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Original Research Article

Analysis of the wear and friction of brake pad added cashew and ulexite using ANSYS

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ABSTRACT

The aim of the current research is a comparison of the wear ratio on the brake pad with the real values and the simulation values. Therefore, brake pad samples prepared from cashew and ulexite mixtures were used. The variation of total deformation on and wear ratio is investigated with using Ansys. Also, in this study, the brake pad, and disc were designed using Catia v5. Data input of pressure is selected 1.05 MPa on pad surface samples and 500 seconds on a brake disc rotating at 6 m/s. This analysis was made for 5 different samples. On the other hand, we are not getting clear results because of some limitations such as creating materials and unknown some material properties. With some approaches, real results were approached. Results showed that the simulation results are linear to the values according to the real values. The results that are found on software, approximately between +%9 and -%14. Also, it was observed that wear occurred in the center of the pad. It was thought that this wear could be reduced by distributing the pressure applied to the surface of the pad.

Keywords: Brake pad, friction coefficient, ulexite, cashew, tribology, ANSYS

1. Introduction

The act of a brake system in all of combustion engine vehicles basically evaluated by the tribological characteristics of a brake pad and disc, which is produced of a gray iron disk and brake pads [1, 2]. Friction materials are desired to be stable under high temperatures with the high friction coefficient [3, 4].

Brake pads have a huge part in the braking system. It provides an opportunity to slow down of a vehicle and make it stop. The working system of braking pads is related to convert energy that is kinetic energy into thermal energy by friction. Friction materials have an effect on the effectiveness of the brake and this eventually affects the performance of the brake pads [5, 6, 7].

Four classes of ingredients: binders, fillers, friction modifiers, and reinforcements [8] are used for making brake pads nowadays. We can give an example about containing such a large number of different constituents like ceramic particles and fibers, minerals, metallic chips, solid lubricants, and elastomers in a matrix material such as phenolic resin.

Along with industry 4.0, the production of automotive and the science of automotive have increased compared to the past. Current automotives' speed, acceleration, engine power, and aerodynamic settings have increased compared to the past. To control these over-speeded vehicles has been very important. The most important control system is the brake system. Current brake systems have been increased and to be increased more and more in the future [2].

Many important properties are required from the brake pad, such as a stable friction coefficient, low wear rate, low noise, vibration, and thermal deformation resistance [9, 10, 11]. In order to provide these properties, lining technology has developed greatly in recent years. Many friction materials continue to be examined in order to reach maximum efficiency in studies carried out with various methods. The wear rate was examined in the studies on the brake pad, but the numerical analysis was not carried out in the studies. In this study, additional numerical analysis to the studies in the literature [12, 13] was carried out.

The finite element analysis method has many advantages over other methods; Solid objects with complex geometry can be modeled, a realistic model can be created with realistic material acceptances, and different models can be created with any number of different materials, stress distribution and location replacements can be achieved precisely. By easily changing the applied forces, material properties, and geometry, it has become possible to perform the analysis easily and repeatably [14].

Yan [15], made a wheel model with the finite element method in his study. In this wheel model, the rubber material of the wheel is according to the LaGrange multiplier method. It has been analyzed. In this analysis, the rubber material of the wheel is defined as a rigid material. The nonlinear mechanical properties of elastomer materials are modeled with the Mooney-Rivlin model. In this modeling; The steel wire, rubber, and ropes used in the wheel texture and the internal structure of the wheels are in the Halpin-Tsai equations defined as equivalent orthotropic material as specified. The contact boundaries of the radial wheel and the rigid rim are determined using the variable limits method. The deformations of this model were calculated by the LaGrange method. The results of this analysis were found to be close to experimental results.

Brake pad contact and wear analysis was performed with Ansys in a study conducted in 2014. With this single-stop study, different friction coefficients and different brake linings were analyzed. According to the results, they have made significant progress for engineering design and analysis stages [16].

During braking, the kinetic energy of the moving masses transforms into heat energy through friction. This heat energy causes the brake pads to be exposed to extreme temperatures. The braking efficiency of the pads decreases over time, and some problems (decrease in the performance of the brakes, faulty operation, rapid pad wear, and noise) are excessive. In this study, modeled with the ABAQUS finite element program, 5 different lining materials, a continuous braking process for 300 s, temperature distributions, and stress conditions were investigated. In order to reveal the condition of the lining caused by the wear, 4 different thicknesses of the same lining have been taken into consideration in the analyzes In the research results, it has been explained since the thermal power acting on the pad changes depending on the distance from the center of the pad, higher temperature values are obtained towards the outer parts of the pad, the highest temperature values occur on the surface where the pad contacts the disc and that with the increase in the amount of wear, the amount of stress that occurs also increases [17].

