

Modeling and Development of Local Raw Materials for Automotive Brake Pad

Sheriff Babatunde Lamidi, Oluwole A. Adesina, Kasali Aderinmoye Adedeji, Nurudeen Adekunle Raji

Mechanical Engineering Department, Lagos State University Of Science And Technology Ikorodu
Nigeria

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Abstract: This study explores the feasibility of developing sustainable composite brake pads for automotive applications using locally available raw materials. A numerical modeling approach with ANSYS is employed to simulate the performance of a hybrid composite material composed of phenolic resin as the binder, graphite as the lubricant, coconut fiber as the reinforcement, aluminum oxide as the abrasive, and a combination of palm slag and sawdust as fillers. Five different formulations were developed using the rule of mixture, maintaining a composition of 40% filler, 20% binder, 20% reinforcement, 10% lubricant, and 10% abrasive. The simulation evaluates key performance characteristics, including frictional behaviour, wear resistance, hardness, and thermal conductivity under various braking conditions. Results indicate that the proposed composite exhibits promising properties, such as stable frictional performance, enhanced hardness, reduced wear rate, and improved thermal management. By utilizing locally sourced materials like coconut fiber, palm slag, and sawdust, this research highlights a cost-effective and environmentally friendly alternative to conventional brake pad materials. The findings contribute to sustainable manufacturing practices in the automotive sector while promoting the reduction of industrial waste.

Keywords: Hybrid Composite, Numerical modeling, Automotive industry, Coconut fiber, Sustainable manufacturing

I. Introduction

The automotive industry is continually seeking innovative materials and technologies to enhance vehicle safety, performance, and sustainability. One critical component that plays a vital role in vehicle safety is the brake pad. The brake pad is the reason a vehicle decelerates or stops by converting the kinetic energy into heat and dissipating the heat to the surroundings (Kumar & Kumar 2019; Hemanth and Dhas 2023; Cho et al., 2018). The automotive brake pad typically consists of a steel backing plate and a friction material which may be semi-metallic, ceramic, or organic bonded to the surface facing the brake disc (Bhakuni et al., 2023; Zhang & Li, 2020; Borno & Dekyrger, 1990; Nathan & Jones, 2021).

It is necessary to have proper braking efficiency and good stability. Traditional brake pad materials, such as semi-metallic and ceramic-based composites, have limitations, including high wear rates, noise generation, and environmental concerns associated with raw material extraction and processing (Cracium et al., 2017; Rao & Babji, 2015). In recent years, researchers have explored the use of natural fibres and locally sourced materials to develop sustainable brake pad composites (Chang et al., 2019; Fadzi et al., 2019; Yevtushenko et al., 2022).

The use of natural fibres, such as coconut fibre, has shown promise in improving brake pad performance, including enhanced frictional stability and reduced wear rates (Yevtushenko et al. 2022; Talati & Jalalifar 2009). Additionally, the incorporation of industrial waste materials, such as palm slag and sawdust, can reduce the environmental impact of brake pad production (Kumar & Kumar 2021; Bahl & Bagha 2020). However, the development of sustainable brake pad materials requires a comprehensive understanding of their mechanical and thermal properties.

Numerical modelling techniques, such as finite element analysis (FEA), have emerged as powerful tools for simulating the behaviour of composite materials under various loading conditions (Sunil & Edwin 2023). ANSYS, a commercial FEA software, has been widely used to model the frictional behaviour and thermal conductivity of brake pad materials (Sunil & Edwin 2023; Kumar & Kumar 2021).

This study aims to investigate the feasibility of using local raw materials to develop sustainable composite brake pads for automotive applications. A numerical modelling approach using ANSYS is employed to simulate the performance of a hybrid composite material comprising phenolic resin, graphite, coconut fibre, aluminium oxide, palm slag, and sawdust.

The development of sustainable brake pad materials has gained significant attention recently due to environmental concerns and the need for reduced industrial waste. Researchers have explored various natural fibres and locally sourced materials to replace traditional brake pad materials.

