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Finite Element Analysis of Solid and Vented Disc

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Abstract: In terms of temperature range, disc brakes have been used for several years and are still improving. To simulate and predict the temperature range of the disc brake, many techniques have been developed. Over time, disc brakes have evolved to be a reliable system for decelerating and stopping a car. For various applications, there have been different prototypes of disc brake systems. A detailed explanation of the different geometries of the components and materials used in the design of disc brakes is given in this research. Despite all the changes, there are still many technical challenges associated with disc brakes that need to be understood and addressed in greater detail. This study deals with the modelling and analysis by SolidWorks and Ansys of solid and ventilated disc brakes. In this research, structural and thermal analysis is performed by using Ansys to fulfil the objective. Comparison can be made for the three-material utilized to suggest the best material for disc brake application.

Keywords: Solid Disc Brake, Ventilated Disc Brake, ANSYS

1. Introduction

The most critical safety components of an automobile are the braking system [1]. Most of the cars used drum brakes. Due to the problems such as stress concentration during use, the development of drum brakes is restricted. An essential prerequisite of safe transportation is reliable and effective braking. In general, there are three main functions of a brake system: to control a vehicle speed when driving downhill, minimize a vehicle's speed when necessary, and keep a car stationary when in parking [2].

A disc brake is a brake that uses calipers to be pressed both pads against both sides of a disc to create friction. The friction can slow and stop the rotational speed of the shaft. When the brake is applied, the brake disc absorbs the vehicle kinetic energy and transfers it into heat. Due to prolonged exposure to frictional heat on the disc, the temperature will rise. When the temperature exceeds a critical value, it will lead to break fail, thermal crack, failure of the bearing, and premature wear. Nevertheless, the disc brake system has higher wear resistance and easier maintenance than drum brakes [3].

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A solid disc brake is just a solid block material, and it is cheap for the manufacturer and affordable to buy. But it won't be as good at managing heat. The ventilated disc brake is known as high-performance brakes, and it is produced by making hollows or slots on the disc surface and side edges [4]. A vented disc typically consists of an inner and outer disc connected by ribs in between them. This profile allows them to dissipate heat faster and result in lower surface temperature. This lower temperature can reduce the risk of brake fade and helps in reducing the wear of the disc [1]. So, an efficient material for disc brake rotor that can dissipate heat faster and structurally safe is analyzed.

Most modern cars utilize disc brakes, which offer much more reliable stopping power than older drum brakes. This method of stopping causes the disc to wear down and can also lead to damaging the disc. Overheating is a common source of problems in all parts of the disc brake system because the entire purpose of a brake system is to convert kinetic energy into heat through friction. Although vented disc help dissipates heat, they create the potential for stress cracks and warping disc. In extreme braking operations such as steep descents or repeated high-speed brake applications, sufficient heat dissipation becomes critical to ensure reliable braking.

The aim of this study is to investigate and analyze the stress distribution for both discs using static and transient analysis through three different materials. This study will also focus to identify the thermal considerations of both discs using thermal analysis and to compare the mechanical response of old material with new material for disc brake.

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Research strategy

This research was an applied one, not new. Instead, many previous academic types of research exist regarding the studies on the finite element of disc brakes, not only on one material in specific but many more other materials such as glass fibre, asbestos, MMC (Metal Matrix Composite), titanium alloy, and E-glass. Therefore, the proposed thesis took the form of a new study, but on existing research.

2.2 Research method

To satisfy the objectives of these studies, a qualitative research strategy was held. This type of research methodology is based on numeral or figures. This research method uses information from primary data, that is, the experiment test is done personally, and secondary data from previous studies to get information. This research method is beneficial in seeking to count, measure or identify patterns in data. The research method is also known as observational analysis because it can be measured consistently and accurately. Quantitative approaches for collecting data are far more organized than methods for collecting qualitative data. Other than that, quantitative data can give measurements to validate and understand each problem. Primary data is any original information that been compiled to answer the research question through experiments and observation. Primary data are also data extracted for the particular purpose of the analysis. Primary data collection led to quantitative research. Research focuses on a specific research purpose that uses deductive reasoning and established theories to establish the hypotheses tested and explained. The experiments approach used SolidWorks 2019 and Ansys 2020 R2 to obtain the results to satisfy the objective. Secondary data is information that has been previously collected or collected for reasons other than the purpose of the review of the scholarly paper. This type of data is already available from some sources in various formats. Secondary data collection led to external secondary data research representing a study that uses existing data on a specific research subject. Secondary data that have been collected are primarily from journal dated range 2000-2020.

