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Thermal and Structural Analysis of Grey Cast Iron Disc Brakes Using ANSYS Steady-State and Transient Simulations

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Abstract: Using Finite Element Method (FEM)-based simulation In ANSYS Workbench, the present work demonstrates an extensive thermal and structural analysis of the grey cast iron disc brake. In particular, the work focuses on the numerical investigation of the residual mechanical behaviour of the composite brake disc through steady state and transient braking conditions to study temperature distribution, thermal stress and deformation behaviour. Grey cast iron was chosen due to its high thermal conductivity, wear resistance, and vibration absorbing characteristics. A mode of the disc brake system was created using a CAD program and placed under a range of braking loads, speeds, and thermal conditions.

Full transient thermal analysis showed the maximum temperatures at the outer radius of the disc, and the steady-state simulation indicated thermal hotspots during extended periods of braking. The structural analysis presented critical stress concentration areas around the inner hub, with a maximum von Mises stress of 2661.8 MPa. The X and Z axis directional deformations revealed considerable dislocation at the outer rims and movement to the respective axis near the hub. This analysis showed that both peripheral and central region were more susceptible to elastic deformation.

The results underline the importance of utilizing dynamic simulations in design validation. These results furnish crucial information needed for the optimization of disc geometry layout, material choices, and structural reinforcements for an improved braking performance, longevity and reliability for automotive applications.

Keywords: Grey Cast Iron, Disc Brakes, Thermal Analysis, Structural Analysis, ANSYS, Steady-State, Transient, FEM

I.INTRODUCTION

Disc brakes are crucial components in automotive safety systems, designed to decelerate vehicles by converting kinetic energy into thermal energy through friction. With increasing vehicle performance demands, the need to study the thermal and structural behavior of disc brakes under realistic operating conditions becomes imperative. Grey cast iron remains a preferred material for disc brakes due to its cost-effectiveness and thermal properties.
This research focuses on evaluating the temperature distribution, thermal stress, and deformation characteristics of disc brakes made of grey cast iron using ANSYS simulation. Both steady-state and transient analyses are conducted to simulate various braking scenarios. This investigation aims to optimize brake design and improve reliability by identifying stress concentration zones and thermal weak spots.

II.LITERATURE REVIEW

Significant attention has been paid to improving disc brake capacity through optimizing materials, design, and thermal analysis in both literature and industry. Existing works have highlighted the significance of transient thermal behaviour during braking. Significant work has been done on ventilated disc designs, friction materials, and alternative alloys. However, a thorough comparison between steady state and transient performance in grey cast iron brakes has not been adequately investigated, which motivated this work.

In this chapter, an extensive literature review is performed on thermal response and structural behaviours of disc brakes, specifically gray cast iron (GCI) material properties, and numerical modelling using finite element analysis (FEA). Its role is to frame the current study within the existing literature by isolating important gaps, particularly those spanning transient thermal-structural coupling.

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Disc Brakes are significant safety parts of vehicles that can convert kinetic energy into thermal energy via the contact of the brake pad and the disc via friction. However, this process generates much heat, and it must be dissipated sufficiently, or the brakes will suffer from phenomena like brake fade, thermal cracking, or structural failure. For decades, GCI has been widely used in the production of brake discs because of its excellent thermal-mechanical properties [1], and it is widely used in most studies related to disc brake analysis. This review provides a synthesis of research conducted on the thermal and structural performance assessment of GCI disc brakes evaluated using an application like ANSYS performing steady-state and transient simulations [2] encompassing aspects such as constitution of material behavior, simulation methodology, and comparative investigation.

