady state temperature for the disc rotor where figure C is used for Experimental Validation

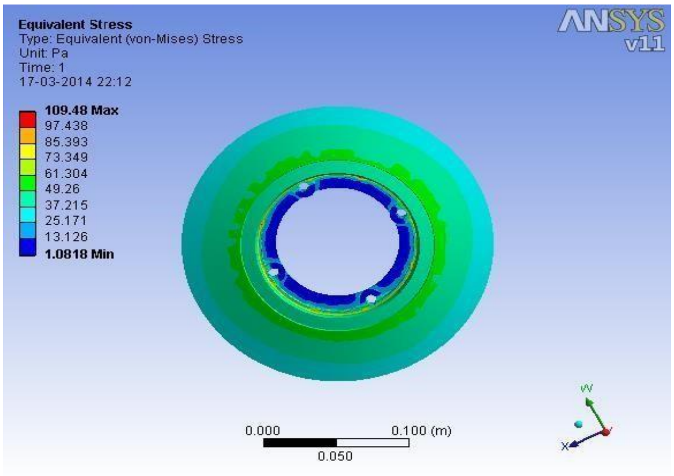

Figure 3 : E

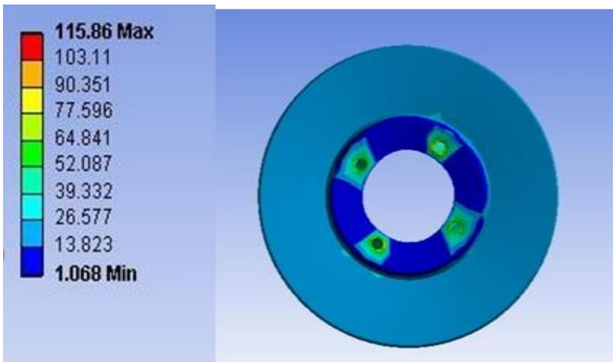

Figure 3: F

Figure 3: E and F shows the equivalent stresses for the disc rotor where figure E is used for Experimental Validation.

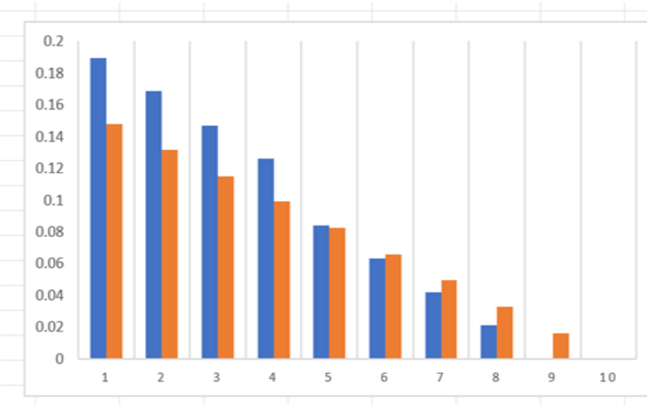

Figure 4 : Total Deformation Graph

This graph represents Total Deformation in which the blue bars indicate the data used for validation and orange bars indicates our results.

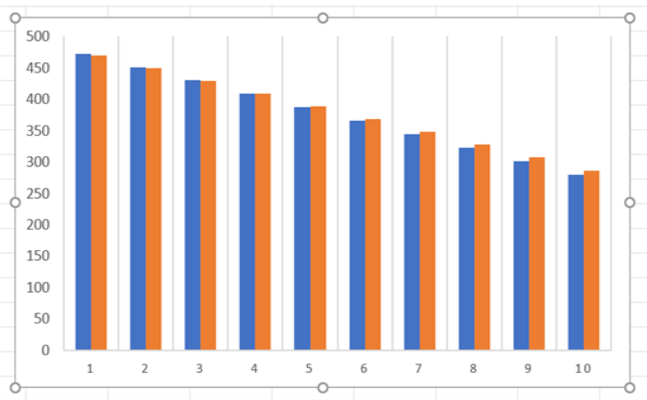

Figure 5: Temperature Graph

This graph represents Temperature in which the blue bars indicate the data used for validation and orange barsindicates our result.