As a result of their analysis at the end of braking, Hohmann et al. [18] detected high contact pressure in the outer radius of the lining and high pressure on the lining support plate when the pressure was applied to the lining while the disk was rotating. Tamari et al. [19], in their study on the estimation of contact pressure in disc brake linings, stated that the contact pressure should also be smooth in order for the wear in disc brakes to be smooth. Abu Bakar et al. tried to model the pressure distribution between pad and disc in a computer environment using different designs, sizes, and materials. They found that the asymmetrical and uneven pressure distribution caused uneven wear and shortened lining life. They concluded that the lining construction has an effect on pressure distribution and wear [20].

Abu Bakar et al. made a 3D analysis of the contact pressure distribution on the disc and pad

surfaces using the brake disc and finite element model. The core of the method is the transmission hardness of the asymmetric solid matrix and the friction coefficient at the disc and pad interfaces. They investigated different levels of model brake disc and contact pressure distribution. By using the appropriate model, it is provided to estimate the pressure distributions in the interfaces of the brake discs [21]. Abu Bakar et al. experimentally found the noise and sound vibration caused by dynamic instability due to friction during braking and analyzed the data using the ABAQUS package program [22]. Valvano and Lee studied the behavior according to the short-term and straight case documents of their study. The maximum temperature of the disc is found in contact with the pad and they have found repetitive braking [23].
Arpat, when light and heavy commercial vehicles are currently loaded, when the lining in the lining is examined due to the temperature on the friction surface of the linings in drum or disc brake systems. He found that the wear on the pad was reduced by reducing the temperature during braking [24]. Jacobsson performed a conventional disc brake analysis. He concluded that it consists of operating forces of mechanical degradation and thermal degradation over time. In the experimental study contact, it turned out that there should be thickened and thickened disc [25].
Mosleh et al. studied the abrasive materials and curettage and friction behavior of pads subjected to braking at various speeds. Drag brake some facts in experimental tests. They stated that due to the difference of brake materials, transmission change depends on low and high sliding speeds [26]. Hwang et al. described thermoelastic irregularity during perspiration during braking. They studied the change of temperature and thermal deformation with a finite element method under complete braking and repeated braking [27]. They found that the maximum temperature of the disc is in the environment in contact with the pad and that repetitive braking occurs emphasizing that the noise formation during braking in disc brakes is caused by the pressure and distribution on the pad surface [28]. Experimental studies and numerical analysis have shown that high pressure with a uniform distribution on the surface and a high-temperature value has emerged. They found that the temperature is effective in noise and vibration on the pad surface.

2. Aims and Background

The aim of the current research is a comparison of the wear ratio on the brake pad with the real values and the simulation values. Therefore, brake pad samples prepared from cashew and ulexite mixtures were used. To create a mixture these materials have been used in different amounts. These specimens are designed to have different ingredients [29]. All samples were produced by powder metallurgy method. The aim of the research is to see the effects of the friction surface on these samples using the Ansys program.
Ulexite and cashew, which were used at different rates in previous studies, were used [30,9]. Ulexite is sifted after grinding to obtain dust as raw boron products, is the reason in order to test the performance of ulexite in automotive friction materials. To create a mixture these materials have been used in different amounts. To have different ingredients five kinds of specimens are designed [31,32].
Mainly important material is cashew for the production of braked pads. It has a ductile structure and provided stability of the braking system. Also, protect the brake pad until 580 degrees temperature and protect more wear and braking capability [33,34].

3. Experimental

In this study, the accuracy of the results of the studies which developed a new automotive brake friction material by using additional ulexite in the simulation software was checked. Comparison of simulation values with actual values.
The composition of the friction materials studied in this work is shown in Table 1. These material properties are created in the Ansys material library (Density, hardness, etc.). Pad samples are designed to be 25.4x25.4 mm and 6 mm in thickness. Five different specimens are assigned on the pad.
Simulating analyses were carried out at 1.05 MPa pressure, 6 m s^{-1} velocity, and temperatures from 50 to 400°C for 100s. Conditions in all samples were the same. Then, friction force is found at each stage.