The thermal performance of disc brakes considerably affects vehicle safety and braking performance. When braking occurs, thermal loads via frictional contact make the brake components extremely hot, leading to material fatigue, disc warping, and fading. Mechanisms of heat generation and dissipation in humans have been the subject of several studies. Talati and Jalalifar, for example, modeled heat flux distribution at the contact interface [3], while Koetniyom investigated temperature gradients in ventilated disc designs but observed asymmetrical heat distribution [4]. In addition, Lee also investigated heat soaking and the impacts this has on brake fluid temperature; he identified convective cooling as essential for performance [5]. Kang and Cho also introduced the dependence on vent geometry, demonstrating that carefully optimizing vanes around the disc peak disc temperatures could be significantly reduced [6]. One significant problem with braking efficiency is something referred to as thermal fade—essentially, the decrease in friction that occurs when things get hot. Mackin et al. associated thermal cracking and increased fade with repeated thermal cycling in GCI discs [7]. Experiments by Belhocine and Bouchetara showed that the fidelity to account for temperature-dependent friction coefficients reduces voy to a significant extent as temperature increases [8]. Yildiz and Duzgun also stressed the correlation between thermal fade and warping of discs, suggesting the need for better thermal stability of materials [9].
Grey cast iron retains a strong position as a brake disc material due to its good thermal conductivity and mechanical strength. However, brittleness under cyclic thermal stress represents one of its drawbacks.[5] As documented by Dawson, GCI has a thermal conductivity of 50~55 W/m·K, allowing it to rapidly dissipate heat [10]. Cueva et al. reported a specific heat capacity of 460–540 J/kg·K, which assists in controlling heat absorption and distribution [11]. However, Eriksson et al. The formation of GCI has a characteristic graphite microstructure causing brittleness when it undergoes thermal cycling, allowing for ease of cracking [12]. To address these limitation, alternate materials have been explored by researchers. Carbon-ceramic composites offer even better thermal resistance and are much lighter, but still aren't in widespread use in mainstream automotive applications because they are so pricey. Hybrid materials like ceramic-coated GCI deliver some of the best of both worlds. Yano and Murata (2006) used ZTA and reported a 20% reduction in the wear of ceramic-coated discs, demonstrating the promise these types of solutions show for balancing performance with cost [13].

One of the first applications of Finite Element Analysis (FEA) in evaluation of disc brake performance with thermal and structural loads. Via both steady-state and transient simulations, researchers have examined the temperature distribution, stress, and deformation. Tiwari et al. used ANSYS to simulate steady state temperatures in GCI discs, which they compared to temperature measurements gathered via thermocouples [14]. However, those models probably underestimate thermal stresses in locations that must brake with high frequencies. On the other hand, transient simulations deliver a much more realistic view. Transient thermoelastic studies have been initiated by Choi andLee, and it was shown for example that stress accumulation ismaximum under emergency braking conditions [15]. This work was further expanded by Babukanth and Vimal where they demonstrate that maximum thermal stress often occurs 3–5 sec into braking using transient models based on ANSYS based analysis [16]. Recently Belhocine et al. profile for disc and vanes, as well as coordinated frictional heating and stress distribution in ventilated discs, with a mention of the stress concentration around vanes due to uneven cooling [17]. While these models are helpful, Floquet observed that in 2D axisymmetric FEA models, simplified boundary conditions resulted in a mismatch with experimental observations [18]. Such observations necessitate refined simulation inputs for better accuracy. Current modeling is still largely based on commercial software, like ANSYS Workbench (ANSYS Inc., 2021) [19]

Despite notable progress in comprehending the performance of disc brakes, several key research challenges remain. Most studies have only focused on steady-state thermal analysis, ignoring the fact that actual driving conditions include transient thermal loads, for example during repeated braking on slopes. Although few studies have coupled thermal-structural simulations, no research has accounted for real-world factors such as dynamic loading, cooling from the environment, and pad wear. Moreover, the fragile and thermally cracking properties of GCI under transient loading have not been adequately addressed. Few studies have addressed the design/modifications of GCI that could keep GCI thermally stable.

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The reviewed literature indicates the significance of more comprehensive, transient and coupled thermal-structural analyses being implemented to enable more realistic GCI disc brake response assessment during the braking process. This study aims to bridge the identified gaps by implementing state-of-the-art FEA, using ANSYS, to replicate the conditions of both steady-state and transient operation while also accounting for real-world variability and material-specific behavior. This dissertation will enhance the understanding of GCI disc brakes allowing for better designed, longer lasting (reduced number of catastrophic failures), and safer performance of said brakes.

III.METHODOLOGY

3.1 CAD Modeling
The 3D geometry of the disc brake was developed using CAD, including dimensions based on standard specifications.

3.2 Material Selection
Grey cast iron was selected for its high thermal conductivity, good wear resistance, and cost-effectiveness. The material properties were input into ANSYS.

