NanoWorld Journal

https://doi.org/10.17756/nwj.2023-s4-063

Research Article

Open Access

Design and Analysis Functionally Graded Disc Under Mechanical Loads

Srikanth Nayak[1*], Naresh Kumar Sarella[1], Shakti Prasanna Jena[2], Manoj Kumar Elipey[1], Bhavanasi Subbaratnam[3] and Deepak Vamja[4]

[1]*Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad, Telangana, India*
[2]*Department of Mechanical Engineering, Nalanda Institute of Technology, Bhubaneswar, Odissa, India*
[3]*Department of Mechanical Engineering, Vijay Rural Engineering College, Nizamabad, Telangana, India*
[4]*Department of Mechanical Engineering, R.K. University, Rajkot, Gujarat, India*

***Correspondence to:**
Srikanth Nayak
Department of Mechanical Engineering,
Vardhaman College of Engineering,
Hyderabad, Telangana, India.
E-mail: nayakpathlavathsrikanth@gmail.com

Received: September 15, 2023
Accepted: November 27, 2023
Published: November 30, 2023

Citation: Nayak S, Sarella NK, Jena SP, Elipey MK, Subbaratnam B, et al. 2023. Design and Analysis Functionally Graded Disc Under Mechanical Loads. *Nano World J* 9(S4): S366-S371.

Published by United Scientific Group

Abstract

This research focused on both vented and solid disc brakes constructed from functionally graded material that were modeledand studied. The main goal of this study is to perform static and modal tests on both rotors in order for a deeper understanding of total deformation, stress and load distribution on the disc brake's rotor. The results were then compared to identify the superiorrotor as well as both results offer an improved understanding of the properties of deformation in disc brake rotors. In turn, they are helping the automotive industry in determining the most efficient and effective disc brake rotors. The process of modeling is carried out utilizing the software CATIA, while the subsequent analysis is performed using ANSYS. In this work examines the mechanical properties of various materials utilized in disc brakes, including copper alloy, ceramic matrix, and titanium alloy, undervarying mechanical loads i.e., at input pressure 1500 Pa and 2000 Pa. The ceramic matrix is regarded as functional graded materialsin this context.

Keywords

Disc brake, CATIA, ANSYS, Functional graded materials

Introduction

A brake is a mechanical or electronic device that is designed to impede or halt the motion of a machine or vehicle. The antithetical constituent of the aforementioned mechanism is a clutch. The subsequent sections of this manuscriptare allocated to diverse classifications of automotive braking systems. The predominant mechanism employed by brakes for the conversion of kinetic energy into heat is friction, although alternative methods of energy conversion may also be utilized [1]. In order to store and use energy for later use, regenerative braking turns a large amount of kinetic energy into electrical energy. Potential energy, which may be stored in a variety of forms like compressed airor pressurized oil, is the result of transforming kinetic energy, the energy in motion, into potential energy. Kinetic energy may be converted into other forms by the use of alternative braking methods, they can, for instance, provide power to the flywheel.

Design and analysis of disc brake by [1], discussed about the recurrent malfunction of the disc brakes under highdeceleration circumstances resulted in a decline in the efficacy and functionality of the rotor. Design and analysisof disc brake rotor using different profiles [2]. Each individual system has undergone research and development to ensure compliance with safety standards. The brake system is considered the most crucial componentof a vehicle, surpassing even air bags, suspension systems, and handling capabilities in terms of safety and importance. Performance and thermal analysis of various functional graded materials of disc brake system by finite element method [3]. The disc brake is a mechanical apparatus utilized for decelerating or halting the rotational motion of a wheel. The brake disc, typically composed of cast iron or ceramic composites such as carbon, Kevlar, and silica, is linked to the wheel and/or axle.

The disc brake can be manufactured using nano-based materials also. Much research is focused on nano-based materials by implementing different compositions to make the components high stability and high strength. Nano based composite materials are in high demand for researchers and there is a lot of scope in this field [4, 5].

