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Thermomechanical Analysis of Automotive Brake Pad Materials

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ABSTRACT

Since the brake pad is an essential part of the automotive braking system, it is also very important to research the thermomechanical properties of the materials of brake pad. Composite materials are preferred for use in brake pads, because composite materials have better mechanical and tribological qualities. However, before formulating the composite, the proper selection of matrix material is essential. Comparing the thermomechanical characteristics of the brake pad matrix materials is the goal of this investigation. ANSYS 16.2 was utilized for the materials' finite element analysis (FEA), whereas Solidworks was utilized for modeling. The materials considered in this study are AA6061, AA6082, and AA6005. In conclusion, the AA6061 is the best material to compare with other materials. These findings may aid in the development of improved composite materials to improve the performance of brake pads.

1. Introduction

Braking system is the most important safety part of every vehicle. The ability of the braking system to bring a vehicle to safe controlled stop is absolutely essential in preventing accident vehicle damage and personal injury. Brake pads play a crucial role in the braking systems of vehicles, responsible for converting kinetic energy into heat through friction to slow down or stop the vehicle. Friction between brake disc and pad always oppose motion and the heat is generated due to conversion of the kinetic energy to heat energy. During the braking, plenty of frictional heat is produced between the brake disc and the brake pad can lead to high temperature [1, 2, 3]. This heat can have many effects. High temperatures can accelerate wear and degradation of the brake pad material, which can result in brake fade. Vibrations and noise are produced when materials experience unequal thermal expansion and contraction. The brake pads and discs may experience thermal stress from frequent heating and cooling cycles, which could result in thermal cracking. These fissures may jeopardize the parts' structural stability and increase the chance of failure when braking. In general, an excessive amount of heat buildup can cause a brake failure or loss of power, which presents a major risk to the safety of the car and its occupants. Additionally, this may lead to a decrease in total braking performance and a longer stopping distance [4, 5, 6].

Thus, thermomechanical properties of materials are one of the major elements affecting the operation of the braking system and have a significant impact on brake pad temperature. As a result, investigating the thermomechanical characteristics of brake pad materials is essential.

Thermomechanical analysis (TMA) provides useful dimensional property characterization data for a variety of materials [7]. Although the upcoming organic brake pads may provide an environmentally beneficial alternative, but under normal operating conditions, their mechanical and tribological qualities will not allow them to meet the high wear resistance requirements of a working braking system. Metal matrix composites, on the other hand, provide the best possible combination of desirable physical qualities and minimal environmental effect [8]. Metallic brake pads exhibit a lower wear rate compared to NAO (Non-Asbestos Organic) and semi-metallic brake pads [9]. It is essential to properly select the matrix materials for composite formulation before assembling the composite. While in use, brake pads endure thermal and frictional stresses, leading to performance degradation. Therefore, it is crucial to identify the best material that can manage heat production and withstand a range of mechanical forces.

During extended descents, vehicles often require frequent braking. This continuous braking can cause the friction lining surface to accumulate significant heat, thereby diminishing the braking material's performance and potentially resulting in brake failure [10]. Currently, brake pad development relies on empirical feedback validated through experimental bench tests. However, these test campaigns are time-consuming, costly, and offer limited insight into the underlying phenomena that affect performance metrics such as friction coefficient, durability, and noise etc. To address these challenges, numerical braking models have been developed in recent years. These models must accurately represent experimental conditions to predict current brake system performance and drive future improvements [11].