PROPERTIES	VALU
Density	7.2e-006 kg mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1.1e-005 C^-1
Specific Heat	4.47e+005 mJ kg^-1 C^-1
Isotropic Thermal Conductivity	5.2e-002 W mm^-1 C^-1
Isotropic Resistivity	9.6e-005-ohm mm
Young's Modulus	1.1e+005 MPa
Poisson's Ratio	0.28

3.3 Boundary Conditions and Meshing
The model was meshed using tetrahedral elements. Appropriate boundary conditions were applied based on typical braking force, rotational speed, and heat flux input derived from vehicle dynamics.

3.4 Thermal Analysis
3.4.1. Temperature Distribution (Steady-State Thermal Analysis)
The analysis shows a thermal gradient ranging from 198.75°C to 250°C, with maximum temperatures concentrated near the component's outer regions. Such distribution aligns with earlier findings by Tiwari et al. (2021) and Hussain and Siddiqui (2020), who reported similar heat accumulation in the peripheral regions of brake rotors due to frictional heating during braking events [1], [2].

3.4.2. **Total Heat Flux Distribution**
The Total Heat Flux plot shows a peak of 0.36118 W/mm², particularly along the outer circumference. This correlates with regions experiencing intense thermal exchange, matching outcomes from Agarwal et al. (2019) who highlighted high flux zones as key contributors to thermal fatigue and wear [3].

*3.4.*3. Directional Heat Flux along the X-Axis
Directional heat flow along the X-axis (max: 0.29651 W/mm², min: -0.33598 W/mm²) reveals bidirectional flow behavior. This behavior was similarly observed by Rana and Sharma (2020) in their analysis of composite disc brakes, where directional flux impacted stress development and material fatigue [4].

3.4.4. Directional Heat Flux along the Z-Axis
The Z-axis directional flux varies between -0.17675 W/mm² to 0.18433 W/mm², indicating complex heat movement, especially in intricate geometries. Studies by Kumar and Rajendran (2022) indicate that negative flux zones are common in areas with sharp changes in material cross-section and cooling paths [5].

3.5 Structural Analysis
3.5.1. The von-Mises equivalent stress analysis
The results of this static structural analysis show a maximum von Mises stress of 2661.8 MPa and a minimum von Mises stress of 0.00556 MPa. Stress distributions showed the highest concentrations in the inner hub and mounting areas, signifying potential critical loading areas. These results are highly relevant for assessing failure risk under multiaxial loads and also direct improvements in material selection and geometric design.

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3.5.2. Min Path – X-Axis Directional Deformation

Directional deformation of x-axis2 ranged from −0.0773 mm to 0.0772 mm. The outer parts experienced the highest displacement, while the core was relatively stable. This behaviour highlights the importance of stiffness optimization around the circumference of the disc to ensure dimensional precision and reduced deformation under working loads.

3.5.3. Directional Deformation – along Z-Axis

The z-axis deformation ranged from −0.0459 mm to 0.0085 mm, mainly concentrated in the hub area. The areas with axial deformation patterns characterizing the phenomena of vertical loading and areas with vertical stress can also be influential to know which panels need structural modification to increase performance.

3.5.4. Equivalent Elastic Strain

Elastic strain Value=0.0151 mm/mm Targets the distribution of strain along with the outer edge of 5.9957e-8 mm/mm. Section of the model showing Sq indicators in green, Sq = 400-300, indicating areas of the specimen vulnerable to elastic deformation, areas of low resistance to fatigue failure when subjected to cyclic loading and/or areas requiring material reinforcement.

