

# EXAMINATION OF HEAT TRANSFER OCCURRING IN THE PADS AT THE TIME OF FRICTION IN BRAKE SYSTEMS IN AUTOMOBILES

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## **Abstract:**

Kinetic energy during braking of the moving mass is converted into heat energy through friction. This heat energy cause brake pads to be exposed to excessive temperature. The breaking efficiency reduces in time and in this case some problems (reducing in brake performance, defect running, rapid brake pad wear and noise) occur. A number of tests were applied on the pads in order to eliminate these negative effects which arise in the brake pads.

Four different brake pad materials were subjected to the braking process during 300 s. in the study that was modeled by the SOLIDWORKS SIMULATION software. The researchers investigated the temperature that occurred during the braking process by using finite elements method. Moreover, in order to expose the status of brake pads after friction, two different thicknesses of the same brake pad were taken into the consideration in the analysis. It is aimed to provide improvement in material analyzing, technology and theory or the possibility of improvement.

**Key Words:** Brake Pad, Heat Transfer, Solidworks Simulation

## **1. Introduction**

The brakes used in the autos are energy changing tools. They convert the mechanic energy of car into heat energy through friction. The car on the move has kinetic energy. So as to be able to lower the speed of the car, it is necessary that the energy it has should be converted into energy. In the braking systems, the kinetic energy of the car is converted into heat energy via the friction of the pads onto disc and this heat emits the atmosphere. If the brakes are given heat more than they can emit to environment, the friction parameter in brake pads declines and the stopping capability of the brakes decreases. After this point, wear is accelerated. The continuous exposure of the brake pads to over temperature leads to the exhaustion of the braking performance of pads. This situation shows itself as decrease, malfunction, fast pad wear and sound in the performance of brakes [1,2]. Hohmann et al.[3] determined high pressure in the outer radius of pad and pad supporting plate as a result of the analysis they carried out at the end of braking. In their study, Tamari et al. [4] made about the prediction of contact pressure in disk brake pads stated that the contact pressure must be proper in disk brakes so that wear can be proper. Abu Bakar et al.[5], tried to model the pressure distribution between pad and disk in computer environment using different design, dimension and

material. They found out that the asymmetric and improper pressure distribution cause improper wear and shortening of pad life. They concluded that pad construction is influential on pressure distribution and wear. Abu Bakar et al. [6] made three dimensional analysis of contact pressure distribution over disc and pad surfaces using brake and finite element model. The conduction hardness of asymmetrical solid matrix, friction parameter in disk and pad interface constituted the core of the method. They researched model brake disks and contact pressure

distribution at different levels. Using a proper model, it was provided to make the predictions of pressure distributions in the interfaces in brake disks. Abu Bakar et al.[7], experimentally found the noise and sound vibration which stem from dynamic ambiguity because of friction during braking and examined the data using Abaqus packet program. In their study, Valvano and Lee [8] examined thermal attitude under short term and stable state. The maximum temperature of the disk is found in the place where a contact is made with pad and they found that the temperature rose at the time of repeating braking. In his study, Arpat, [9] examined the amount of wear of the pads in drum or disk brake systems occurring because of the increase of heat on the surface of friction as a result of

frequent braking of light and heavy commercial vehicles. He found out that with the decrease of temperature at the moment of braking, wear in the pad declined. Jacobsson [10], made a conventional disk brake analysis. He reached the conclusion that thermal degradation occurred because of friction depending on the time, and mechanic degradations because of operating forces applied. As a result of the experimental study, it was found that wear appeared in the friction material couple and there was a decrease in the thickness of the disk. Mosleh et al.[11] made analyses about the wear and friction behaviours in the pads which were exposed to braking at different speeds and the tribological characteristics of erosive materials. In the tests experimentally achieved, the characteristics of brake material were determined. Depending on the differentiability of the brake material, they determined that the change in the wear rate was dependent on the low and high sliding speeds. Hwang et al.[12] defined the thermo elastic irregularity resulting from the heat which occurred because of friction at the time of braking. They tried to solve the heat and thermal deformation change under a single proper braking and repeating braking through the method of finite elements. They found that the maximum temperature of the disk is found in the place where a connection is made with the pad and occurs during repeating braking. Li et al.[13] argued that the occurrence of vibration and noise at the time of braking in the disk brakes result from pressure and heat distribution on the surface of pad. As a consequence of the experimental studies and numerical analyses, it was seen that the temperature distribution was not appropriate and there was high pressure in the locations where temperature value was high. They ascertained that temperature was effective in noise and vibration occurring on the surface of pad.