ANSYS 19 ventilated cast iron brake disc with semi-metallic and organic fiber composite brake pad was used for the computational thermomechanical investigation. Both in the computational simulation and the experimental evaluations, the composite brake pad exhibits less complete deformation and temperature than the semi-metallic pad. The temperature range is influenced by the thermo-physical characteristics of the material used to make brake pads [12]. Thermal stress condition of the wagon's composite brake pad, simulated using the finite element method with solid work. It has been discovered that the largest stresses, which do not beyond the allowable limits, occur in the upper portion of the pad in the contact area between the side plate and the back plate [13]. The analysis in ANSYS of various materials like palm kernel fiber, coconut coir, bamboo, banana peels, etc., focuses on structural analysis under static conditions. Transient conditions over time are also considered. Parameters such as total deformation, equivalent (Von-Mises) stress, and maximum principal stresses are calculated under assumptions of constant hydraulic pressure [14]. In order to determine the appropriateness and cost-effectiveness of stainless steel (SS) discs for an ATV (all-terrain vehicle) brake disc application, thermal and structural evaluations were carried out on SS304, SS321, SS410, and SS310. The disc design was done with SOLIDWORKS, while the static structural and thermal calculations were done with ANSYS Workbench. SS410 is the best material for brake discs since it has better thermal characteristics than SS304, SS321, and SS310. An examination of the strain, peak temperature, equivalent stress, and strain on the SS410 disc yielded important information about its functionality [15]. The simulation aids in predicting the challenging-to-measure interface temperature between the brake pad and disc, which is difficult to measure experimentally. Using ANSYS software, transient thermal analysis was conducted on a ceramic composite brake pad material, varying disc temperatures of 25 °C, 170 °C, 200 °C, 250 °C and 300 °C. The analysis successfully predicted the interface temperature and distribution of the brake pad materials, demonstrating close agreement between predicted and experimental temperature values [16]. The disc brake was studied in terms of temperature distribution, stress fluctuations, and deformation over the rotor profile using a CATIA model and FEA analysis with ANSYS 14.5. Comparing aluminum MMC, mild steel, and cast iron in vented disc brakes with and without holes. Based on the results, aluminum MMC emerged as the optimal material due to minimal deformation [17]. Brake discs were modeled and simulated with five materials: LM13, Ti-6Al-4V, AISI6150, Cast Iron, and Al-SiC MMC. Their temperature distribution, heat flux, and thermal gradient were analyzed. Al-SiC MMC stood out as the lightest material, efficiently dispersing heat over a larger area, showing higher heat flux, and maintaining a lower thermal gradient [18].

These prior investigations looked at the effects of natural fibers, organic fibers, ceramic composites, and semi-metallic materials' thermomechanical characteristics. However, there haven't been any studies assessing the aluminum alloys AA6061, AA6082, and AA6005 materials. Therefore, the purpose of this work is to compare the thermomechanical properties of three aluminum alloys of brake pad.

2. Materials and Methods

This section presents the investigation procedure associated with the design of automotive brake pad from aluminum alloys. The different materials considered for the development of the brake pad are AA6061, AA6082, and AA6005. The study employed finite element analysis (FEA) in ANSYS 16.2 to study the thermomechanical analysis of the aforementioned materials under the required service condition. The investigation began by produced the 3D model of the pad using SolidWorks, whilst the FEA was performed using ANSYS software. The material properties are listed in Table 1. Since the same design model is used in this analysis, the only variables affecting the thermomechanical results are material properties. Figure 1, depicts the designed brake pad. The mesh was constructed and its properties were examined using ANSYS 16.2 software. After importing the brake pad's 3D model designed by solid work into ANSYS Workbench, mesh components were created from a grid of nodes using the finite element method (FEM). The model's behavior under loads and boundary conditions is specified by this mesh. The model of the meshed brake pad is shown in Figure 2, and the fixed support of the model as shown in figure 3.

Table 1. Properties of materials [19, 20, 21, 22].

Materials	Density (g/cc)	Ultimate Tensile strength (MPa)	Thermal conductivity (w /m. k)	Tensile strength yield (MPa)	Compressive yield strength (MPa)	Compressive ultimate strength (MPa)
AA6061	2.7	310	167	276	276	310
AA6082	2.7	290	170	250	240	260
AA6005	2.7	260	189	240	220	260

2.1 Structural Loading and Boundary Condition

The material properties were entered into engineering data in the material setup in ANSYS and then applied to the 3D models of brake pads prior to the completion of the structural simulation of the 3D model. The model's mesh was created. A force of magnitude 5000 N was applied to the brake pad model's front surface while a fixed support was placed on the pad's rear surface [23]. The outcomes were deformation and von Misess stress. The brake pad model's mechanical simulation setup is depicted in Figure 5.

2.2 Thermal Loading and Boundary Condition

The generated 3D model of the brake pad was loaded into ANSYS 16.2 to perform thermal simulation, just like the mechanical simulation. Mesh was then created onto the brake pad model using the same material attributes that were initially established, including thermal conductivity. 500°C temperature was applied to the brake pad model's front surface. The convection option was then applied to the other components of the brake pad model. Ultimately, the solution option was chosen in order to get the intended temperature result.