Finite element modeling and analysis of functionally graded disc (FGD) was done by Chintala et al. [6]. A disc brake and mechanical device used to limit the speed of rotation or to slow down the turning motion of wheels. The disc brake, usually composed out of cast iron or composites like carbon, Kevlar and silicais usually attached to the wheel or to the axle. Computer aided design and analysis of disc brake rotors [7]. The purpose of this research is to analyze different types of disc brake rotors, which are commonly used in automobile industry and to propose a new design of brake rotor. A disc brake design and analysis by using functional graded materials [8]. The braking device is a vital part of the automobile industry. It is used to maintain vehicle speed and control. Therefore, it is necessary to find appropriate materials which can withstand heat generation and sustain the alternating mechanical load. Design and analysis of disc brake with titanium [9, 10] by discussing ventilated disc brake by thermal behavior. Review of the disc brake featuring slots exhibits superior design for disc brake systems, while ceramic material represents the optimal choice for disc brake composition. According to literature, this work examines the mechanical properties of various materials utilized in disc brakes, including copper alloy, ceramic matrix, and titanium alloy, under varying mechanical loads i.e. at input pressure 1500 Pa and 2000 Pa. The ceramic matrix is regarded as functional graded materials in this context.

Methodology

CAD model

Rotor disc dimension = 288 mm, Rotor disc material = carbon ceramic matrix, Pad brake area = 2000 mm^2, Pad brake material = asbestos, Coefficient of friction (wet) = 0.07 to 0.13, Coefficient of friction (dry) = 0.3 to 0.5, Maximum temperature = 350 °C, and Maximum pressure = 1 MPa (10^6 Pa). Figure 1 presents disc brake.

Analysis of model in ANSYS

This paper presents a detailed analysis of a model using ANSYS, a widely used finite element analysis softwarepackage. The aim of this study was to evaluate the structural behavior and performance of the model under various loading conditions. The analysis included the determination of static structural analysis, deformation, and modal analysis to assess the model's structural integrity. The results obtained from the ANSYS analysis were analyzed andinterpreted, providing valuable insights into the model's performance. This study demonstrates the effectiveness of ANSYS in conducting accurate and reliable structural analyses. Figure 2 presents methodology.

Figure 1: Disc brake.

Case 1: Static structural analysis of disc with holes at input pressure 1500 Pa

Titanium alloy

Titanium alloys are lightweight and have excellent strength-to-weight ratios, making them ideal for applications where weight reduction is crucial. They possess high corrosion resistance, even in harsh environments, making them suitable for aerospace, marine, andchemical industries. Titanium alloys exhibit good bio compatibility, making them suitable for medical implants. They have a high melting point, allowing them to withstand high temperatures. Titanium alloys are known for theirexcellent fatigue resistance, making them suitable for applications subjected to cyclic loading.

Copper alloy

Copper alloys, such as brass and bronze, are known for their high thermal and electrical conductivity. They possessexcellent corrosion resistance and can retain their mechanical properties at elevated temperatures. Copper alloys exhibit good form ability, making them suitable for various manufacturing processes, including casting, forging, andmachining. They are widely used in electrical and electronic applications, plumbing systems, and heat exchangers. Copper alloys can be susceptible

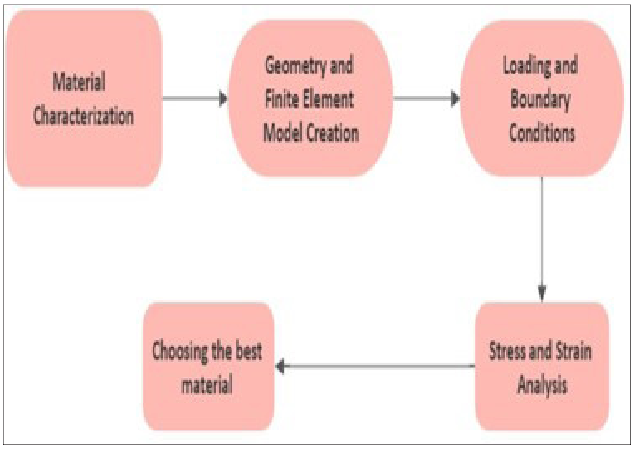


Figure 2: Methodology.

to stress corrosion cracking in certain environments.