2.3 Data collection tools

For this research, SolidWorks and Ansys were used. The software mentioned helps to answer specified questions from studies, test hypotheses and analyze findings. However, the focus remains the same on ensuring precise and truthful selection.

2.4 SolidWorks Software

Figures 1 and 2 show the layout and dimensions of both type disc brake.

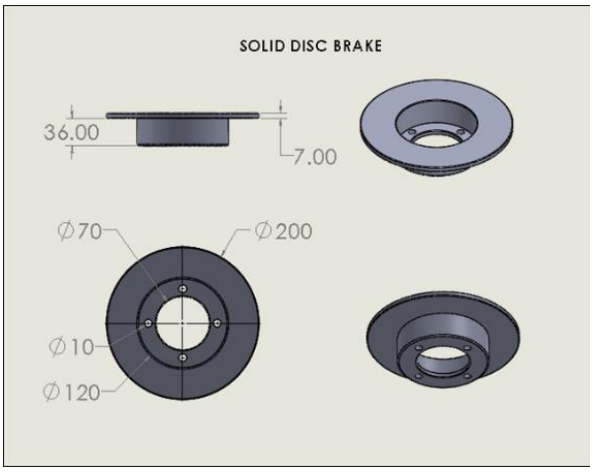

Figure 1: Solid Disc Brake

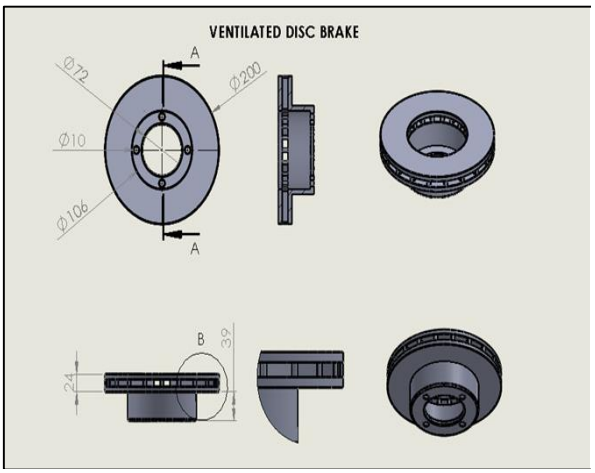

Figure 2: Ventilated Disc Brake

2.5 ANSYS Finite Element Software

The program for structural analysis from Ansys helps you solve complex problems in structural engineering and make smarter, quicker design decisions. Ansys structural analysis software is used across industries to help engineers refine their product designs and reduce material testing costs.

Thermal analysis is used to determine the temperature distribution, thermal gradient, heat flow and other such thermal quantities in a structure. Ansys tools provide an environment for highly accurate thermal simulation, including convection, radiation and conduction loads, and the effect of power losses and thermal energy from friction and other external sources.

Thermal or structural transient analysis. By definition, a transient analysis involves time-dependent demands. You can do a transient structural analysis (also known as time-history analysis) in the Mechanical application using the transient structural analysis that mainly utilizes the ANSYS Mechanical APDL solver. This form of research is used to assess a structure's dynamic reaction when subjected to generic time-dependent loads.

2.6 Finite element method (FEM)

The model used must be divided into several small pieces known as finite elements. Proper meshing, irrespective of whether the process is automated or manual, enables precise analysis.

Sensitivity analysis is used to examine the effect of changing the value of an independent variable on a specific dependent variable under a specified set of assumptions. This technique is employed under certain constraints determined by one or more input variables. Sensitivity analysis is a model that determines the effect of changes in other variables, referred to as input variables, on target variables. This model is also known as a what-if analysis or a simulation analysis. It is a technique for forecasting the result of a decision given a set of variables.