Table 1: Ingredients of samples (wt.%)

	Specimen Codes				
	UC-4	**UC-8**	**UC-12**	**UC-16**	**UC-20**
Phenolic Resin	22	22	22	22	22
Steel Fibre	15	15	15	15	15
Al_2O_3	3	3	3	3	3
Brass Particles	5	5	5	5	5
Graphite	3	3	3	3	3
Barite	20	20	20	20	20
Cu particles	8	8	8	8	8
Cashew	4	8	12	16	20
Ulexite	20	16	12	8	4
Total	100	100	100	100	100

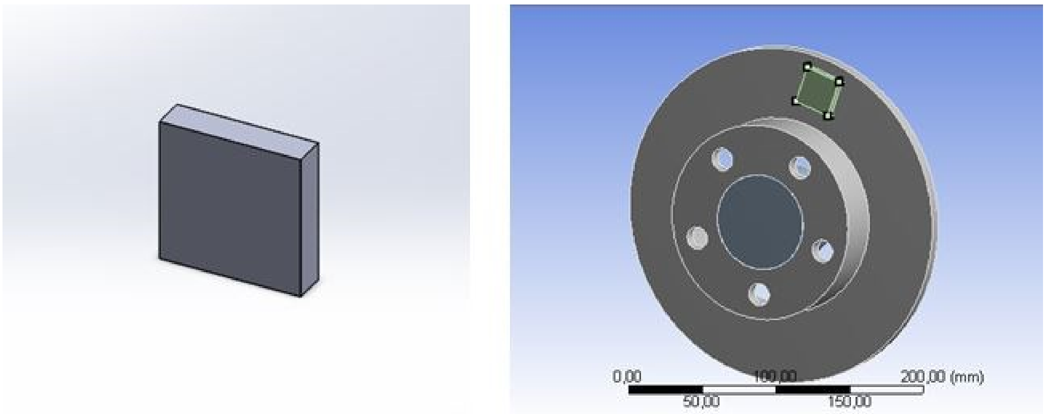

Fig.1. Sample 3D isometric view and brake disc isometric view

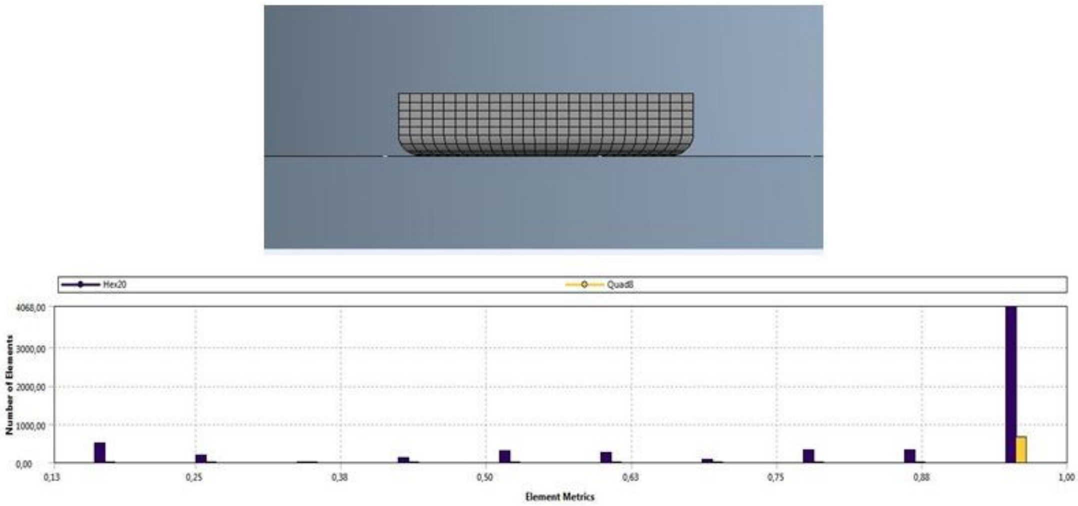

Fig. 2. Mesh view and mesh quality

About the wear, Archard's classical wear model has been used for disk brakes. Archard's wear law shows that the wear ratio scales for slip velocity and normal contact force. The studies that's been processed on the Ansys workbench, the formulas have been integrated according to Archard's classical wear model, fort o calculate the thickness of the wear. In that way, it can be calculated that the weight that's been lost from the wear [21].

$$Q = \frac{KWL}{H} \quad (1)$$

Q is the total volume of wear debris produced
K is a dimensionless constant
W is the total normal load
L is the sliding distance
H is the hardness of the softest contacting surfaces