Material ceramic

Ceramics are a class of inorganic materials that are typically non-metallic and brittle in nature.They possess excellent hardness, wear resistance, and high-temperature stability. Ceramics have low thermal and electrical conductivity. They are chemically inert, making them resistant to corrosion and suitable for applications in harsh chemical environments. Due to their brittleness, ceramics can be prone to cracking or fracture under tensile stresses, which should be considered in the design and analysis.

In the design and analysis of FGDs under mechanical loads, these materials can be strategically distributed to optimize the performance of the disc. By adjusting the composition and distribution of these materials, designers can tailor the properties of the disc to achieve specific objectives, such as improved strength, thermal stability, or wear resistance. The use of functionally graded materials allows for a smooth transition in material properties throughout the disc, reducing stress concentrations and improving overall performance. The selection of specific materials, including titanium alloys, copper alloys, and ceramics, depends on the desired characteristics andrequirements of the application.

The above findings of static structural analysis of disc with holes are placed in table 1. Similarly, the static structural analysis of disc without holes at same input pressure of 1500 Pa is carried out and findings are placed in table 2. Table 3 presents case-2 static analysis of disc without holes. Table 4 presents case-2 modal analysis of disc without holes.

Table 1: Case-1 static analysis of disc with holes.

Materials	Input pressure load	Total deformation	Stress (MPa)	Strain
Ceramic	1500	$1.003\ e^{-7}$	$1.4742\ e^{5}$	$7.8723\ e^{-6}$
	2000	$1.3374\ e^{-7}$	$1.9656\ e^{5}$	$1.0496\ e^{-6}$
Titanium alloy	1500	$2.0278\ e^{-7}$	$1.3089\ e^{5}$	$1.4636\ e^{-6}$
	2000	$2.7038\ e^{-7}$	$1.7452\ e^{5}$	$1.9515\ e^{-6}$
Copper alloy	1500	$1.7893\ e^{-7}$	$1.364\ e^{5}$	$1.3322\ e^{-6}$
	2000	$3.7152\ e^{-7}$	$1.8575\ e^{5}$	$2.8056\ e^{-6}$

Table 2: Case-1 modal analysis of disc with holes.

Materials	Total deformation 1	Total deformation 2	Total deformation 3	Total deformation 4
Ceramic	0.82523	0.82117	0.60757	0.83288
Titanium alloy	1.0668	1.0682	0.78399	1.0893
Copper alloy	1.3838	1.3809	1.0178	1.4044

Table 3: Case-2 static analysis of disc without holes.

Materials	Input pressure load	Total deformation	Stress (MPa)	Strain
Ceramic	1500	$1.7622\ e^{-8}$	24114	$1.2826\ e^{-7}$
	2000	$2.3496\ e^{-8}$	32151	$1.2102\ e^{-7}$
Titanium alloy	1500	$3.5686\ e^{-8}$	23601	$2.6063\ e^{-7}$
	2000	$4.7582\ e^{-8}$	31468	$3.4751\ e^{-7}$
Copper alloy	1500	$3.1474\ e^{-8}$	23786	$2.2931\ e^{-7}$
	2000	$4.1966\ e^{-8}$	31715	$3.0574\ e^{-7}$

Table 4: Case-2 modal analysis of disc without holes.

Materials	Total deformation 1	Total deformation 2	Total deformation 3	Total deformation 4
Ceramic	0.9952	1.0011	0.73148	0.9977
Titanium alloy	1.2951	1.2992	0.95039	1.3009
Copper alloy	0.96676	0.97074	0.70969	0.97049

Stress and strain analysis

Stress analysis

The stress analysis section presents the results of the stress distribution throughout the FGDs under mechanical loads. The contour plots and stress diagrams are provided to visualize the stress patterns in different regions of the disc. The maximum stresses and their locations are identified and discussed. The effects of different loading conditions on thestress distribution are analyzed.