Table 1: Sensitivity Analysis Result

Size element (mm)	Max stress (Pa)
5	3.2108
10	2.7519
20	0.046924
30	1.9035
40	1.904
50	1.8266
60	1.8758
70	1.3452
80	1.6622
90	2.0804
100	1.6988
200	2.1214
300	2.1215

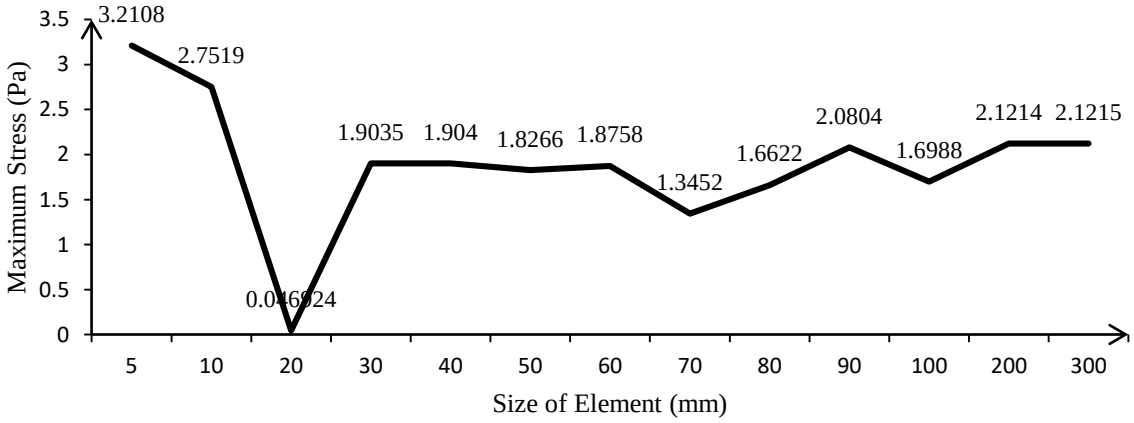

Figure 3: Sensitivity Analysis Graph

Table 2: Meshing details

Model	Node number	Element number
Solid disc brake	5958	3103
Ventilated disc brake	10446	5515

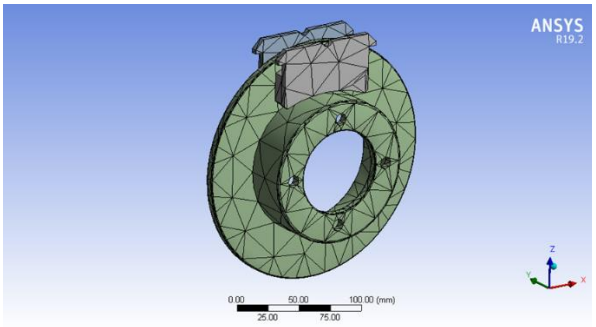

Figure 4: Meshing result in solid disc brake

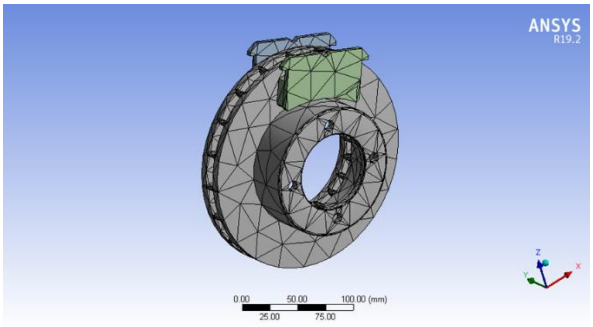

Figure 5: Meshing result ventilated disc brake

2.7 Material properties

The material used for this study is grey cast iron, titanium alloy, and magnesium alloy.

Table 3: Material Properties

	Grey cast iron	Titanium Alloy	Magnesium Alloy
Density (kg/m^3)	7200	4620	1800
Young's Modulus (Gpa)	110	96	45
Poisson's ratio	0.28	0.36	0.35
Thermal conductivity (w/m^{o}c)	52	21.9	156
Specific heat (J/kg^{o}c)	447	522	1024
Coefficient of thermal expansion (10^{-6}k^{-1})	10.5	9.9	24.8

3. Results and Discussion

The analysis carried out using Ansys is done through three types of analysis static structural, steady-state thermal, and transient structural. In addition, both discs are analyzed with three different materials: cast iron, titanium alloy, and magnesium alloy.

Table 4: Static Structural Analysis

	Total Deformation		Equivalent Stress (Von-Mises)	
	Solid Disc	Vented Disc	Solid Disc	Vented Disc
Gray Cast Iron	17.453 mm	17.453 mm	0.82591 Pa	1.2751 Pa
Titanium Alloy	17.453 mm	17.453 mm	2.1603 Pa	2.0635 Pa
Magnesium Alloy	17.453 mm	17.453 mm	0.36866 Pa	0.86361 Pa

The overall deformation is the same for all materials and both types of disc brakes, according to table 4.25. Therefore, when a brake force is applied to disc brakes made of various materials, magnesium alloy produces minor stress compared to other solid and vented disc brakes.