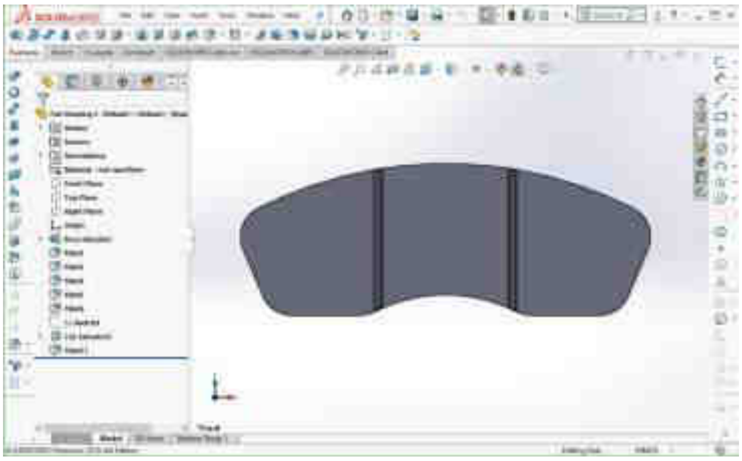

Figure 1. CAD model generated in SOLIDWORKS.

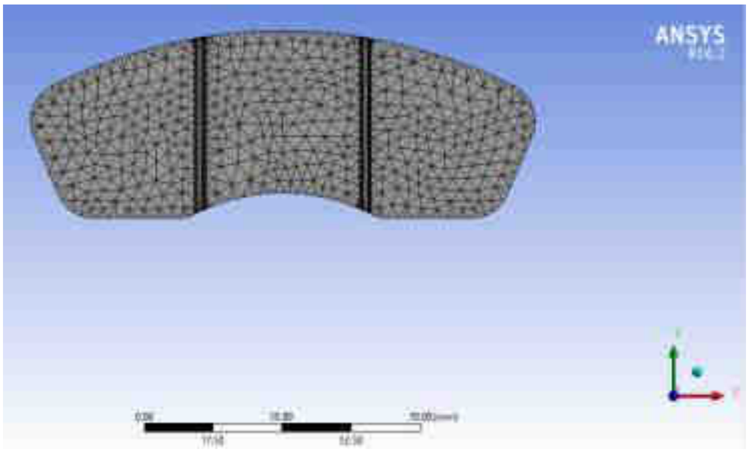

Figure 2. Mesh model of Brake pad.

Figure 3. Fixed support

3. Result and Discussion

3.1 Result of Mechanical simulation

The project schematic of mechanical simulation are as shown in figure 4. The mechanical simulation result of the brake pad modeled by three materials are shown in Figure 5 and 6.

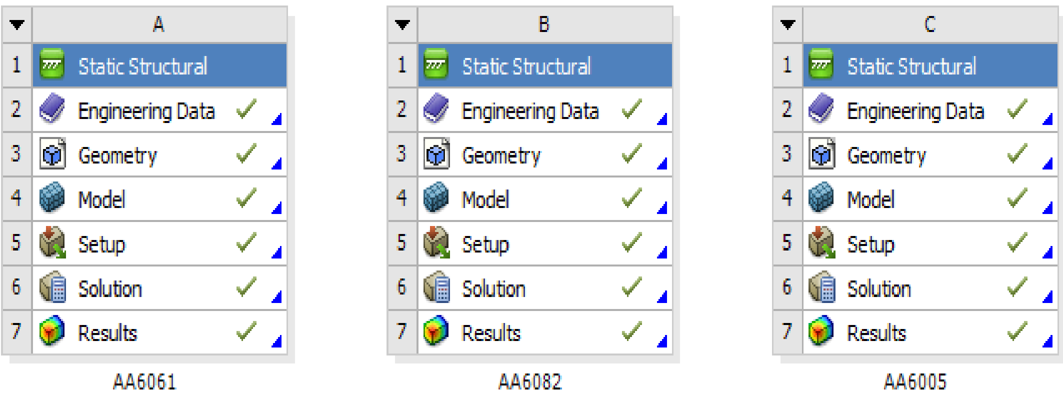

Figure 4. Project schematic mechanical simulation.

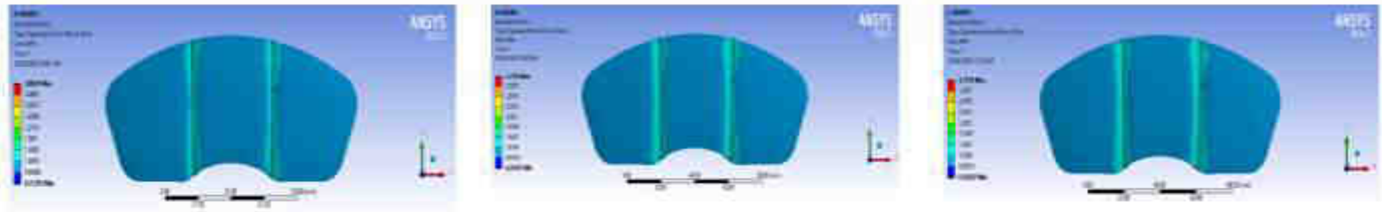

Figure 5. The von-mises stress of AA6061, AA6082, and AA6005.