Strain analysis

In this section, the strain analysis results for the FGDs under mechanical loads are presented. The strain distribution, both axial and circumferential, is analyzed and visualized using contour plots and strain diagrams. The strain concentrations and variations along the disc are discussed. The effects of different loading conditions on the strain distribution are analyzed.

Results and Discussion

Here we found the results for 2 cases such as static and modal analysis of disc with holes and another case such as static and modal analysis of disc without holes. Selecting the best material based on results. The comparative analysis section presents the results obtained from the design and analysis of FGDs made from titanium alloy, copper alloy, and ceramic under mechanical loads. The results of modal analysis indicate that the total deformation is greater for the ceramic materi-

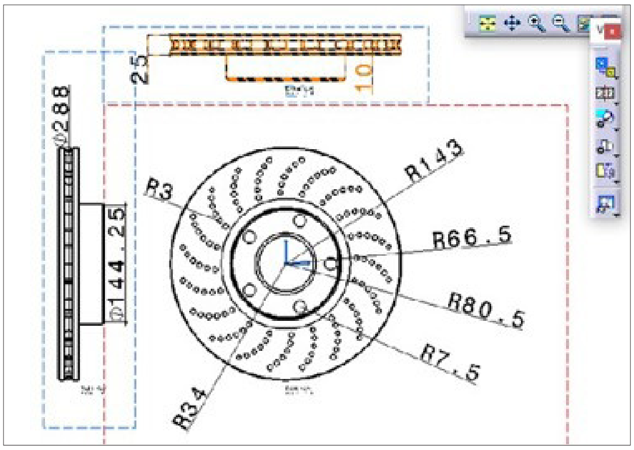


Figure 3: 2D drawing of disc brake.

al with a slot model when compared to that of titanium and copper alloy. Figure 3 presents a 2D drawing of disc brake. Figure 4 presents a 3D model of disc brake with holes. Figure 5 presents boundary conditions. Figure 6 presents modeling and applying boundary conditions. Figure 7 presents results of ceramic alloys. Figure 8 presents results of titanium alloy. Figure 9 presents results of copper alloy. Figure 10 presents a deformation plot. Figure 11 presents stress plot. Figure 12 presents strain plot.

Conclusion

The phenomenon of friction results in the deceleration or cessation of the disc and the wheel that is affixed to it. The process of converting friction into heat is a fundamental function of brakes. However, in the event that the brakes become excessively heated, their efficacy may be compromised due to an inability to adequately dissipate the heat. The phenomenon whereby a vehicle's braking system experiences a decrease in its ability to decelerate the vehicle iscommonly referred to as brake fade. Disc brakes experience significant thermal stresses during regular braking and even more extreme thermal stresses during intense braking maneuvers. Upon examination of the static analysis outcomes, it can be deduced that the stress levels exhibited by the ceramic material are comparatively lower in the design model of the disc brake with slots and without slots as compared. Theresults of modal analysis indicate that the total deformation is greater for the ceramic material with a slot model whencompared to that of titanium and copper alloy. In conclusion, the disc brake featuring slots exhibits superior design for disc brake systems, while ceramic material represents the optimal choice for disc brake composition.

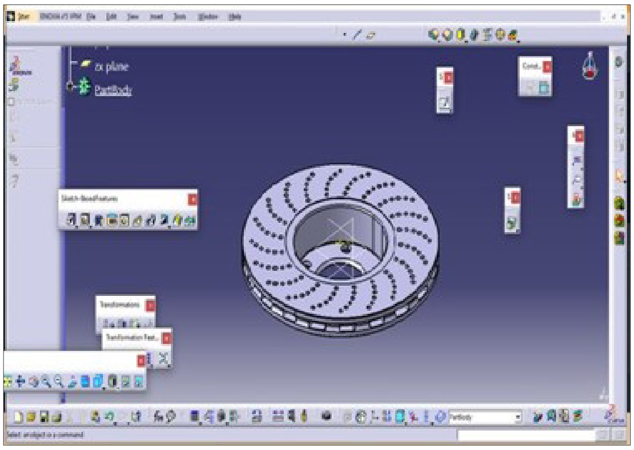


Figure 4: 3D model of disc brake with holes.

