# ANALYSIS OF CONTACT MATERIAL OF SINGLE FRICTION PLATE IN CLUTCH SYSTEM

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## Summary

Many different materials are used in the clutch systems to satisfy different types of clutches. Research on different types of clutch systems and consequently friction materials is still ongoing. The transmission systems are still needed even if the number of electric cars is increasing, because of the effect of the transmission systems on energy efficiency. In this paper, the 3D design and FEA simulation of a single friction plate material in a clutch system are studied.

**KEYWORDS**: clutch system, material analysis, electric vehicle

## Introduction

Alternative energy sources are the way to create a clean and green environment for the world and are used for sources other than fossil fuels, which are commonly used to generate energy (Michaelides, 2012). The alternative energy source implementations are increasing day by day. It is sustainable, even if the high initial cost, maintainability is cheaper than regular dirty energy sources. Germany is one of the best examples of alternative energy usage. Germany planned to produce with the combining all alternative energy sources, like wind, solar, hydro, tidal etc. the electricity production will be 65% in 2030 (Telli et al., 2020).

Europe achieves to decrease in greenhouse gas emissions by 23.45% from 1990 to 2017 (González-Sánchez and Martín-Ortega,2020). Likewise, the automobiles involved in this change. Hybrid or fully electric cars prefer rather than gasoline and diesel cars. As part of this change, some of the traditional automotive parts have to develop and change to adapt to hybrid or electric cars. Some of the automobile parts are no longer needed, additionally, some of them change in form or material. The part involved in this change is the transmission system. The transmission system is between the engine and the gearbox. Different transmission systems are still in the development phase (Tian et al., 2020; Jinglai et al., 2018; Ruan et al., 2016; Sorniotti et al., 2011; Sorniotti et al., 2012; Maguire et al., 2013; Walker et al., 2015; Walker et al., 2011; Mousavi et al., 2015; Di Nicola et al., 2012 ). Because of the characteristic of the electric motor that provides high torque even at high speeds without a gearbox. However, the transmission systems are not only used for transferring engine power to the gearbox but also used for creating additional power without lowering the efficiency.

The entire transmission system for internal combustion engines is divided into seven parts which are the clutch, the gearbox, propeller shaft, universal joints, axle, wheel, and tires. However, the only clutch will be investigated in this paper. The clutch system is made of several discs in the transmission system. Around the clutch plates, there are numerous types of friction materials and also patterns that affect the performance and wear of the clutch (Jonoadji et al., 2020; Nyman et al., 2006; Yagi et al., 2015; Jang et al., 2011). There are two different types of clutches: wet clutches and dry clutches. The difference is the fluid inside the transmission system. Dry clutches work with no oil. Wet clutches work with lubricating or engine oil. Oil helps to reduce the friction between plates, reduce heat generation, and increase heat dissipation. Relatively, wet clutches work more silent than dry clutches (Kim and Choi, 2010).

This paper analyzes different wet clutch friction materials with the help of 3D modeling and ANSYS structural and thermal analysis for hybrid or fully electric cars.

## Material and Method

The clutch friction disks have similar features to the brake disks. The common brake disk materials and its characteristics are listed below:

**Table 1**

**Characteristics of Materials**

| Material | Characteristics |
|---|---|
| Metallic | Low to medium dynamic friction<br>Excellent resistance to heat<br>Excellent durability<br>High compressive strength |
| Polymeric | High dynamic friction<br>Good resistance to heat<br>Excellent durability |

| | |
|---|---|
| | High compressive strength |
| Graphitic | Medium dynamic friction<br>Excellent resistance to heat<br>Excellent durability<br>Medium compressive strength |
| Paper | High dynamic friction<br>Fair to very good resistance to heat<br>Fairly good to very good durability<br>Low to medium compressive strength |
| Woven | Medium dynamic friction<br>Good resistance to heat<br>Very good durability<br>Medium compressive strength |