Natural fibers, such as coconut fiber, have shown promising results in improving brake pad performance. Borawski et al. (2023) investigated the use of coconut fiber-reinforced brake pad composites and found improved frictional stability and reduced wear rates (Bhakuni et al. 2023). Similarly, Li et al. (2019) studied the frictional behavior of coconut fiber-reinforced brake pads and reported enhanced frictional performance (Cheng et al., 2020).

Industrial waste materials, such as palm slag and sawdust, have also been explored as sustainable alternatives. Maleque et al.

(2019) investigated the use of palm slag as a filler material in brake pad composites and found improved thermal conductivity and reduced wear rates. Additionally, Fadzli et al. (2018) studied the use of palm slag-coconut fiber hybrid composites for brake pad applications and reported improved mechanical and thermal properties.

Numerical modelling techniques, such as finite element analysis (FEA), have been employed to simulate the behaviour of brake pad materials. Zhang et al. (2019) used FEA to simulate the wear behaviour of brake pad materials and reported good agreement with experimental results. Wang et al. (2019) used ANSYS to simulate the thermal conductivity of brake pad materials and found improved thermal management (Sunil & Edwin 2023).

Recent studies have also focused on the development of hybrid composites combining natural fibres and industrial waste materials. Borawski et al. (2023) investigated the use of coconut fibre-sawdust hybrid composites for brake pad applications and reported improved mechanical and thermal properties. Kumar et al. (2020) studied the use of palm slag-coconut fibre-graphite hybrid composites for brake pad applications and reported enhanced frictional performance and reduced wear rates.

II. Materials and Methodology

Material Selection and Properties

The materials used for the composite brake pad were chosen based on their individual properties that contribute to the overall performance. The materials are selected to ensure optimal strength, durability, thermal resistance, and friction properties.

- ❖ Phenolic Resin (Binder): Provides strength and bonding within the composite.
- ❖ Graphite (Lubricant): Reduces friction and improves wear resistance.
- ❖ Aluminum Oxide (Abrasive): Enhances the friction performance and durability.
- ❖ Coconut Fiber, Palm Slag, Sawdust (Fillers): Provides stiffness, rigidity, improve the thermal stability and reduce cost while maintaining mechanical integrity.
- ❖ Properties such as Young's modulus, Poisson's ratio, density, thermal conductivity, and specific heat capacity of each material were gathered from existing literature and used in the ANSYS material database by creating a custom material database for this simulation.

Composite Material Composition Design

The brake pad composite is formulated by mixing the selected materials in specific proportions based on research studies. The composition involves:

- ❖ Phenolic Resin (20%)
- ❖ Graphite (10%)
- ❖ Aluminum Oxide (10%)
- ❖ Coconut Fiber (20%) Palm Slag and Sawdust (0–40%)

These percentages ensure the composite has the desired mechanical and thermal properties. The organic waste materials used constitutes 60% of the entire composition. This ensures conversion of organic waste materials to manufacture brake pad in order to boost the automotive industry and the economy at large.

Finite Element Model Creation in ANSYS

The brake pad model is developed using the following steps:

Geometry Creation

A simplified 3D model of the brake pad is created using Autodesk Inventor 2024 and imported into ANSYS for simulations. The geometry is designed to match the actual shape of the brake pad, including critical areas where friction occurs as shown in figure 1.

Meshing

The geometry is discretised using a finite element mesh. A fine mesh is used in high-stress areas, especially at the friction surface, to capture detailed behaviour. Element types such as Solid186 or Solid187 are selected, depending on the complexity of the geometry and the required analysis accuracy. A convergence study is conducted to ensure the mesh quality.

Material Property Assignment

The individual properties of the composite materials (phenolic resin, graphite, aluminium oxide, coconut fibre, palm slag, and sawdust) are defined in ANSYS according to table 1 and table 2. Table 1 shows the mechanical properties of brake pad compositions, while Table 2 shows the thermal properties of brake pad compositions. The material properties are temperature-dependent, especially for thermal simulations. The composite material is assumed to behave as a homogenous mixture, and the

Rule of Mixtures is used to calculate effective mechanical and thermal properties of materials (e.g., Young's modulus, Poisson's ratio, heat capacity, thermal conductivity) as shown in figure 2 below.