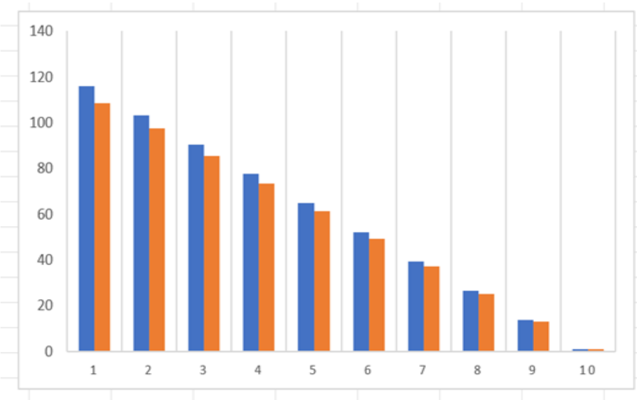

Figure 6 : Stress Graph

This graph represents Stress Graph in which the blue bars indicate the data used for validation and orange bars indicates our results

IV. RESULTS OF PROPOSED DESIGN

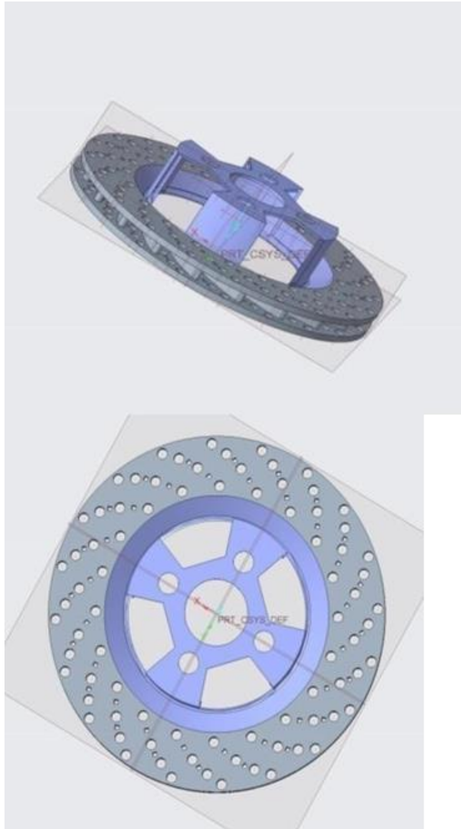

Figure **7:** Proposed Design

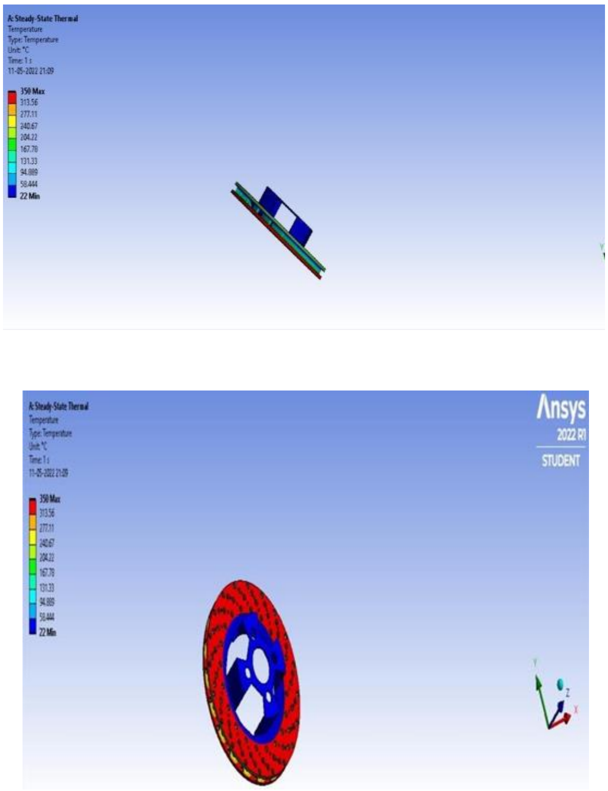

Figure 8: Steady-State Thermal-Temperature

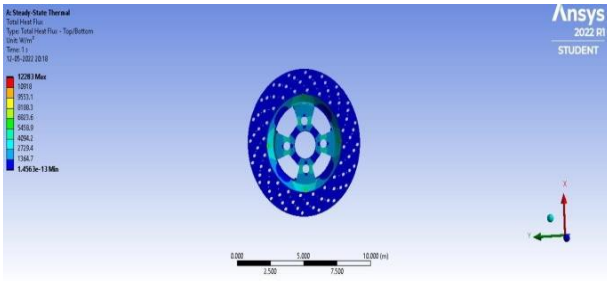

Figure 9 : Steady-State Thermal-Total Heat Flux

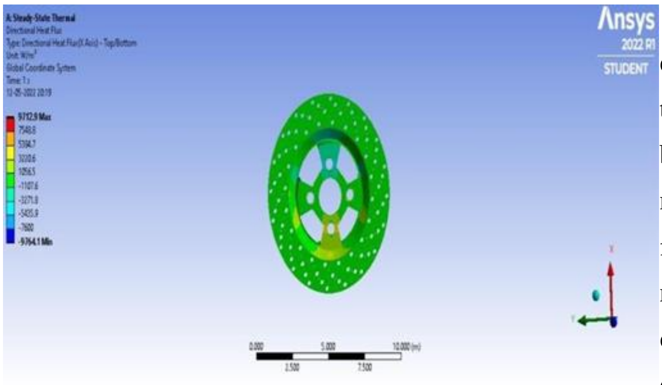

Figure 10: Steady-State Thermal-Directional Heat Flux

TABLE 3 :
RESULT TABLE

Parameters	Carbon Composite	
	Max	Min
Temperature	350℃	22℃
Total Heat Flux	12283 W/m^2	1.4563e-13 W/m^2
Directional Heat Flux	9712.9 W/m^2	-9764.1 W/m^2

V. CONCLUSION

This conclusion can be made in light of the simulation results mentioned above:

1. The new purpose design will be 50% lighter than the existing design because of material property of carbon ceramic.
2. In chapter 1 we studied different types of disc brake working of disc brake and studied the properties of carbon ceramic.
3. The steady state thermal, total deformation, stress calculated in a Ansys which is validated in section 3.
4. The results for carbon ceramic rotor are discussed in chapter 4
5. The temperature result is 350℃ max temperature and 22℃ minimum temperatures.
6. Total Heat Flux results is 12283 W/m2maximum value and1.4563e-13 W/m2 minimum value
7. Finally, the analysis we carried in this report is fully satisfied the conditions

VI. FUTURE SCOPE

The future scope of work in this area might include determining comparison of average of convective heat transfer coefficients of both and studying transient cooling behaviour of brakes using this virtual prototype. If the model improves significantly, it might be used for both family and sports cars, but this would necessitate a simple manufacturing process. As a result, manufacturing this sort of rotor at a reasonable cost will be difficult due to the design's high cost.