Archard equation is defined into the system using Ansys APDL. Specific wear rate is determined by the mass method following the Turkish Standard (TS 555) and British Standard (BS AU142) and calculated by the following equation:

$$V = \frac{(m1 - m2)}{L.f_m \rho} \quad (2)$$

Where:

V is specific wear (mm^3/MJ),

m_1 – the mass of the brake pad before testing (kg),

m_2 – the mass of brake pad after testing (kg),

L – friction distance calculated by using the number of revolutions and radius of the disc (m),

f_m – average friction force (N),

ρ – the density of brake pad (kg/mm^3) [35,36].

Mesh is a very important step for this studying. Because it is necessary to define the contact surfaces in wear analysis. Mesh quality and mesh elements increased.

4. Results and Discussion

Effect of hardness and density on wear ratio, in the present study, 5 specimens were used. These specimens contain copper particles, phenolic resin, Al_2O_3, steel fibre, brass particles, graphite, barite, ulexite, and cashew (Table 1). These samples include 4–20% ulexite and 20–4% cashew, and the mean of friction coefficient is ranging from 0.394 to 0.437. It is also known that hardness and density are different for 5 materials (Table 2). In this analysis, the effects of hardness and density on material wear were observed.

According to the results, the loss to volume due to wear can be found. It can be reported graphically (Fig.3, 4, 5).

Effect of hardness and density on wear distribution, parallel to the loss to the volume due to the wear solutions. With this analysis, the distribution of wear on the surface of the pad can be found. It can be reported graphically (Fig.6, 7, 8).

Table 2: Typical characteristics of the brake pad used [30]

Sample Code	Mean coefficient of friction	Standard deviation	Density (g/cm^3)	Hardness (Brinell)	Specific wear (g/mm^2)
UC-4	0.394	0.0182	1.935	18.2	$0.26x10^{-6}$
UC-8	0.401	0.0172	1.842	16.2	$0.27x10^{-6}$
UC-12	0.420	0.0192	1.765	15.9	$0.34x10^{-6}$
UC-16	0.427	0.0216	1.704	14.7	$0.37x10^{-6}$
UC-20	0.437	0.0223	1.680	13.9	$0.38x10^{-6}$

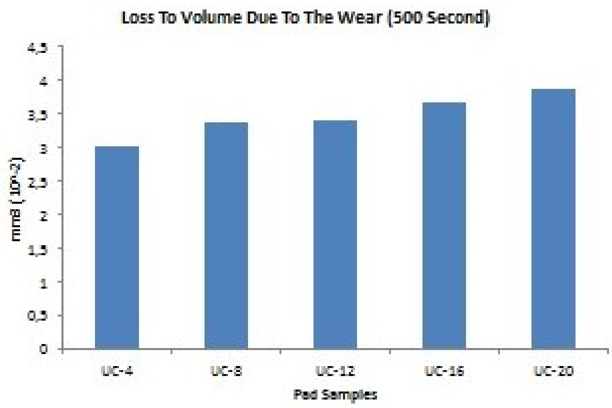

Fig. 3. Loss to volume due to wear of samples

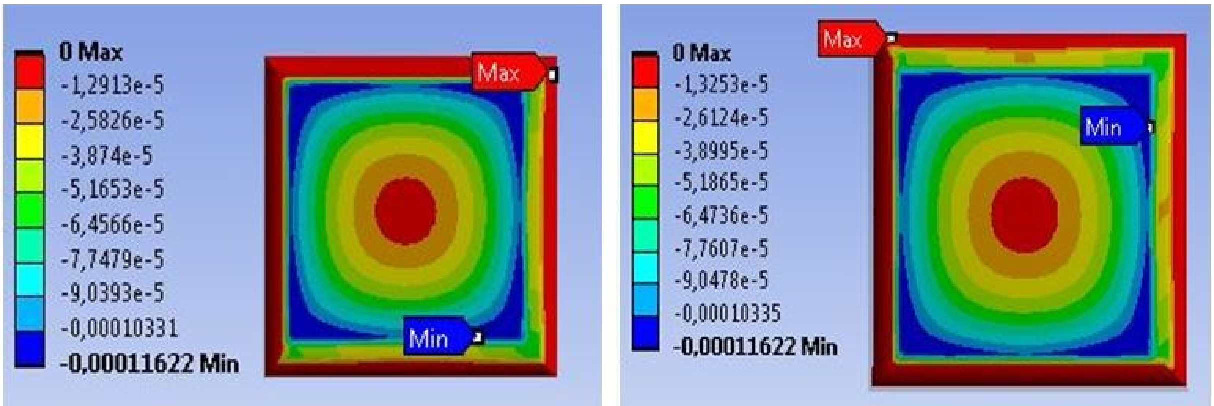

Fig.4. Wear distribution on the surface of UC-4&UC-8 Samples.