Table 5: Transient Structural Analysis

	Total Deformation		Equivalent Stress (Von-Mises)	
	Solid Disc	Vented Disc	Solid Disc	Vented Disc
Gray Cast Iron	141.41 mm	141.44 mm	1305.1 MPa	990.14 MPa
Titanium Alloy	141.41 mm	141.44 mm	1288.1 MPa	850.17 MPa
Magnesium Alloy	141.41 mm	141.44 mm	683.44 MPa	422.39 MPa

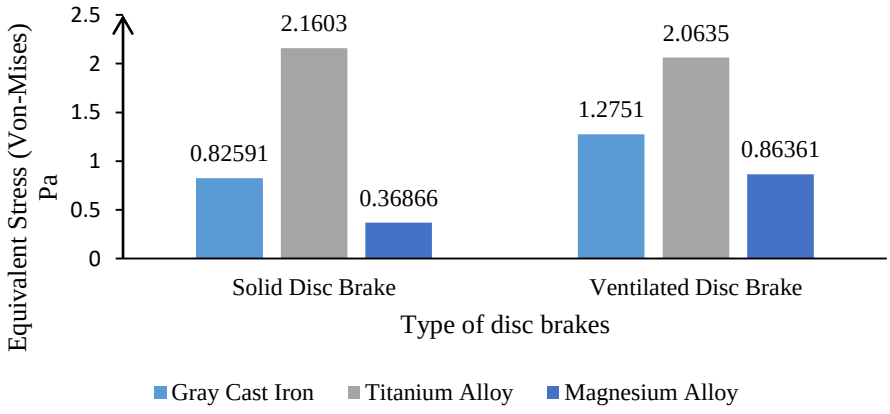

Figure 6: Comparison of equivalent von-Mises stress for static analysis

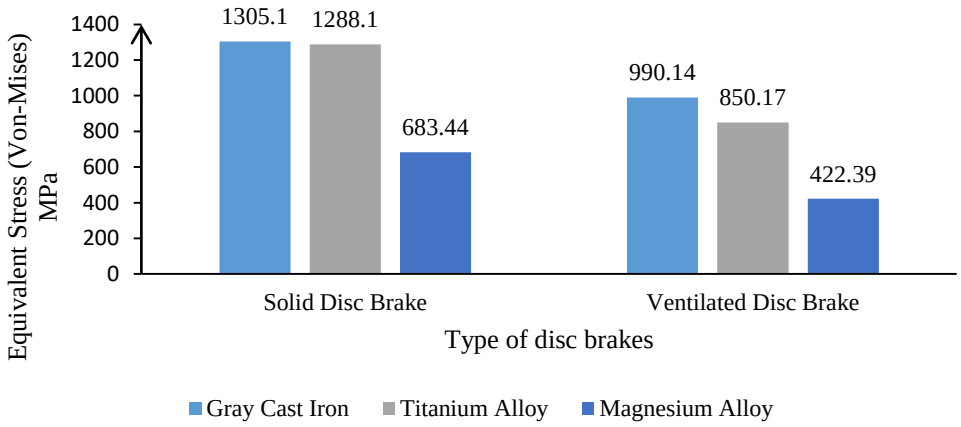

Figure 7: Comparison of equivalent von-Mises stress for transient analysis.

The three materials Gray Cast Iron, Titanium Alloy, and Magnesium Alloy are compared in Figure 4.56. It demonstrates that a Vented type disc brake constructed of Magnesium Alloy produces less stress when loads are applied.

Table 6: Steady-State Thermal Analysis

	Temperature		Total Heat Flux	
	Solid Disc	Vented Disc	Solid Disc	Vented Disc
Gray Cast Iron	1987.5 °C	1753.1 °C	2.7103 W/mm²	1.257 W/mm²
Titanium Alloy	2463 °C	2014.4 °C	2.4972 W/mm²	1.1934 W/mm²
Magnesium Alloy	1727.5 °C	1589.7 °C	2.4086 W/mm²	1.228 W/mm²

This analysis compares both types of the disc brake and all materials. The ventilated disc brake magnesium alloy generates a minor temperature when the brake force is applied, as shown in figure 4.57. However, the created heat should be dispersed more quickly; similarly, the total heat flux for ventilated disc magnesium alloy also the lowest among other materials.