*Source: (Chan and Stachowiak, 2004; Lloyd and DiPino, 1980)*

Popescu et al.' mentions that the new electric vehicles can provide 430 Nm peak torque and their highest speed values can reach up to 12000 RPM 95Kw (Popescu et al., 2015). Also, in this paper, uniform pressure theory and uniform wear theory are used (Brar and Bansal, 2010).

$$T = \frac{2*\mu*(r_o^2-r_i^2)*F_{upt}}{(r_o^3-r_i^3)} \tag{1}$$

$$F_{upt} = \frac{3*T*(r_o^2-r_i^2)}{2*\mu*(r_o^3-r_i^3)} \tag{2}$$

$$P_{upt} = \frac{F}{\pi*(r_o^2-r_i^2)} \tag{3}$$

For the uniform wear theory;

$$T = \frac{\mu*F_{uwt}*(r_o^2+r_i^2)}{2} \tag{4}$$

$$F_{uwt} = \frac{2*T}{\mu*(r_o+r_i)}(1)$$

$$P_{uwt} = \frac{F_{uwt}}{2*\pi*(r_o-r_i)*r_{mean,effective}} \tag{5}$$

For the heat generation and heat flux; (1)

$$A = \pi * (r_o^2 - r_i^2) \tag{6}$$

$$\omega = \frac{2*\pi*N}{60} \tag{7}$$

$$Q_{Gain} = \mu * P_{max,intensity} * \omega \tag{8}$$

$$Q_{Flux} = Q_{Gain} * A \tag{9}$$

Even though the hybrid and electric vehicles' working principle is different from the traditional internal combustion engines, the traditional materials can be used for the hybrid vehicles and electric vehicles' clutches in the view of supply and cost. The acceleration of the vehicle differs depending on this principle. Which also leads to the different heat generation and dissipation characteristics. The traditional and new clutch materials that investigated in this paper according to the materials stiffness, coefficient of friction, and heat dissipation characteristics, which are listed below:

**Table 2**

**Properties of Selected Materials**

| Material | Density (g/cm$^3$) | Young's modulus (GPa) | Poisson ratio | Ultimate Tensile strength (Mpa) | Coefficient of Friction |
|---|---|---|---|---|---|
| Titanium diboride (TiB$_2$) | 4.50 | 420 | 0.108 | 373.6 | 0.9 |
| AL6063-T83 | 2.70 | 241 | 0.33 | 255 | 0.19 |
| Gray Cast Iron (I) | 7.20 | 124 | 0.29 | 400 | 0.4 |
| AL/T-800 | 1.80 | 234.5 | 0.24 | 124.1 | 0.04 |

*Source: (Munro, 2000; Metals handbook, 1990; Holt et al., 1996; Mohammed et al., 2019; Vlack, 1982; Jang et al., 2004; Speich et al.,1980; Chapman and Hatch, 1977; Potluri, 2018; Wei et al., 2015)*