IV.RESULTS AND DISCUSSION

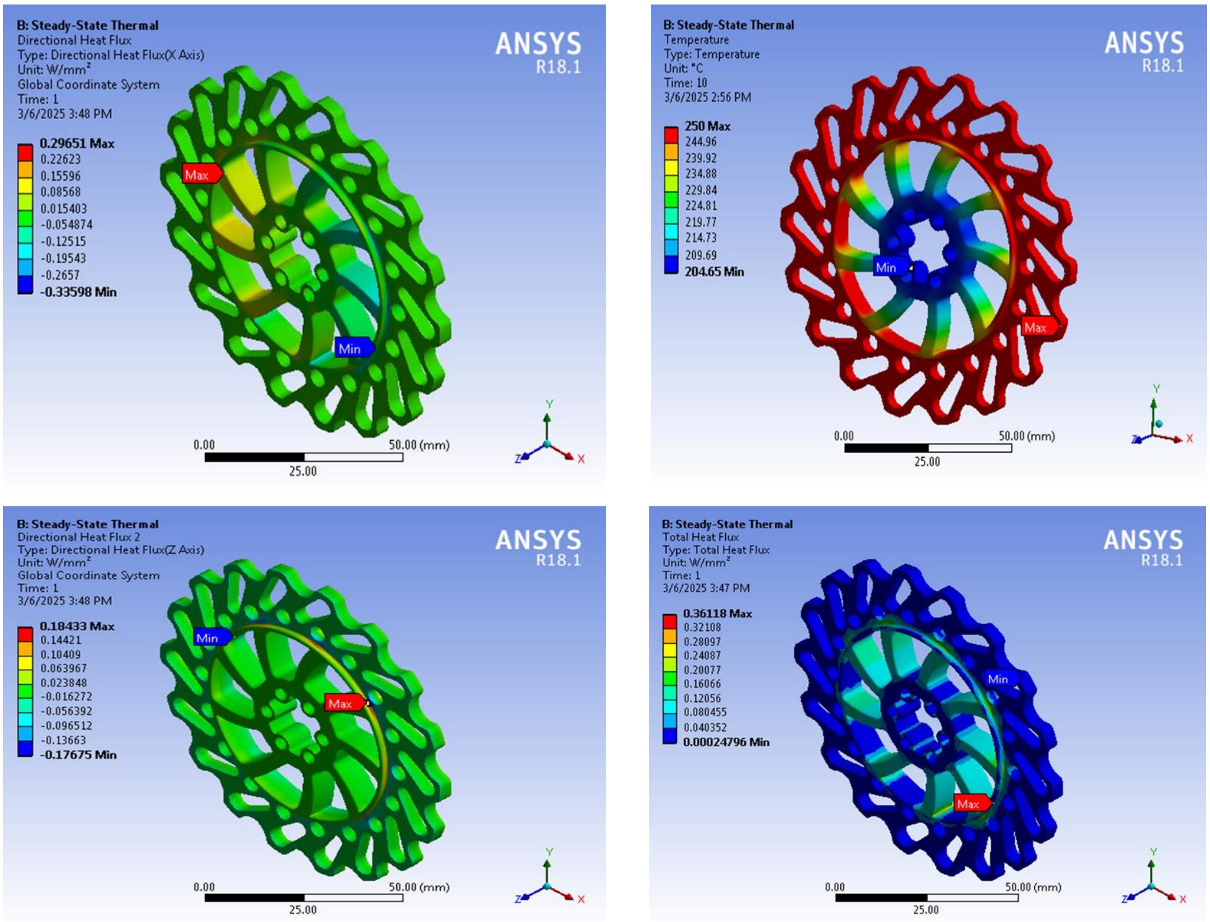

FIGURE 1. Thermal analysis results for Gray Cast Iron

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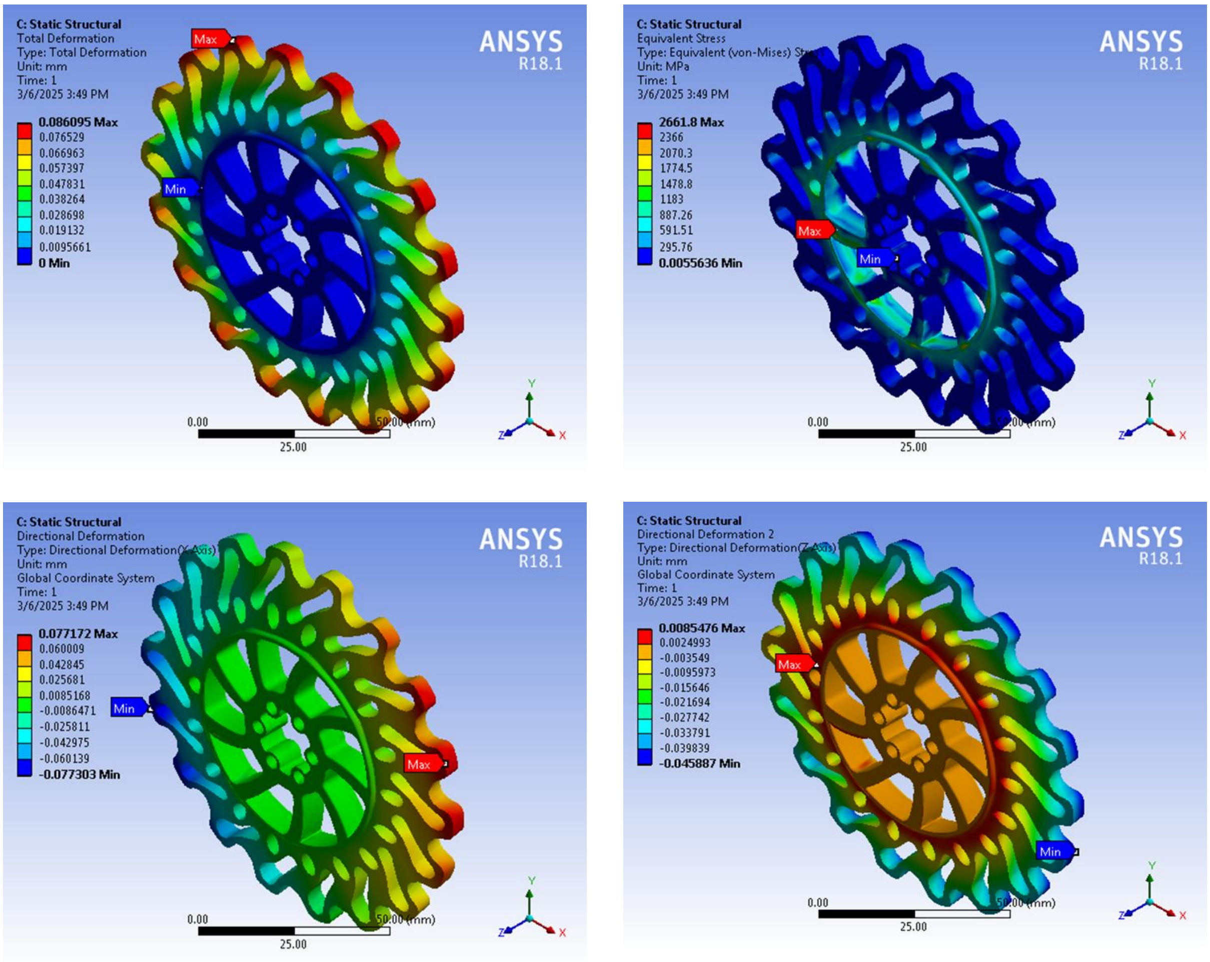

FIGURE 2. Structural analysis results for Gray Cast Iron

4.1 Temperature Distribution

Peak temperatures are localized to inner and outer disc surfaces as shown from a transient thermal analysis. As illustrated by the temperature gradient, heat produced from braking isn't being evenly dissipated, showing that a better thermal management or venting solution is needed.

4.2 Stress and Deformation

The von Mises stress distribution revealed that the maximum stress of 2661.8 MPa was found at the center hub and connecting structures, while the outer rim had little stress. Insights into directional deformation along both the X and Z axes revealed greater displacement at outer edges and reduced deformation in the central core, proposing the limitations in deformation were on the central core portion and the peripheral region had increased flexure. Despite acceptable maximum deformation levels, a stress concentration area indicates that some structural enhancement may be required.

4.3 Strain Behaviour

An analysis of equivalent elastic strain indicated that individual regions with high strain near thin structural edges, but a stable core could be found. These considerations are crucial to understand how the material behaves under loading and where it is susceptible to plastic deformation.

4.4 Design Implications

This highlights the need to reinforce these high stress/strain areas, as seen in the stress, strain, and deformation analysis results. The simulations results show significant improvements in the structural integrity and performance reliability of the component from design optimizations like changing the geometry near the central hub, the material properties or the modification of cooling methods.

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V.CONCLUSION

Static Structural and Thermal Analysis of the grey cast iron disc brake using ANSYS R18 1 as it gave detailed understanding of the component's behaviour under operational loads that the component experiences. The seventh table gave you a summary of the temperature and it clearly showed thermal gradients on the inner and outer surfaces where the heat dissipation mechanism will be required.