Following that, experimental validation would be the next step. An experimental setup must be created for experimental validation, in which the three disc rotors will be tested: plane rotor disc, perforated disc, and the suggested one. Based on this discovery, the rotor with the highest heat dissipation will be selected. If the recommended rotor's heat dissipation is the highest, a vibrational study will be performed to determine which rotor has the most vibration, as vibration is major causes of customer discontent.

The The experimental system would include rotors to be tested, a motor, and callipers with brake pads, among other things. Infrared sensors will be used to measure temperature, and the findings will be compared to those obtained in ANSYS for validation. Similarly, vibrations will be measured using a Vibrometer, and the Vibrometer data will be compared to the ANSYS results, resulting in validation. If the experimental results are similar to or less than the ANSYS findings, then the endeavour was successful.

VII. Acknowledgment

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REFERENCES

[1] W. Li, X. Yang, S. Wang, J. Xiao, Q. Hou, Comprehensive analysis on the performance and material of automobile brake discs, Metals 10, 1–18 (2020)

[2] NJ Kanu, E Gupta, UK Vates, GK Singh, Self-healing composites: A state-of-the-art review. Composites Part A: Applied Science and Manufacturing. 121 (2019) 474-486. https://doi.org/10.1016/j.compositesa.2019.04.012.

[3] NJ Kanu, UK Vates, GK Singh, S Chavan, Fracture problems, vibration, buckling, and bending analyses of functionally graded materials: A state-of-the-art review including smart FGMS. Particulate Science and Technology. 37 (2019) 583-608. https://doi.org/10.1080/02726351.2017.1410265.