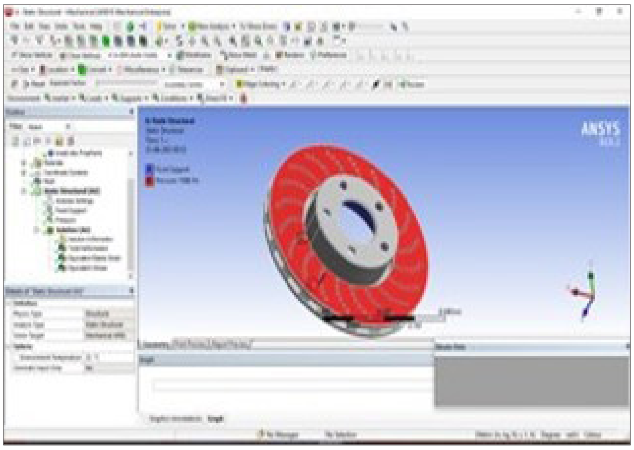


Figure 5: Boundary conditions.

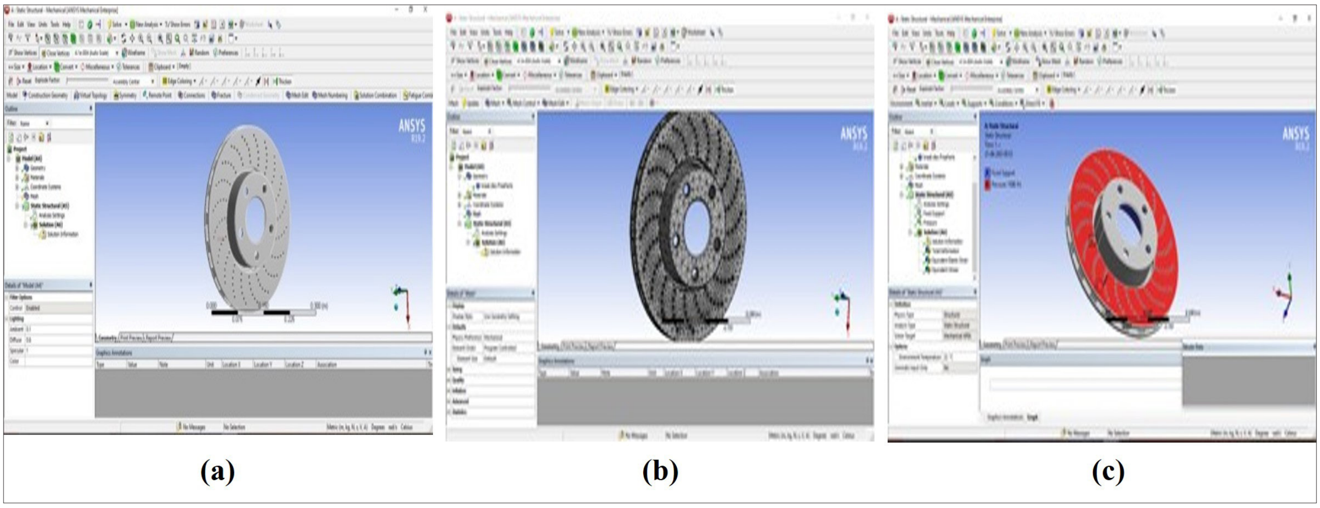


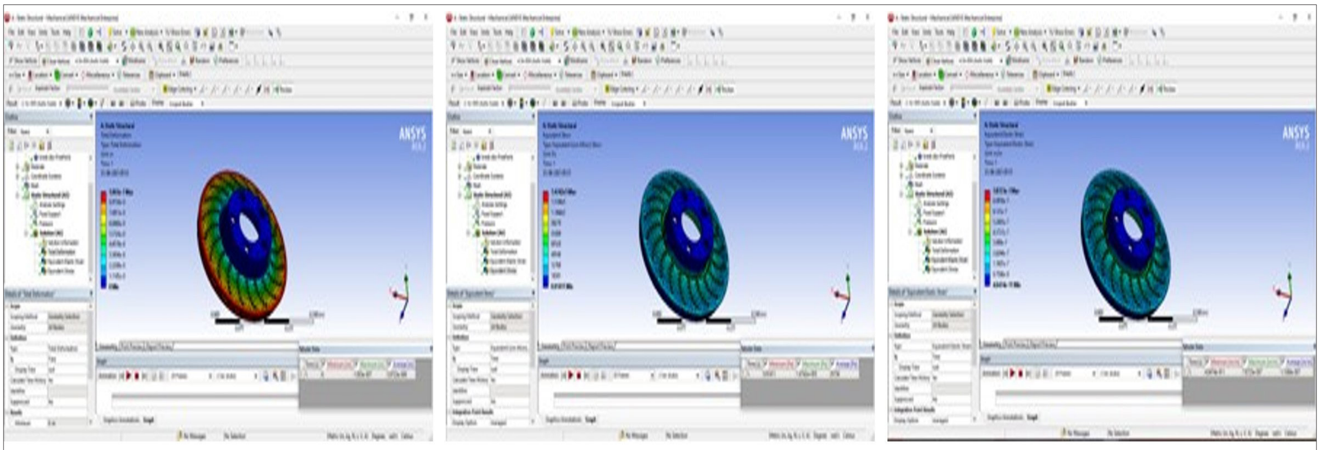
Figure 6: Modeling and applying boundary conditions: **(a)** Import geometry, **(b)** Meshing, and **(c)** Boundary conditions.