In this study, the temperature-stress distribution and change occurring during braking of brake pad material was examined. The thermal and mechanic features of four different pad materials which were mentioned earlier as pad material in literature, the thermal and mechanic behaviour of the pads were tried to be determined using SOLIDWORKS SIMULATION SOLUTIONS program. In addition, in the study, the impact of wear rate of pad was aimed to be revealed. The thermal power forming through the conversion of motional energy into thermal energy during braking was mathematically calculated. Using SOLIDWORKS packet program, the pad in the brake system was modelled, and the calculated thermal power was entered in the program and analysis results were obtained [16].

## 2. Material and Method

### 2.1. Material

In this study it is aimed to determine the effects of thermal and mechanic characteristics of various materials developed as pad material on pad. As a result of literary survey made for this purpose, the characteristics of material developed by different researchers were taken into consideration. The characteristics belonging to the materials were given in chart 2.1 [1].

Table 1. Properties of pad materials

Material No	Thermal conductivity coefficient, k (W/mk)	Specific heat, c (j/kgK)	Density, $\rho$ (kg/m <sup>3</sup> )	Thermal expansion coefficient, $\alpha$ (10 <sup>-6</sup> /K)	Young's modulus, E (GPa)	Poisson's ratio ( $\nu$ )	Reference
1	50	1880	1800	0,3	50,2	0,3	Choi [14]
2	5	1000	1400	10	1	0,25	Choi [14]
3	0,5	1034	3660	30	0,53	0,25	Hwang [12]
4	5	350	4000	0,001	1	0,25	Voldrich [15]

In the table Material-1 was made of carbon-carbon combined composite material. As seen in the table, it is the material that has the highest specific heat. Its density and heat conductivity parameter is also high. It is the material whose Poisson ratio is the highest.

Material-2 was made of carbon-carbon combined composite material. It is the second highest material in terms of thermal expansion parameter. Comparing with

Material-1, its thermal conductivity parameter is ten times and its elasticity module is fifty times smaller.

Material-3 is the material that has the smallest elasticity module and thermal conductivity parameter. In terms of density value, it is the second highest material.

Material-4 is the material that has the highest density value, the lowest thermal expansion parameter and specific heat value.

## 2.2. The Geometry of the Problem and Limit Conditions

The geometry of the examined pad was given in Fig. 2.1 (a). This pad is situated on a 187mm diameter disk as seen in Fig. 2.1 (b). For the problem, in all of the materials as a common value  $\mu = 0,45$  was taken. In this case, depending on the distance of each nodal point of the object to the center, thermal power was calculated as  $[\rho]$ .

$$\rho = \mu * P * A * \omega * R \quad (1)$$

$$\rho = 0,45 * 1050000 * 0,00305 * 64,3 * R \quad (2)$$

$$\rho = 92800 * R \quad (3)$$

The brake pressure was (P) 1050 kPa, rotation speed was  $(\omega) = 64,3 \frac{1}{s}$  and pad surface space was (A) 0,00305 mm<sup>2</sup>. R shows the distance of the examined point from the center of the pad.