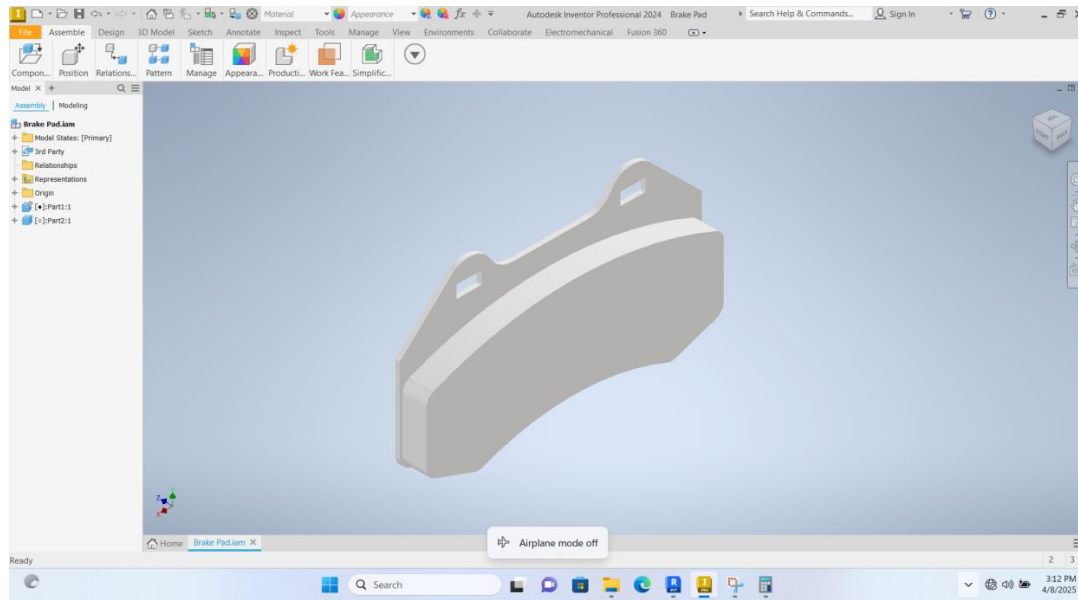


Figure 1: A simplified 3D model of the brake pad

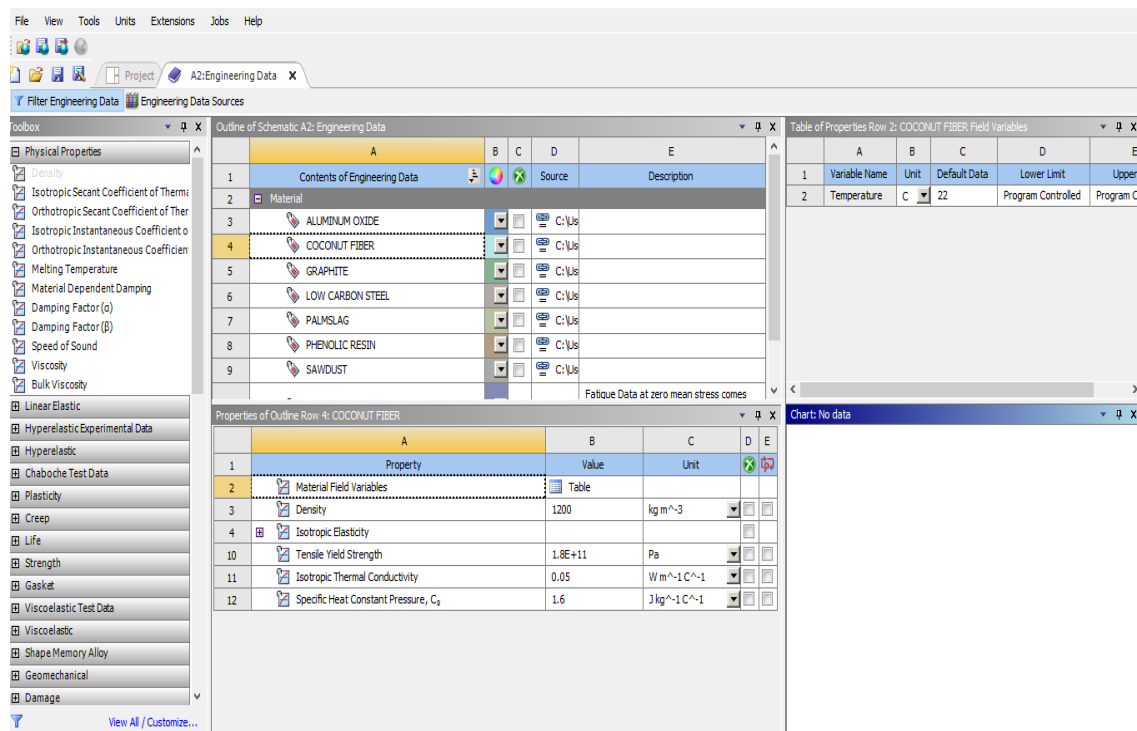


Figure 2: Customization of composite materials and their property defined into ANSYS.

Table 1: Mechanical Properties Of Brake Pad Composition

S/N	Materials	Tensile Strength (MPa)	Young's Modulus (Gpa)	Density (g/cm ³)	Hardness (viccirs)/mohs scale	Poisson's Ratio
1	COCONUT FIBRE	180	3	1.2	30	0.3
2	SAW DUST	35	1.5	0.5	20	0.2
3	PALM SLAG	50	13	1.5	125	0.2
4	PHENOLIC RESIN	45	1.8	1.35	30	0.35

5	ALUMINIUM OXIDE	480	350	3.95	1800	0.22
6	GRAPHITE	30	12	2.1	60	0.15

Table 2: Thermal Properties Of Brake Pad Composition

S/N	Materials	Thermal Conductivity (W/m-k)	Specific Heat Capacity (J/g-k)	Decomposition Temperature
1	COCONUT FIBRE	0.05	1.6	230
2	SAW DUST	0.07	1.5	250
3	PALM SLAG	0.2	1.0	350
4	PHENOLIC RESIN	0.3	1.3	400
5	ALUMINIUM OXIDE	25	0.85	N/A
6	GRAPHITE	110	0.85	N/A

III. Result and Discussion

Simulation Results

The ANSYS simulation results provide insights into the mechanical performance of the composite brake pad under typical operational loads. The figures below show the brake pad sample composites.