Acknowledgments

I wish to acknowledge the help provided by the department of Mechanical Engineering and I would like to express my gratitude to the management, Vardhaman College of Engineering.

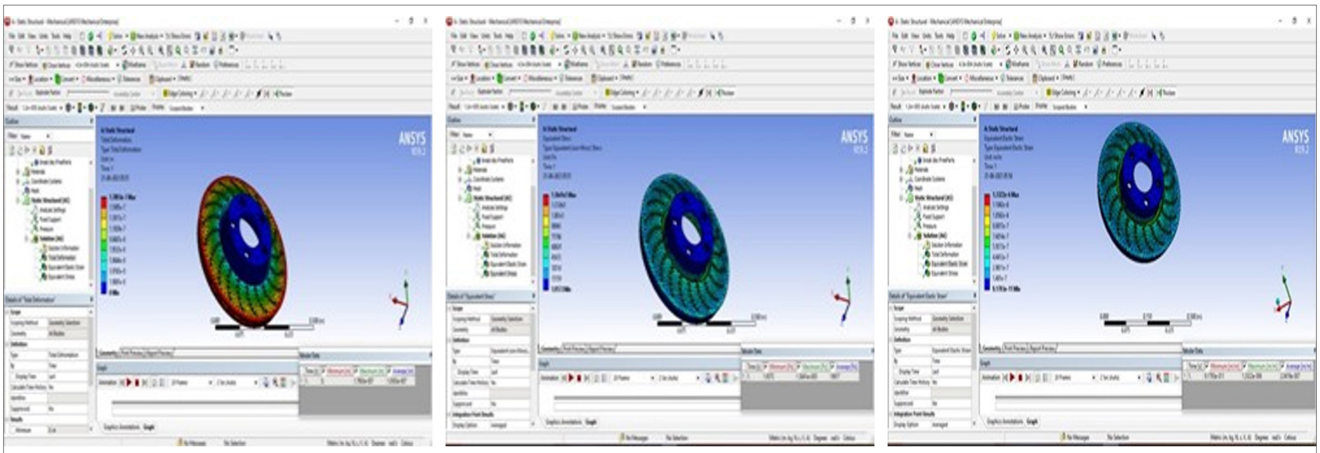
Conflict of Interest

None.