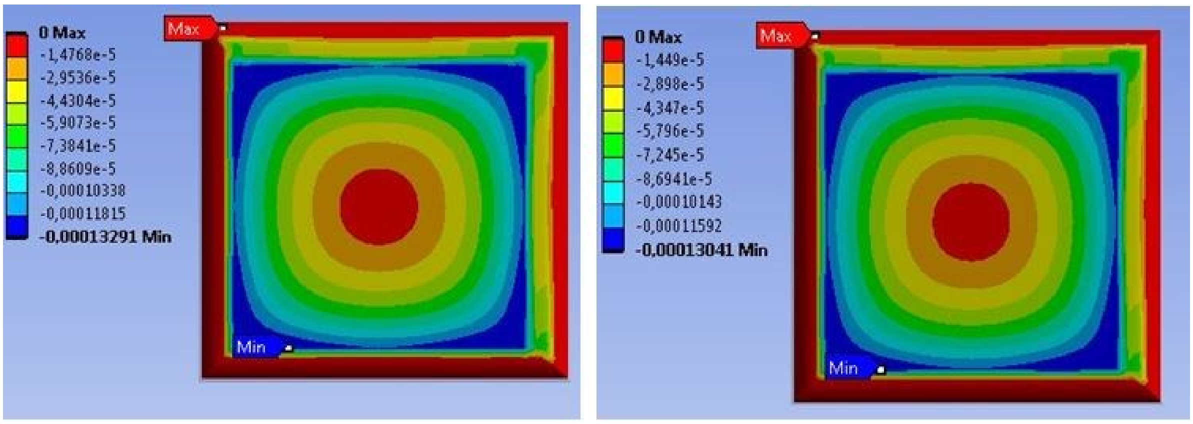

Fig. 5. Wear distribution on the surface of UC-12&UC-16 Samples.

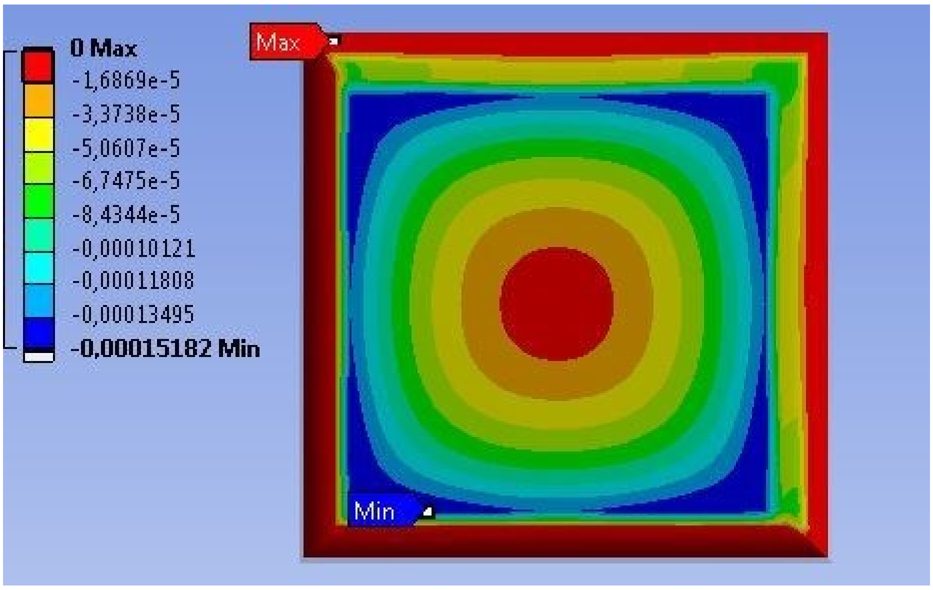

Fig. 6. Wear distribution on the surface of UC-20 Sample.