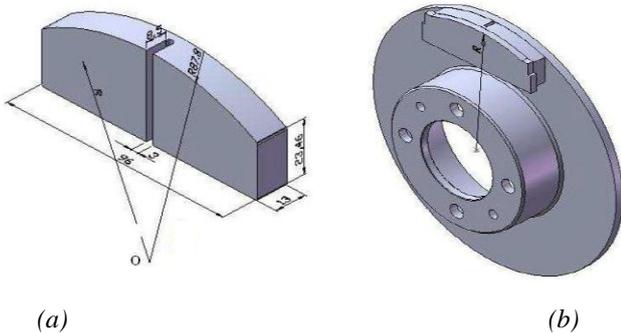


Fig. 2.1 The geometry measurement of pad (a) the brake disk-pad view (b)

Pad was accepted (300k) under room temperature in the beginning. The thermal heat condition applied for the pad under these conditions was given in Fig. 2.2. It is seen that 10% of heat input is emitted from the back surface of the pad. From other surfaces, however, there is heat transfer through convection. Here the convection coefficient was taken as;

$$h = 28 \left( \frac{w}{m^2 K} \right) \quad (4)$$

While taking these values, the formula of;

$$h = 10,45 - V + 10\sqrt{V} \quad (5)$$

which was given by Siple ve Passel [17] was used. Air speed (V) was taken as the peripheral of the disk.

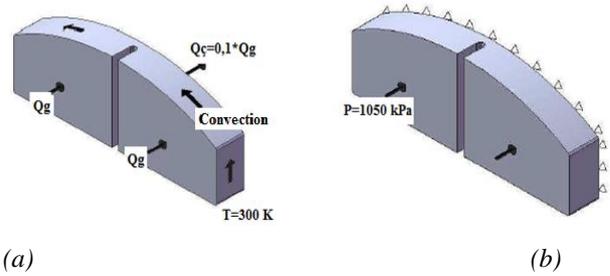


Fig. 2.2 The limit conditions applied on the pad are thermal (a) and mechanical (b)

The mechanical limit conditions applied to the problem are shown in Figure 2.2 b. Since pads were produced as stuck on a base, the bottom of was taken stable. A pressure of 1050 kPa was applied on the surface between the pad and disk [16]. The problem was solved under these conditions considering different ways of wear (unworn, 6mm worn) for the wear occurring at the end of 300 sn. While composing finite member net, triangular pyramid which is most suitable member type in the modelling of curved edges was chosen, it was provided to compose thinner member in the regions where temperature change is huge across the thickness. The net structured obtained were given in Fig. 2.3. According to the wear states of Material 1, there are 19806 nodal points for the unworn and 22783 for the worned respectively [16].

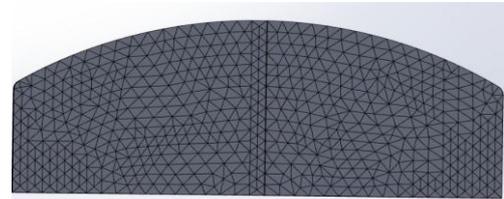


Fig. 2.3 Mesh view of brake pad

## 3. Findings and Discussion

The findings of the analyses made in this part were given in two sections for the temperature analyses first and for the stress analyses then.

### 3.1. Findings with Temperature

In the findings section about temperature, firstly, as a result of the solution made for 300s, figures belonging to the temperature distribution attained in the pad were given. The temperature change occurring in the unworn and 6mm worned pad material and deformation result at the end of 300 second were given in Fig. 3.1.

As seen, in all figures, depending upon the radius of the pad, the temperature emerging in the outer part is higher. Besides, it is seen that temperature is decreasing from the surface of pad touching disk towards outside. For pad, besides the surface temperature, the spread of heat in the pad is also important. For this reason, while making a comparison among the materials, it is necessary to be careful with both maximum and minimum values and the dif-