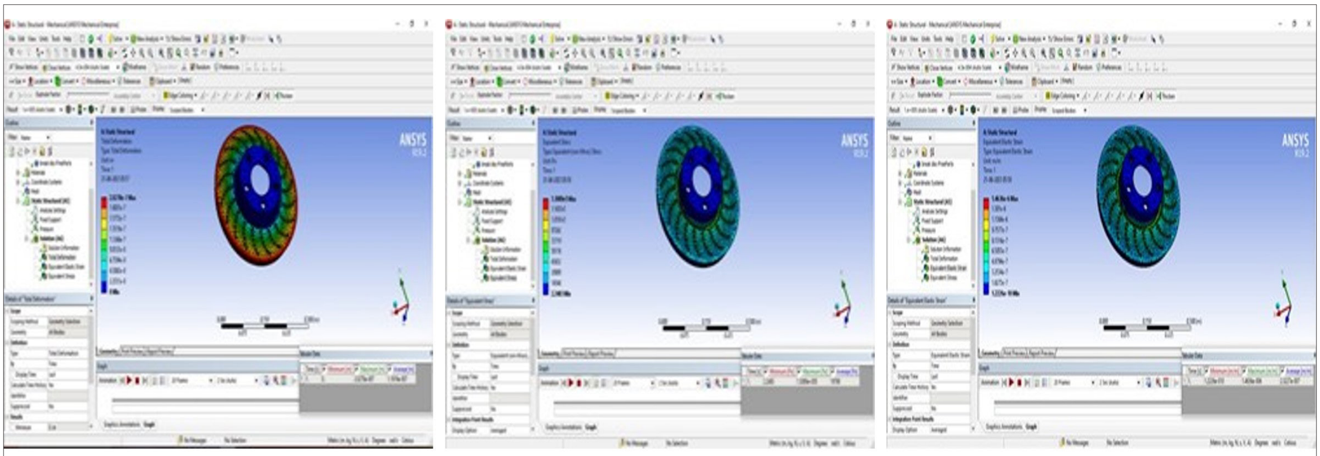
(a) **(b)** **(c)**

Figure 7: Results of ceramic alloys: **(a)** Deformation, **(b)** Stress, and **(c)** Strain.



(a) **(b)** **(c)**

Figure 8: Results of titanium alloy: **(a)** Deformation, **(b)** Stress, and **(c)** Strain.



(a) **(b)** **(c)**

Figure 9: Results of copper alloy: **(a)** Deformation, **(b)** Stress, and **(c)** Strain.

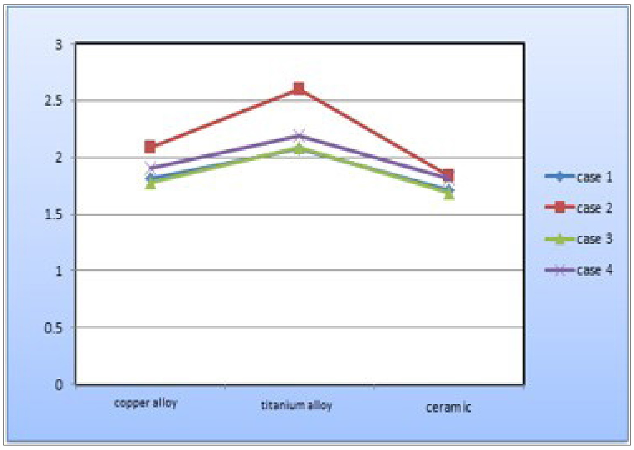


Figure 10: Deformation plot.