## Analysis

*The model for this paper can be seen in Figure 1.*

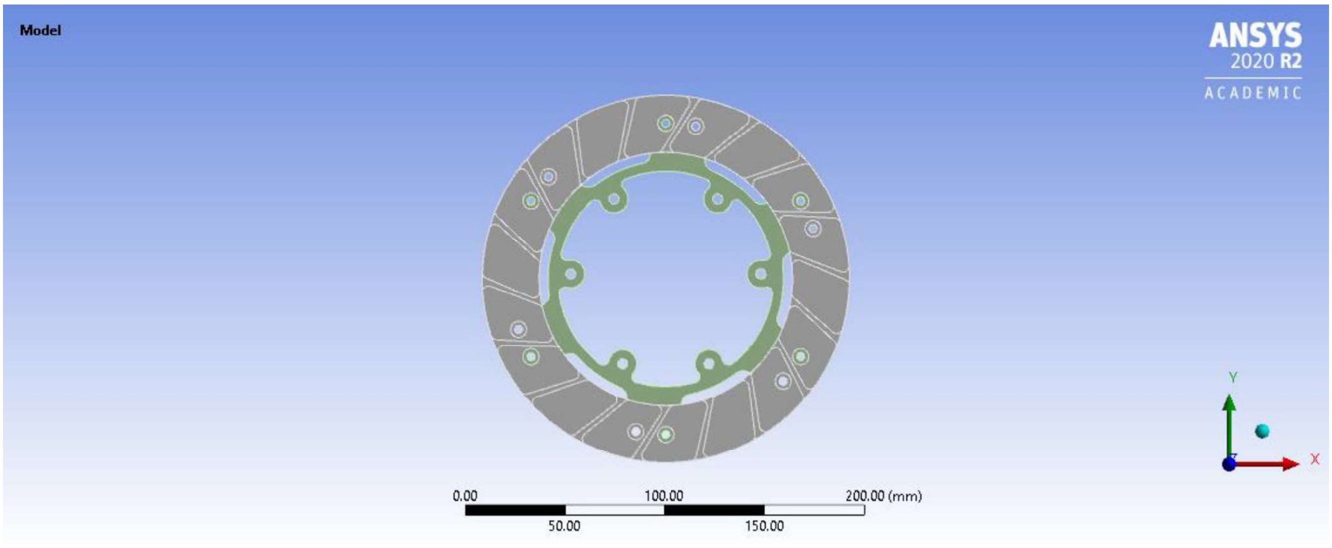

***Fig. 1.*** *Clutch Model*

According to the results of the formulas (1)-(6) on Matlab, the results of the formulas can be seen in Table 3.

**Table 3**

**Properties of Selected Materials**

| Material | Uniform Pressure Theory | | Uniform Wear Theory | | Heat Gen. Watt | Heat Flux Clutch |
|---|---|---|---|---|---|---|
| | F [N] | P [MPa] | F [N] | P [MPa] | | |
| $TiB_2$ | 5653 | 0.4060 | 5716.3 | 0.4060 | 565.4867 | 0.0406 |
| AL6063-T83 | 26778 | 1.9233 | 27077 | 1.9233 | 119.3805 | 0.0086 |
| Gray Cast Iron (I) | 12719 | 0.9136 | 12862 | 0.9136 | 251.3274 | 0.0181 |
| AL/T800 | 127190 | 9.1356 | 128620 | 9.1356 | 25.1327 | 0.0018 |

According to Table 3's results, ANSYS FEA analysis results can be seen in Table 4 for Uniform Pressure Theory;

**Table 4**

**Total Deformation, Directional Deformation and Equivalent Stress Results for Uniform Pressure Theory**

| Material | Uniform Pressure Theory | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Deformation | | | Directional Deformation | | | Equivalent Stress | | |
| | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum |
| $TiB_2$ | 4.2517e-003 mm | 3.7276e-004 mm | 0 | 4.3158e-004 mm | -4.1167e-010 mm | -5.1797e-004 mm | 47.909 MPa | 2.3126 MPa | 2.8517e-012 MPa |
| AL6063-T83 | 0.11242 mm | 9.5542e-003 mm | 0 | 1.0756e-002 mm | 1.2237e-006 mm | -1.3058e-002 mm | 196.44 MPa | 11.202 MPa | 4.342e-011 MPa |
| Gray Cast Iron (I) | 3.5695e-002 mm | 3.0592e-003 mm | 0 | 3.4962e-003 mm | 2.8081e-007 mm | -4.2191e-003 mm | 102.25 MPa | 5.5659 MPa | 1.6859e-011 MPa |
| AL/T800 | 0.17017 mm | 1.4672e-002 mm | 0 | 1.6881e-002 mm | 9.7558e-007 mm | -2.0315e-002 mm | 1088.9 MPa | 57.343 MPa | 1.2646e-010 MPa |

According to Table 3's results, ANSYS FEA analysis results can be seen in Table 5 for Uniform Wear Theory;