ference between them. The unworn pad material is at -3, the highest surface value is 206 °C and the lowest surface temperature value is 203 °C, the difference of temperature is 3 °C. The reason for this is that the thermal conductivity parameter is low and specific heat value is not high. Taking the wearing rate into account, the surface temperature of the 6mm worn pad material is 509 °C at -3 and the lowest surface temperature value is 502 °C, the difference of temperature is 7°C. considering the wearing rate in Material -3, when the rate of wear rises, the temperature difference between two surfaces also rises. In other materials as well, with the increase of wear rate, the temperature value occurring on the pad surface and the temperature difference between two surfaces rises as well. In the unworn pad material series, the highest temperature occurring on the surface was at material -3. The highest temperature occurring on the surface of 6mm worn pad series is seen to emerge in material -3. The specific heat, density and heat conductivity parameter multiplication of Material -2 and 4 are equal and higher than material -3. As the heat conductivity parameter, specific heat and density values are high in material-1, the temperature value occurring on the surface of pad is lower comparing with other material series. The highest surface temperature existing in this material is 206 °C for the unworn, 509 ° for 6mm worn, and the lowest surface temperature is 203 °C for the unworn, 502 °C for 6mm worn and the temperature difference between two surfaces is 5 °C on average.

If the thermal heat conductivity and density value of the material is high, the temperature difference on the surface is low. If the density and heat conductivity parameter of the material is low, the temperature value forming on the surface becomes high. If the temperature difference between the pad surfaces had been high, the temperature shapes on the surface would have taken quite a messy shape. Because the temperature difference between the pad surfaces in unworn and 6mm worn pad materials surface, temperature shapes seem to exist in a place close to pad center and in round shape [16].

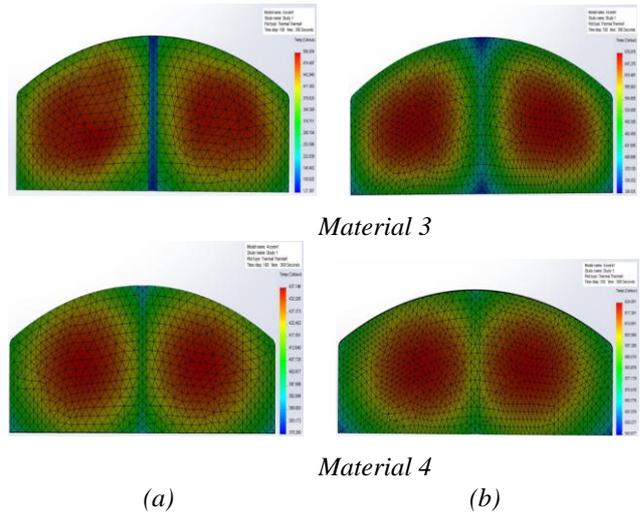
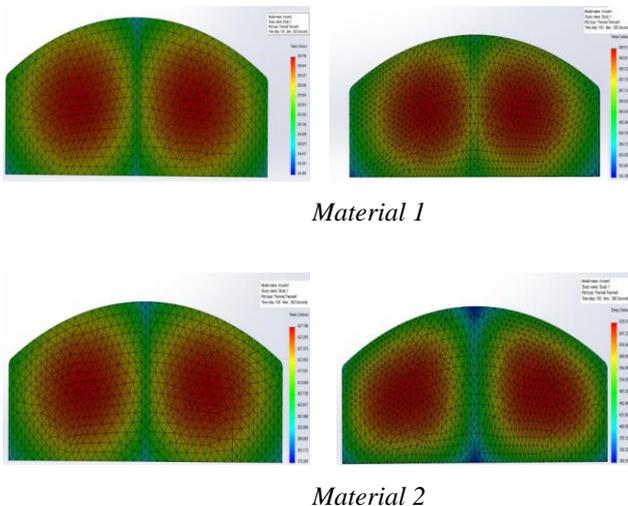


Fig. 3.1 Temperature distributions and deformation states after braking in the unworn (a) and 6 mm worn (b) pad at the end of 300 seconds

As seen in Fig. 3.1, generally in the rate of wear of pad materials, there is a linear increase in the pad surface temperatures according to wear rates. The surface of pad material rubbing against disk often plays a determining role among temperatures. with the fact that wear rate is 6mm, there is seen a significant rise in pad temperatures in different materials in the same time period. The temperature difference occurring in material -3 whose thermal conductivity parameter is the lowest becomes the highest. However, in material-1 whose thermal conductivity parameter is the biggest, the pad temperature difference is very low. Since the thermal conductivity parameter of material-2 and 4 is equal, the shapes showing the temperature value on the surface that changes according to unworn and worn amounts are similar [16].