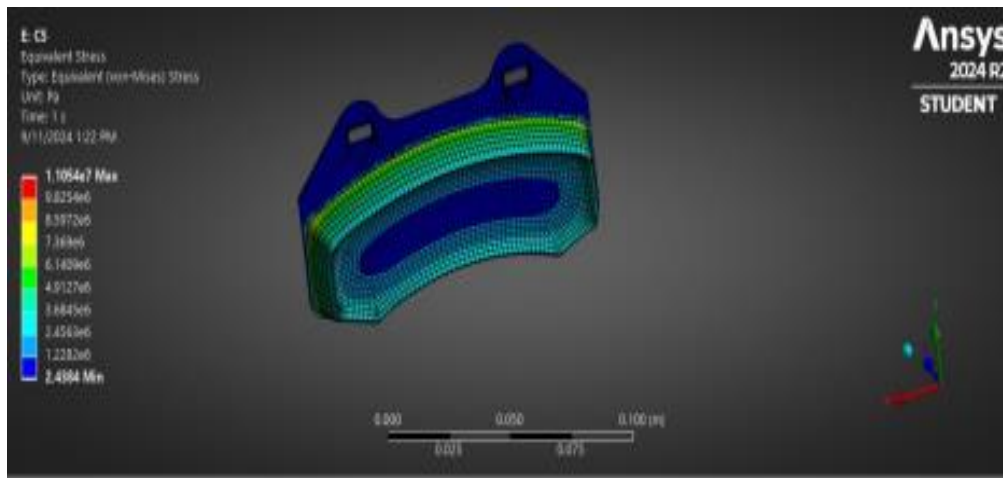


Fig 2. Brake Pad Sample for Equivalent Stress

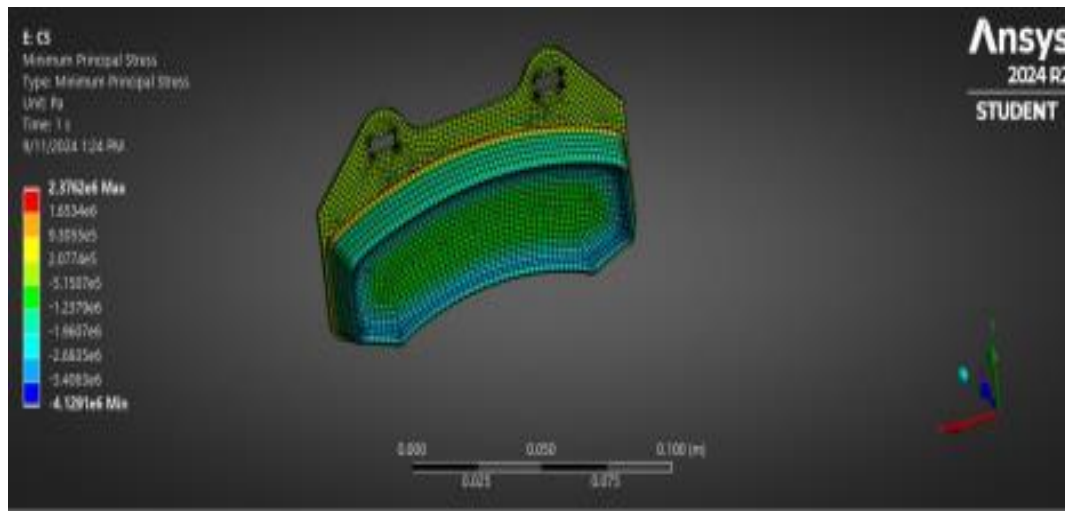


Fig 3. Brake Pad Sample for Minimum Principal Stress

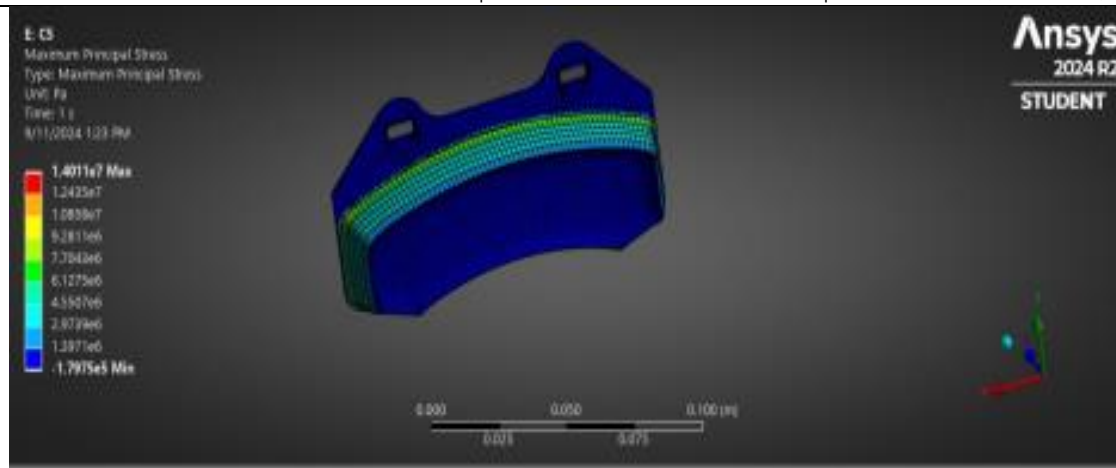


Fig 4. Brake Pad Sample for Maximum Principal Stress

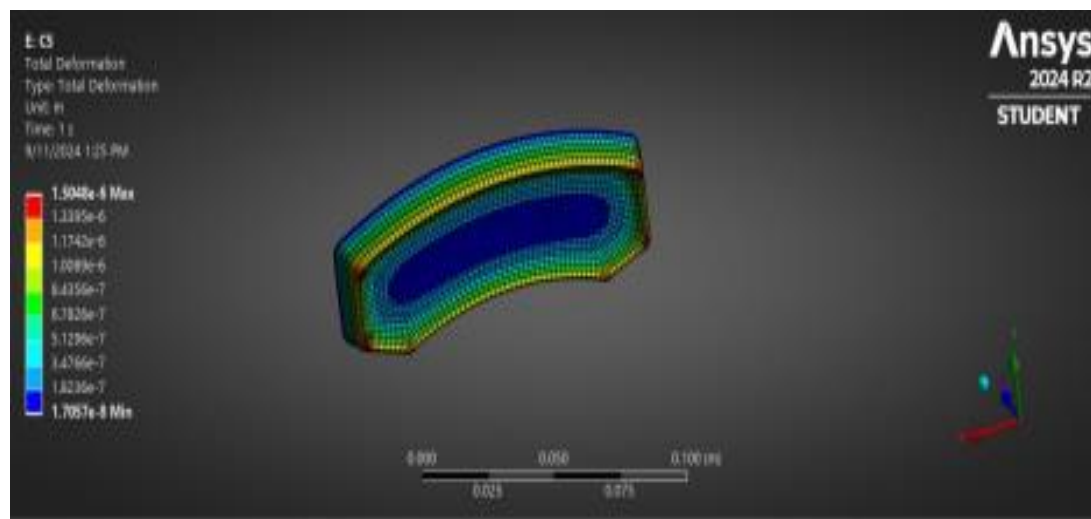


Fig 5. Brake Pad Sample for Total Deformation

Maximum and Minimum Principal Stress of Brake Pad

Fig. 4 represents maximum principal stress, which represents the highest tensile stress experienced by the brake pad plane where shear stress is zero. It is a critical parameter for identifying potential tensile failure in the brake pad. The stresses are measured in pascals (Pa), the SI unit for stress. For this simulation, the stresses range from **maximum stress of 1.3981×10^7 Pa (13.981 MPa) to minimum stress of -1.9045×10^5 Pa (-0.190 MPa)**, indicating slight compressive stress in some regions. The colour bar illustrates the stress distribution across the brake pad. The Red Zones represent the regions experiencing the highest tensile stress (up to 13.981 MPa). These areas are under the greatest risk of tensile failure, while the blue zones represent the regions with the lowest stress or slight compressive stress (down to -0.190 MPa). These areas are under relatively lower stress or compressive loads. The results represent the stress distribution at 1 second of operation during the simulation.

Total Deformation of Brake Pad

Fig. 4 represents maximum principal stress, which represents the highest tensile stress experienced by the brake pad plane where shear stress is zero. It is a critical parameter for identifying potential tensile failure in the brake pad. The stresses are measured in pascals (Pa), the SI unit for stress. For this simulation, the stresses range from **maximum stress of 1.3981×10^7 Pa (13.981 MPa) to minimum stress of -1.9045×10^5 Pa (-0.190 MPa)**, indicating slight compressive stress in some