[4] UK Vates, BP Sharma, NJ Kanu, NA Daniel, S Subramanian, P Sharma, Optimization of process parameters of galvanizing steel in resistance seam welding using RSM. Proceedings of International Conference in Mechanical and Energy Technology, Springer, Singapore. (2020) 695-706. https://doi.org/10.1007/978-981-15-2647-3_65.

[5] NJ Kanu, E Gupta, UK Vates, GK Singh, An insight into biomimetic 4D printing. RSC Advances. 9 (2019) 38209-38226. https://doi.org/10.1039/C9RA07342F.

[6] NJ Kanu, D Patwardhan, E Gupta, UK Vates, GK Singh, Numerical investigations of stress-deformation responses in fractured paediatric bones with prosthetic bone plates. IOP Conference Series: Materials Science and Engineering. 814 (2020) 012038. https://doi.org/10.1088/1757-899X/814/1/012038.

[7] A Lal, NJ Kanu, The nonlinear deflection response of CNT/nanoclay reinforced polymer hybrid composite plate under different loading conditions. IOP Conference Series: Materials Science and Engineering. 814 (2020) 012033. https://doi.org/10.1088/1757-899X/814/1/012033.

[8] H.S. Qi, A.J. Day, Investigation of disc/pad interface temperatures in friction braking, Wear 262, 505–513 (2007)

[9] A. Borowski, Common methods in analyzing the tribological properties of brake pads and discs a review, Acta Mech. Autom. 13, 189–199 (2019)

[10] NJ Kanu, E Gupta, UK Vates, GK Singh, An insight into smart self-lubricating composites. Smart Polymer Nanocomposites: Biomedical and Environmental Applications. (2021) 85-101. https://doi.org/10.1016/B978-0-12-819961-9.00012-8.

[11] NJ Kanu, D Patwardhan, E Gupta, UK Vates, GK Singh, Finite element analysis of mechanical response of fracture fixation functionally graded bone plate at paediatric femur bone fracture site under compressive and torsional loadings. Materials Today: Proceedings. 38 (2021) 2817-2823. https://doi.org/10.1016/j.matpr.2020.08.740.

[12] V Pandey, NJ Kanu, GK Singh, B Gadissa, AZ31-alloy, H13-die combination heat transfer characteristics by using inverse heat conduction algorithm. Materials Today: Proceedings. 44 (2021) 4762-4766. https://doi.org/10.1016/j.matpr.2020.11.258.

[13] A Chauhan, UK Vates, NJ Kanu, E Gupta, GK Singh, BP Sharma, SR Gorrepati, Fabrication and characterization of novel nitinol particulate reinforced aluminium alloy metal matrix composites (NiTip/AA6061 MMCs). Materials Today: Proceedings. 38 (2021) 3027-3034. https://doi.org/10.1016/j.matpr.2020.09.326.

[14] R. Bhat, K.S. Lee, Optimization of brake parameters for a disc brake system to improve the heat dissipation using Taguchi method, Int. J. Mech. Eng. Technol. 8, 44–52 (2017).

[15] N Jain, NJ Kanu, The potential application of carbon nanotubes in water Treatment: A state-of-the-art-review. Materials Today: Proceedings. 43 (2021) 2998-3005. https://doi.org/10.1016/j.matpr.2021.01.331.

[16] P. Liu, H. Zheng, C. Cai, Y. Wang, C. Lu, K.H. Ang, G.R. Liu, Analysis of disc brake squeal using the complex eigenvalue method, Appl. Acoust. 68, 603–615 (2007)

[17] NJ Kanu, SA Patil, V Sutar, E Gupta, GK Singh, UK Vates, S Chavan, Design and CFD analyses of aluminium alloy-based vortex tubes with multiple inlet nozzles for their optimum performances in sustainable applications. Materials Today: Proceedings. 47 (2021) 2808-2813. https://doi.org/10.1016/j.matpr.2021.03.482.

[18] S Kadam, S Chavan, NJ Kanu, An insight into advance self-healing composites. Materials Research Express. 8 (2021) 052001. https://doi.org/10.1088/2053-1591/abfba5.

[19] M. Chopade, A. Valavade, Experimental investigation using CFD for thermal performance of ventilated disc brake rotor, Int. J. Autom. Technol. 18, 235–244 (2017).