### 3.2. Findings with Stress

In the chapter concerned with the results of strain, the shapes about the strain distribution obtained in the pad as a result of the solution made for 300 s were given. The strain changes that occurred in the unworn pad material and the results of deformation at the end of 300 second were given in Figure 3.2. The places where stresses emerged most are the corner parts where the surface of pad is held and the middle channels of pad. In terms of thermal stresses, the most important subjects are the thermal expansion parameter and module of elasticity. For this reason, while comparing the stresses, this characteristic of the material needs to be considered. On the other hand, the highest temperature and temperature differences occurring in the material are the factors which become influential in the formation of thermal stresses.

As the thermal expansion parameter of the unworn material-4 is the lowest, the stress distribution emerging on the surface contacting with the disk is proper. On the contrary to this, the biggest strain value emerging in the pad is 2,2 MPa which is the lowest value comparing with the other unworn materials. Comparing it with 6mm worn materials in terms of the strain value occurring on its surface, it

is seen that the lowest value is got. Although the material characteristics of stress values occurring in the unworn and 6mm worn material-4 are the same, the fact that they happened to result differently is seen to stem from the biggest and lowest temperature value emerging on its surface and the difference between this temperature value. It is observed that the stain in unworn pad material emerges in the biggest value 24,4MPa and material-3. In the 6mm worn pad material, however, the biggest strain value is in the material-3 with 35,3 MPa. The multiplication of elasticity module and heat expansion parameter of this material is the highest. That the strain value forming through the materials whose multiplication of elasticity module and thermal expansion parameter are low is also low is seen in Fig. 3.3. The stress distribution occurring on the surface of the pad touching the disk shows a quite proper view except for the Material 1 and 3. However, these two materials display a higher distribution in the sides and lower in the inner parts. For these materials, the multiplication of elasticity module with thermal expansion parameter takes nearly the same value [16].

The change of the stresses talent from four material in time is shown in Fig. 3.2. The stress values obtained while composing these shapes were divided to 1050 kPa strain value which was applied on the surface and they were made non-dimensional. Each shape shows different situations depending on the wear amount for a material. In all of the pads, there is an amount of wear at first, later stresses begin to increase. This decline period is short or long depending upon the thermal characteristics of the materials. For example, in the material 4 whose thermal capacity is the lowest, there hasn't been any rise during braking time. In other materials, however, there was a decline for a short or long time at first, then, there was a rise again. Notwithstanding, no change is seen in the unworn materials in 1 and 2 materials. In this case, it can be said that the change of stress in time is also related with pad thickness as well as thermal and mechanic features. This situation is clearly seen in 6mm worn number 1 and 2 materials.

The amount of stress also rises with the rise of wear amount. This situation demonstrates that the life of pad dies out not linearly but rapidly depending on the rise of wear amount. In the cases where the elasticity module and thermal expansion parameter are low in the materials, in the strain analysis carried out in 300s time, it will be seen as a result of the analyses made that the stresses decrease at first properly and they rise later [16].