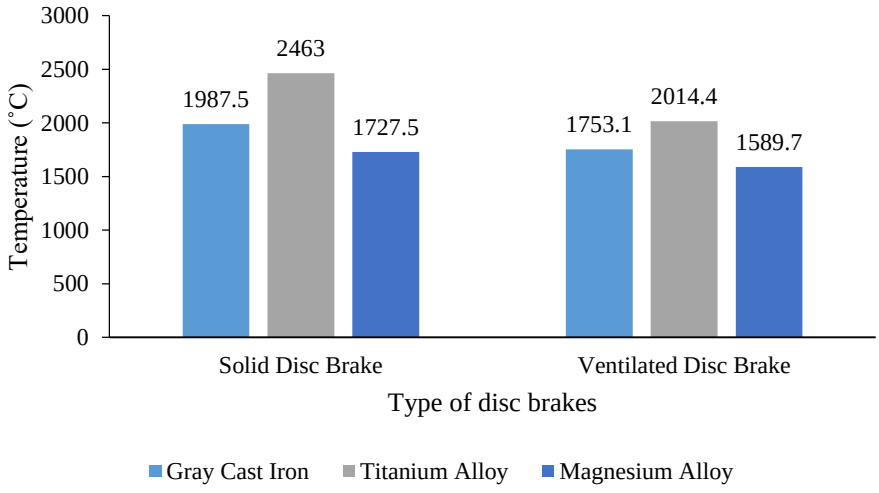

Figure 8: Comparison of maximum temperature

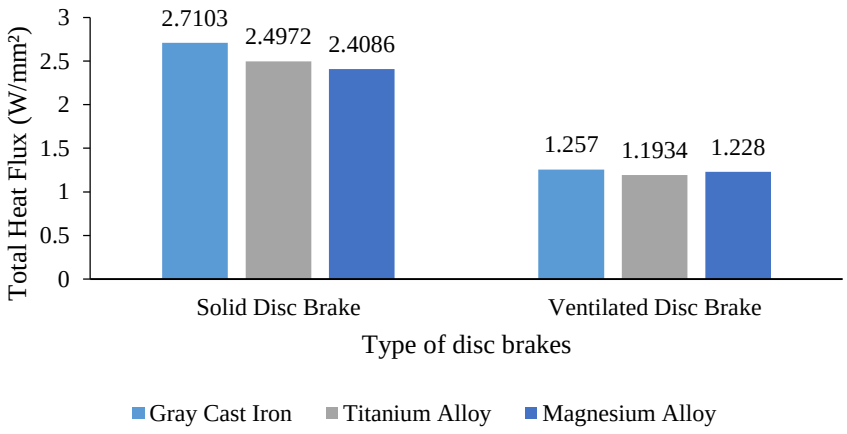

Figure 9: Comparison of total heat flux

4. Conclusion

At present, to find the new and improve material and increase braking efficiency and provide a safer environment for the automotive world, an investigation is performed to find new types of material for disc brake. Based on static structural analysis, both disc brake types and ventilated magnesium alloys showed the lowest stress value. The transient structural analysis also showed that magnesium alloy solid and ventilated disc brake generates low stress during brake force is applied. Steady-state thermal analysis is performed, and the result shows that the lowest temperature while braking is magnesium alloy ventilated disc similarly lowest total heat flux also ventilated disc magnesium alloy. The ventilation system is critical in cooling the discs, providing adequate resistivity to high temperatures, and brake discs are less likely to overheat. By considering various data analysis, it is found that a ventilated type disc brake rapidly disperses frictional heating. Based on three material, magnesium alloy is the best material among gray cast iron and titanium alloy because of low stress while braking. Finally, it is concluded that magnesium alloy ventilated disc brake is the best combination for the application.

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References

[1] K. S. Narayana, G. U. Rao, D. Simhachalam, and B. Nagaraju, "Finite Element Analysis of Solid and Ventilated Disc Brake," *Int. J. Sci. Res.*, vol. 3, no. 9, pp. 875–882, 2014.

[2] K. N. Kumar, D. B. N. Raju, and M. R. Roy, "Static and thermal analysis of disc brake with Brake pad," *Int. J. Eng. Trends Technol.*, vol. 23, no. 8, pp. 411–420, 2015.

[3] S. Macužić, I. Saveljić, J. Lukić, J. Glišović, and N. Filipović, "Thermal analysis of solid and vented disc brake during the braking process," *J. Serbian Soc. Comput. Mech.*, vol. 9, no. 2, pp. 19–26, 2015.