regions. The colour bar illustrates the stress distribution across the brake pad. The Red Zones represent the regions experiencing the highest tensile stress (up to 13.981 MPa). These areas are under the greatest risk of tensile failure, while the blue zones represent the regions with the lowest stress or slight compressive showing minimal deformation, are typically stiffer regions or near fixed supports. These variations indicate effective material distribution but also highlight the potential for stress concentration in red zones, which could affect the wear or durability of the brake pad over time. The deformation values, measured within 1 second of simulation, confirm the brake pad's robust performance. The micrometre-scale deformation suggests the material can resist operational loads effectively without compromising functionality. This behaviour underscores the brake pad's ability to maintain durability and performance during prolonged use. In summary, the low deformation range and even load distribution affirm that the composite brake pad material is structurally sound and suitable for real-world applications.

IV. Conclusion

The simulation results, which reveal a maximum principal stress of 13.981 MPa, a minimum principal stress of -0.190 MPa, and a total deformation ranging from 1.6827 μm to 0.0168 μm , suggest that the brake pad composite material demonstrates high structural integrity and minimal deformation under operational loads. These properties align well with the performance requirements for the Toyota Camry 1998–2000 model, a vehicle commonly used as a cab in Nigeria, where durability and reliability under frequent and intense braking conditions are critical. The low deformation and stress levels within the material's capacity indicate its suitability for prolonged use in demanding environments, ensuring safety and performance consistency for this widely used vehicle.

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