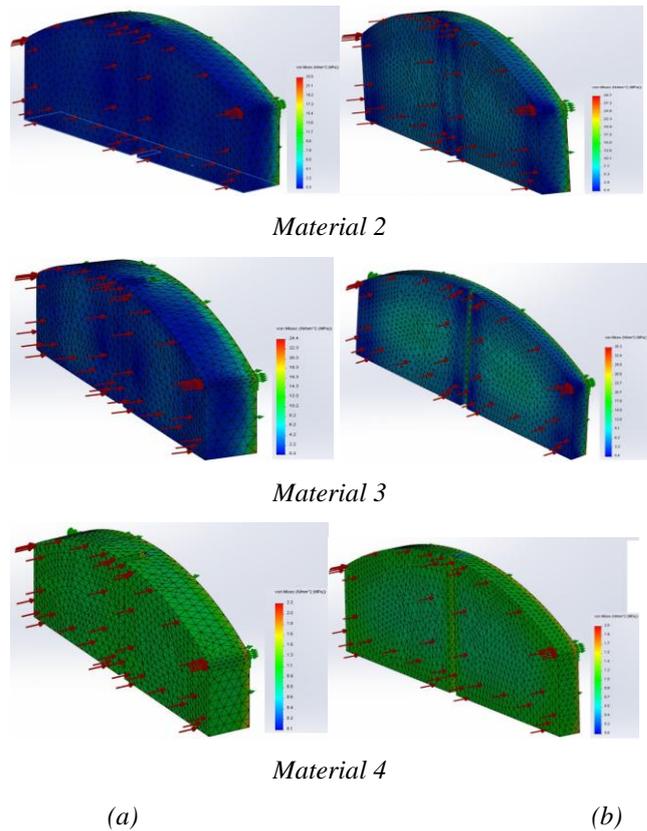
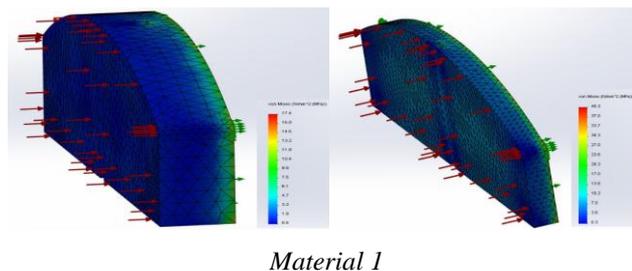


Fig. 3. 2 Stress distributions and deformation states after braking in the unworn (a) and 6 mm worn (b) pad

#### 4. Conclusions And Recommendations

In this study, the temperature distributions and stress situations of four different pad materials during 300s occurring as a result of permanently braking were examined using SOLIDWORKS SIMULATION SOLUTIONS packet program with finite element method. In the study, in order to consider the impact of pad's wear, two pads of different thicknesses were examined as well.

The main results attained at the end of the study can be listed as:

1. Because the thermal power affecting the pad changes depending on the distance from the center of pad, higher temperature values are obtained towards the outer parts of the pad.
2. The highest temperature values occur on the surface where pad touches the disk.
3. While examining the temperature distribution emerging in the pad, not only the highest temperature but also the difference between the highest and lowest temperatures is to be considered.
4. It has been found out that there is an inverse proportion between the thermal conductivity parameter of material and specific temperature and density. The temperature and temperature difference value occurring on the surface of the pad material whose thermal conductivity parameter and specific heat and density are high become the maximum. The temperature and temperature difference value occurring on the surface of the pad material whose thermal conductivity parameter and specific heat and density are high become the minimum.

5. As the rate of wear increases, the temperature value and difference also increases and it is seen that the deformation formed decreases.

6. The places that have the biggest stresses are the corner parts which sit the holding surface of pad and the middle channel part of the pad. The most important points in terms of thermal stresses are the thermal expansion parameter and elasticity module. For this reason, while comparing the stresses, these characteristics of the materials should be taken into account. On the other hand, the highest temperature and temperature differences are the factors becoming influential in the occurrence of the stresses. If the thermal expansion parameter and elasticity are big, the value of strain becomes big as well.

7. In all of the pads, at first there is an amount of decrease, then these stresses begin to increase. This decreasing period is short or long depending on the thermal characteristics of materials. In this case, it can be said that the change of strain in time is also related with pad thickness besides the thermal and mechanic features.

8. With the rise of wear amount, the amounts of stress also rises. This situation demonstrates that the life of pad dies out not linearly but rapidly depending on the rise of wear amount.

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