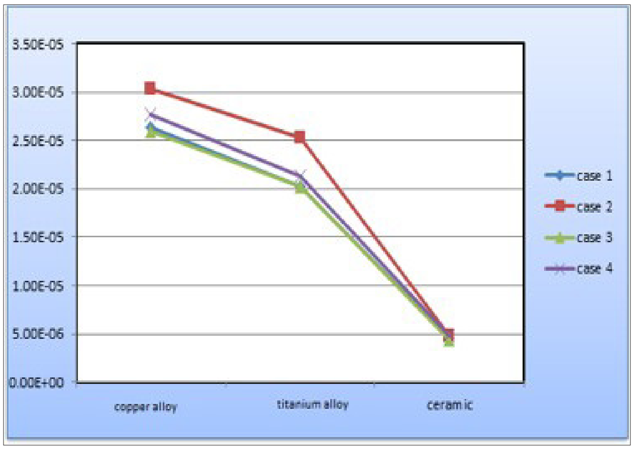


Figure 11: Stress plot.

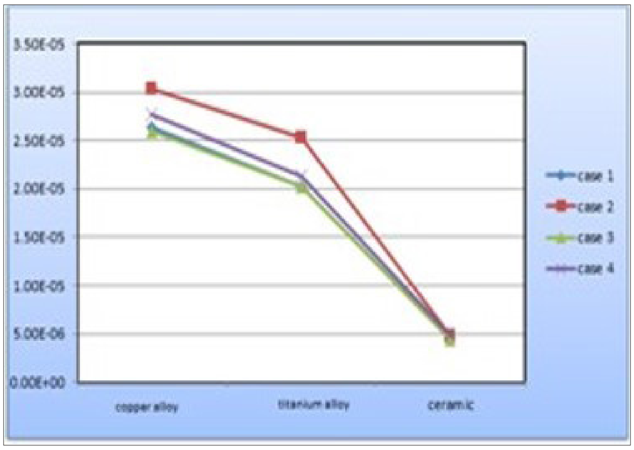


Figure 12: Strain plot.

References

1. Radhakrishnan C, Yokeswaran K, Vengadeshprasadh M, Vishnuhasan A, Vimalraj T, et al. 2015. Design and analysis of disc brake with titanium alloy. *Int J Innov Sci Eng Technol* 2(5): 1044-1050.
2. Ahmed AA, Kumar VA, Gokul S, Vijay P, Parthasarathy C. 2020. Design and analysis of disc brake rotor using different profiles. *Int J Eng Appl Sci Technol* 4(9): 286-293.
3. Nagabhaskar C, Rao KP, Krishna RV, Kanth VL. 2020. Performance and thermal analysis of various functional graded materials (FGM) of disc brake system by FEM. *Open Access Int J Sci Eng* 5(8): 71-82.
4. Vardhan VM, Renita KR, Kumar SH. 2023. Hand gestures controlled intelligent wheelchair with device switch. *NanoWorld J* 9(S1): S1-S5. https://doi.org/10.17756/nwj.2023-s1-001
5. Mukkoti VV, Mohanty CP, Gandla S, Sarkar P, Rao PS, et al. 2020. Optimization of process parameters in CNC milling of P20 steel by cryo-treated tungsten carbide tools using NSGA-II. *Prod Manuf Res* 8(1): 291-312. https://doi.org/10.1080/21693277.2020.1790436
6. Chintala S, Raju LB, Chintalapudi R, Babu VV, Nagaraj S. 2023. Thermal analysis of functionally graded disc brake using FEA techniques. *AIP Conf Proc* 2492(1): 020027. https://doi.org/10.1063/5.0113304
7. Amrish PN. 2016. Computer aided design and analysis of disc brake rotors. *Adv Automob Eng* 5(02): 1-13.
8. Krishna MNV, Babu KS, Kondaiah G. 2023. A disc brake design and analysis by using functional graded materials. *J Optoelectron Laser* 42(1): 88-98.
9. Radhakrishnan C, Yokeswaran K, Vengadeshprasadh M, Vishnuhasan A, Vimalraj T, et al. 2015. Design and analysis of disc brake with titanium alloy. *Int J Innov Sci Eng Technol* 2(5): 1044-1050.
10. Rashid A. 2014. Overview of disc brakes and related phenomena-a review. *Int J Veh Noise Vib* 10(4): 257-301. https://doi.org/10.1504/IJVNV.2014.065634