**Table 5**
**Total Deformation, Directional Deformation and Equivalent Stress Results for Uniform Wear Theory**

| Material | Uniform Wear Theory | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Deformation | | | Directional Deformation (X-Direction) | | | Equivalent Stress | | |
| | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum |
| TiB$_2$ | 4.2993e-003 mm | 3.7693e-004 mm | 0 | 4.3641e-004 mm | -4.5045e-010 mm | -5.2377e-004 mm | 57.625 MPa | 2.7815 MPa | 3.43e-012 MPa |
| AL6063-T83 | 0.11368 mm | 9.6609e-003 mm | 0 | 1.0876e-002 mm | 1.2374e-006 mm | -1.3203e-002 mm | 198.63 MPa | 11.327 MPa | 4.3904e-011 MPa |
| Gray Cast Iron (I) | 3.6096e-002 mm | 3.0936e-003 mm | 0 | 3.5355e-003 mm | 2.8396e-007 mm | -4.2665e-003 mm | 103.4 MPa | 5.6285 MPa | 1.7049e-011 MPa |
| AL/T800 | 0.17208 mm | 1.4837e-002 mm | 0 | 1.7071e-002 mm | 9.8655e-007 mm | -2.0543e-002 mm | 1101.2 MPa | 57.988 MPa | 1.2788e-010 MPa |

According to Table 3's results, ANSYS transient thermal analysis results can be seen in Table 6 for temperature and heat flux;

**Table 5**
**Temperature and Heat Flux results according to the materials**

| Material | Temperature | | | Heat Flux | | |
|---|---|---|---|---|---|---|
| | Maximum | Average | Minimum | Maximum | Average | Minimum |
| TiB$_2$ | 281.95 °C | 281. °C | 276.52 °C | 0.35015 W/mm$^2$ | 3.6791e-002 W/mm$^2$ | 1.5696e-003 W/mm$^2$ |
| AL6063-T83 | 433.89 °C | 429.26 °C | 407.55 °C | 0.35013 W/mm$^2$ | 3.679e-002 W/mm$^2$ | 1.5949e-003 W/mm$^2$ |
| Gray Cast Iron (I) | 163.18 °C | 156.21 °C | 124. °C | 0.1557 W/mm$^2$ | 1.637e-002 W/mm$^2$ | 7.0425e-004 W/mm$^2$ |
| AL/T800 | 22.186 °C | 22.022 °C | 21.99 °C | 6.9671e-004 W/mm$^2$ | 6.0607e-005 W/mm$^2$ | 2.0077e-016 W/mm$^2$ |

## Conclusion

1. The electric vehicles both full electric or hybrid ones have different needs for the clutch system due to the high performance and speed. However, the tested materials have different material characteristics for different vehicle characteristics. There is no rule of thumb to find an optimal material for all vehicles. For the specific vehicle, specific materials should be used only for that kind of transmission.

2. The Gray Cast Iron is the most optimal material given total deformation and temperatures. However, the material should be investigated how long it will last. This way, it can be understood that material is the optimal choice or not.
3. $TiB_2$ is the second-best selection due to the temperature and total deformations. TiB2 has known as a strong material with good heat conductivity. In this case, $TiB_2$ reaches up to 281.95 °C with the 4.2993e-003 mm at maximum at uniform wear conditions.
4. This paper is for the preparation for future researches. Later, it can be investigated to different materials with similar mechanical characteristics with Gray Cast Iron and $TiB_2$. Also, for future works, these materials can experiment on the car itself.

## Nomenclature

$T = Torque$
$P_{max,intensity} = Maximum\ Pressure\ Intensity$
$\omega = Angular\ Velocity$
$A = Frictional\ Area$
$N = Revolution$
$F_{upt} = Axial\ force\ according\ to\ the\ Uniform\ Pressure\ Theory$
$F_{uwt} = Axial\ force\ according\ to\ the\ Uniform\ Wear\ Theory$
$r_o = outer\ radius$
$r_i = inner\ radius$
$\mu = coefficient\ of\ friction$

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