[20] S. Subhasis, P.P. Rathod, A.J. Modi, Research paper on modelling and simulation of Disc brake to analyze temperature distribution using FEA, Int. J. Sci. Res. Dev. 2, 491–494 (2014).

[21] MA Kumbhalkar, DV Bhope, AV Vanalkar, "Analysis of Rail Vehicle Suspension Spring with Special Emphasis on Curving, Tracking and Tractive Efforts", IOP Conference Series: Materials Science and Engineering 149 (1), 012131. https://doi.org/10.1088/1757-899X/149/1/012131.

[22] NJ Kanu, A Mangalam, E Gupta, UK Vates, GK Singh, DK Sinha, Investigation on secondary deformation of ultrafine SiC particles reinforced LM25 metal matrix composites. Materials Today: Proceedings. 47 (2021) 3054-3058. https://doi.org/10.1016/j.matpr.2021.05.640.

[23] V Pandey, A Bekele, GMS Ahmed, NJ Kanu, GK Singh, An application of conjugate gradient technique for determination of thermal conductivity as an inverse engineering problem. Materials Today: Proceedings. 47 (2021) 3082-3087. https://doi.org/10.1016/j.matpr.2021.06.073.

[24] N. Idusuyi, I. Babajide, O.K. Ajayi, T.T. Olugasa, A computational study on the use of an Aluminium metal matrix composite and Aramid as alternative brake disc and brake pad material, J. Eng. 2014, 1–6 (2014).

[25] N Jain, E Gupta, NJ Kanu, Plethora of Carbon nanotubes applications in various fields–A state-of-the-art-review. Smart Science. (2021). https://doi.org/10.1080/23080477.2021.1940752.

[26] G. Ganesan, S. Magibalan, S. Gokul, K.P. Gopalakrishnan, S. Packayiraj, Design and fabrication of disc brake by using aluminum metal matrix composites, J. Emerg. Technolog. Innov. Res. 4, 77–81 (2017)

[27] M.H. Dakhil, A.K. Rai, P.R. Reddy, A.A.H. Jabbar, Design and structural analysis of disc brake in automobiles, Int. J. Mech. Product. Res. Dev. 4, 95–112 (2014)

[28] Ayushi, UK Vates, S Mishra, NJ Kanu, Biomimetic 4D printed materials: A state-of-the-art review on concepts, opportunities, and challenges. Materials Today: Proceedings. 47 (2021) 3313-3319. https://doi.org/10.1016/j.matpr.2021.07.148.

[29] NJ Kanu, Modeling of stress wave propagation in matrix cracked laminates. AIP Advances. 11 (2021) 085217. https://doi.org/10.1063/5.0057749.

[30] NJ Kanu, S Bapat, H Deodhar, E Gupta, GK Singh, UK Vates, GC Verma, V Pandey, An Insight into Processing and Properties of Smart Carbon Nanotubes Reinforced Nanocomposites. Smart Science. (2021). https://doi.org/10.1080/23080477.2021.1972913.

[31] D.K. Dhir, Thermo-Mechanical performance of automotive disc brakes, Mater. Today Proc. 1, 1864–1871 (2018)

[32] M. Nouby, J. Abdo, D. Mathivanan, K. Srinivasan, Evaluation of disc brake materials for squeal reduction, Tribol. Trans. 4, 644–656 (2011).

[33] SA Sakhare, SM Pendkar, NJ Kanu, E Gupta, UK Vates, GK Singh, GC Verma, Design suggestions on modified self-sustainable space toilet. SN Applied Sciences. 4 (2022) 13. https://doi.org/10.1007/s42452-021-04878-w.

[34] UK Vates, BP Sharma, NJ Kanu, E Gupta, GK Singh, Modeling and optimization of IOT factors to enhance agile manufacturing strategy-based production system using SCM and RSM. Smart Science. (2021). https://doi.org/10.1080/23080477.2021.2017543.

[35] NJ Kanu, A Lal, Nonlinear static and dynamic performance of CNT reinforced and nanoclay modified laminated nanocomposite plate. AIP Advances. 12 (2022) 025102. https://doi.org/10.1063/5.0074987.

[36] NJ Kanu, A Lal, Nonlinear static analysis of CNT/nanoclay particles reinforced polymer matrix composite plate using secant function-based shear deformation theory. Smart Science. (2022). https://doi.org/10.1080/23080477.2022.2066052.