Figure 6. The total deformation of AA6061, AA6082, and AA6005.

Table 2, displays the outcome of the mechanical simulation used to analyze and compare the properties of the various materials.

Table 2. Result of mechanical simulation.

Materials	AA6061	AA6082	AA6005
Von mises stress (MPa)	3.8629	3.7559	3.7559
Total deformation (mm)	7.8959 $x10^{-5}$	$8.0388x10^{-5}$	8.0388 $x10^{-5}$

From the findings provided, AA6061 exhibited the least total deformation, whereas AA6082 and AA6005 demonstrated identical deformation levels. Notably, AA6061 recorded the highest maximum Von Mises stress, whereas AA6082 and AA6005 shared the distinction of having the lowest maximum Von Mises stress values, which were equivalent.

3.2 Result of Thermal simulation

Figure 6, displays the outcome of the thermal simulation used to analyze and compare the properties of the various materials. The project schematic of thermal simulations are as shown in figure 7.

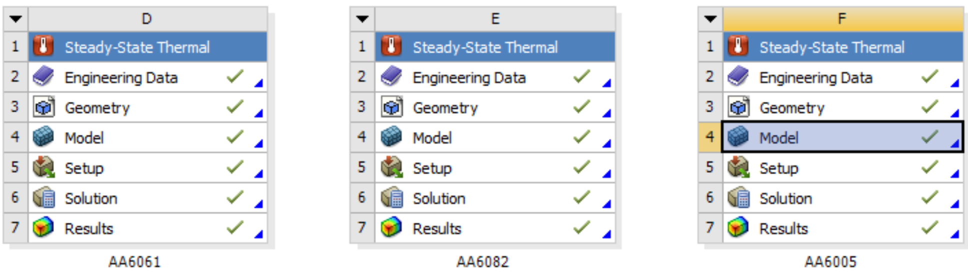

Figure 7. Project schematic of thermal simulation.

Figure 8. The thermal simulation result of AA6061, AA6082, and AA6005.

After the thermal simulation results have been acquired, they have been organized into Table 3, for analysis and comparison purposes.

Table 3. Result of thermal simulation

Materials	AA6061	AA6082	AA6005
Temperature Max. (500 ^{0}c)	500	500	500
Temperature Min. (500 ^{0}c)	499.77	499.78	499.8

In the provided Table 3, the temperatures of three different materials (AA6061, AA6082, and AA6005) are listed at their maximum and minimum values when subjected to a thermal simulation at 500°C. These values indicate the maximum and minimum temperatures reached by each material during the thermal simulation at the specified 500°C temperature. The slight variations in the minimum temperatures suggest differences in how efficiently each material absorbs or dissipates heat during the simulation. For a brake pad application, where thermal properties are crucial due to the heat generated during braking, the material's ability to withstand high temperatures and dissipate heat effectively is paramount. AA6061 reached a minimum temperature of 499.77 °C. AA6082 reached a minimum temperature of 499.78 °C. AA6005 reached a minimum temperature of 499.8 °C. The slightly lower minimum temperature for AA6061 suggests that it may dissipate heat more efficiently compared to AA6082 and AA6005. Therefore, based on the information provided, AA6061 could be considered the most suitable material for a brake pad application due to its slightly better thermal performance at the given temperature range of 500 °C.

4. Conclusion

In comparison to AA6082 and AA6005, AA6061 is the best appropriate material for automotive brake pads, according to the study's overall findings. When force was applied, AA6082 and AA6005 were able to undergo significant deformation. AA6061's marginally lower minimum temperature raises the possibility that it dissipates heat more effectively than AA6082 and AA6005. Deformation and stresses are the primary factors that should be minimized in a brake pad in order to improve braking effectiveness and keep the pad from becoming damaged too quickly. Lastly, since modeling and simulation software have been improving over time and may eventually be more accurate than human labor, they are particularly helpful for a variety of design analysis and engineering activities.

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

This work does not require any ethical statement.

Reference

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