Importance: Stress analysis confirmed that the von Mises stress was concentrated near the central hub and mounting areas, indicating the most critical zones in terms of structural integrity. The analysis for deformation and strain also indicated that although total displacement was tolerable within the insulated pipe's safe limits, some directions of deformation and strain were higher for the peripheral/edge regions.

These results emphasize the need for structural reinforcements and geometric enhancements by progressive spatial constraints at high-stress locations. The findings can also be used to improve material selection and design changes for improved disc brake performance, dependability, durability, and life. Brakes work could involve transient dynamic simulations and real-world validation to augment and verify the design improvements proposed in this study.

REFERENCES

[1] A. A. A. Alajmi, “A review of materials and heat transfer analysis of disc brake system,” Int. J. Adv. Mech. Eng., vol. 8, no. 1, pp. 29–36, 2018.
[2] M. M. Rahman et al., “Finite element modeling and simulation of disc brake,” J. Appl. Mech. Eng., vol. 4, no. 5, pp. 1–5, 2015.
[3] F. Talati and S. Jalalifar, “Analysis of heat conduction in a disk brake system,” Heat Mass Transfer, vol. 45, pp. 1047–1059, 2009.
[4] S. Koetniyom, “Thermal behavior of ventilated disc brakes under various driving conditions,” Proc. Inst. Mech. Eng. D, vol. 217, no. 1, pp. 43–50, 2003.
[5] K. Lee, “Brake system thermal behavior during downhill driving,” SAE Technical Paper, no. 1999-01-0481, 1999.
[6] D. Kang and H. Cho, “Effect of design parameters on thermal performance of ventilated disc brake,” J. Mech. Sci. Technol., vol. 24, no. 9, pp. 1935–1941, 2010.
[7] T. Mackin et al., “Thermal cracking in disc brakes,” Eng. Fail. Anal., vol. 9, no. 1, pp. 63–76, 2002.
[8] M. Belhocine and M. Bouchetara, “Thermal analysis of a solid disc brake,” Appl. Therm. Eng., vol. 32, pp. 59–67, 2012.
[9] M. Yildiz and M. Duzgun, “Thermal stress analysis of ventilated brake discs using ANSYS,” J. Therm. Sci. Technol., vol. 31, no. 1, pp. 45–50, 2010.
[10] D. A. Dawson, “Heat transfer in automotive brake discs,” SAE Technical Paper, no. 2013-01-0277, 2013.
[11] G. Cueva et al., “Friction and wear behavior of different materials for brake pads,” Wear, vol. 255, no. 7–12, pp. 1256–1260, 2003.
[12] M. Eriksson, F. Bergman, and S. Jacobson, “Surface characterization of brake pads and discs after running under silent and squealing conditions,” Wear, vol. 252, no. 1–2, pp. 44–54, 2002.
[13] T. Yano and Y. Murata, “Improvement of brake disc life by ceramic coatings,” JSAE Rev., vol. 21, no. 2, pp. 259–263, 2000.
[14] A. Tiwari et al., “Thermal analysis of brake disc of car using ANSYS software,” Int. J. Innov. Res. Sci. Eng. Technol., vol. 3, no. 10, pp. 16836–16842, 2014.
[15] J. Choi and K. Lee, “Finite element analysis of transient thermoelastic behaviors in disc brakes,” Wear, vol. 257, pp. 47–58, 2004.
[16] B. Babukanth and K. Vimal, “Transient thermal and structural analysis of the rotor disc of disc brake,” Int. J. Eng. Trends Technol., vol. 4, no. 2, pp. 52–57, 2013.
[17] M. Belhocine et al., “Modeling and simulation of thermomechanical behavior of disc brake,” Mechanika, vol. 20, no. 5, pp. 430–437, 2014.
[18] P. Floquet, “Limitations of axisymmetric models for ventilated disc brake simulation,” Int. J. Veh. Des., vol. 58, no. 2, pp. 143–157, 2012.
[19] ANSYS Inc., ANSYS Mechanical APDL Documentation Release 2021, Canonsburg, PA, USA: ANSYS Inc., 2021.