[4] Y. Yildiz and M. Duzgun, "Stress analysis of ventilated brake discs using the finite element method," *Int. J. Automot. Technol.*, vol. 11, no. 1, pp. 133–138, 2010.

[5] J. Pateriya, R. K. Yadav, V. Mukhraiya, and P. Singh, "Brake Disc Analysis With the Help," vol. 6, no. 11, pp. 114–122, 2015.

[6] O. Maluf and M. T. Milan, "Development of Materials for Automotive Disc Brakes," *Minerva*, vol. 4, no. 2, pp. 149–158, 2004.

[7] R. Jaiswal *et al.*, "Structural and thermal analysis of disc brake using solidworks and ansys," *Int. J. Mech. Eng. Technol.*, vol. 7, no. 1, pp. 67–77, 2016.

[8] M. A. S. Hemraj Nimhal, Chitranjan Agarwal, S. Jindal, "Thermal Analysis of Disc Brake using Ansys Software," *Int. J. Adv. Eng. Res. Dev.*, vol. Volume 3, no. Issue 3, p. 8, 2016.

[9] A. Naga Phaneendra, S. Junaid Razi, L. Wasee Ul Kareem, G. M. Adnan, and S. M. Abdul Ahad, "Thermal analysis of solid disc brake rotor," *Int. J. Mech. Prod. Eng. Res. Dev.*, vol. 8, no. 2, pp. 1039–1048, 2018.

[10] J. Vyas, M. Zinzuvadia, and M. I. Kathadi, "Design and Analysis of Solid and Cross-Drilled Disc Brake Rotors," vol. 1, no. 1, pp. 294–285, 2018.

[11] A. Belhocine and M. Bouchetara, "Investigation of temperature and thermal stress in ventilated disc brake based on 3D thermomechanical coupling model," *Ain Shams Eng. J.*, vol. 4, no. 3, pp. 475–483, 2013.

[12] Jaenudin, J. Jamari, and M. Tauviqirrahman, "Thermal analysis of disc brakes using finite element method," *AIP Conf. Proc.*, vol. 1788, no. January, pp. 1–6, 2017.

[13] S. P. Gautam *et al.*, "Finite-Element-Analysis-Of-Disc-Brake-using-ANSYS-WORKBENCH-Software.docx," vol. 6, no. 4, pp. 1954–1959, 2015, [Online]. Available: https://www.ijser.org/researchpaper/Finite-Element-Analysis-Of-Disc-Brake-using-ANSYS-WORKBENCH-Software.pdf.

[14] V. Agnihotri and D. M. . Chopra, "Optimized Thermo –Structural Analysis of Solid and Vented Disc Brake Using Finite Element Mathod (A Case Study)," *IOSR J. Mech. Civ. Eng.*, vol. 11, no. 4, pp. 40–49, 2014.

[15] M. Sathya, S. Dattu, and S. Nayeem, "COMPOSITE DISC BRAKE DESIGN AND ANALYSIS Composite Disc Brake Design and Analysis," vol. 15, no. 3, pp. 92–103, 2020.

[16] P. Gurram, S. A. Komakula, and G. V. Kumar, "Design and Analysis of Vented Disc Brake Rotor," *Int. J. Eng. Res.*, vol. 14, no. 9, pp. 2228-2233, 2019.

[17] P. Gnanesh, C. Naresh and S. A. Hussain, "Finite Element Analysis of Normal and Vented Disc Brake Rotor," *Int. J. Mech. Eng. Robot. Res.*, vol. 3, no. 1, 2014.

[18] R. Jaiswal *et al.*, "Structural and thermal analysis of disc brake using solidworks and ansys," *Int. J. Mech. Eng. Technol.*, vol. 7, no. 1, pp. 67–77, 2016.

[19] H. Hu, L. Zhang, Y. Bai, and J. Hong, "Finite Element Analysis of Moving Platform Based on ANSYS Workbench," *MATEC Web Conf.*, vol. 22, no.Icaita, pp. 89–92, 2015.

[20] S. Lee and T. Yeo, "Temperature and coning analysis of brake rotor using an axisymmetric finite element technique," *Proc. - KORUS 2000 4th Korea-Russia Int. Symp. Sci. Technol.*, vol. 3, pp. 17–22, 2000.

[21] "Carbon-ceramic discs", *Brembo – Official WebSite*, 2021. [Online]. Available: https://www.brembo.com/en/car/original-equipment/products/carbon-ceramic-discs.