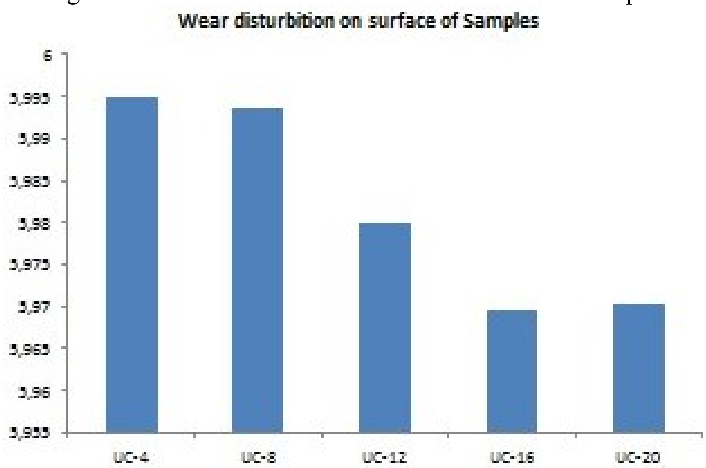

Fig. 7. Wear distribution on the surface of samples.

Table 3: Compare Simulation Results Table

Sample	Specific Wear/Ansys	Specific Wear/Experimental	Density	Percentage of Tolerance	*K* Constant
UC-4	2.65E-07	2.60E-07	1.935	+%2	0.000003
UC-8	2.95E-07	2.70E-07	1.842	+%9	0.000003
UC-12	2.95E-07	3.40E-07	1.765	-%13	0.000003
UC-16	3.14E-07	3.70E-07	1.704	-%14	0.000003
UC-20	3.30E-07	3.80E-07	1.68	-%13	0.000003

Effect of hardness and density on total deformation, UC-4 has observed the most total deformation according to other samples. This means more density and hardness affect total deformation negatively.

According to the results, the wear ratios that's been found are different to real solutions. This kind of difference is normal because the mean friction factor could not been calculated out of analyses. Also, material properties are not clear, so data input is limited. Although there are differences in results, parallel results were obtained according to the actual results. The results are founded approximately between +%9 and -%14 (Table 3). While the *k* coefficient used in the previous study is 0.018, this is 0.000003.

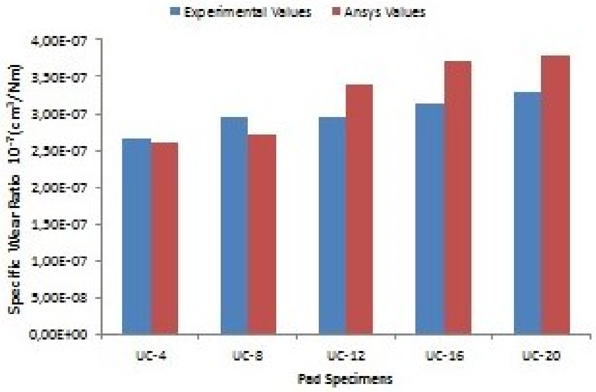

Fig. 8. Specific wear for experimental values and ANSYS values of specimens

The UC-4 sample has the highest density and hardness all of the samples. Its chemical structure has 20% of ulexite and 4% of cashew; the specific gravity of ulexite is bigger than that of cashew. More ulexite means high density. The UC-4 has less wear than other samples. The hardness of UC-4 is bigger than other samples. According to data, the material with high hardness has a low wear rate. Wear rate increases while hardness decreases. The UC-20 has more wear than other samples. The hardness of UC-20 is lower than other samples. According to data, the material with low hardness has a high wear rate. Wear rate increases while hardness decreases. The UC-4 has less wear than other samples. The density of UC-4 is bigger than other samples. According to data, the material with high density has a low wear rate. Wear rate increases while density decreases. The UC-20 has more wear than other samples. The density of UC-20 is lower than in other samples. According to data, the material with low density has a high wear rate. Wear rate increases while density decreases. Time was used as 500 seconds in this analysis. The rate of wear increases depending on the time. Also, brake disc speed is used as 6 m/s. This speed can be increased or decreased. In this study, pad surface temperature increased from 22 °C to 400 °C depending on time. Depending on the temperature and speed, stickiness on the surface of pad samples is observed (Fig.9). While the stickiness is very high in the center of the pad, it decreases towards the edges.

Also, in this study, is observed the pressure distribution of the pad surface. The highest pressure zone is in the center of pad samples. Pressure decrease from the center towards the outer regions. Minimum pressure is occurred outside of samples.

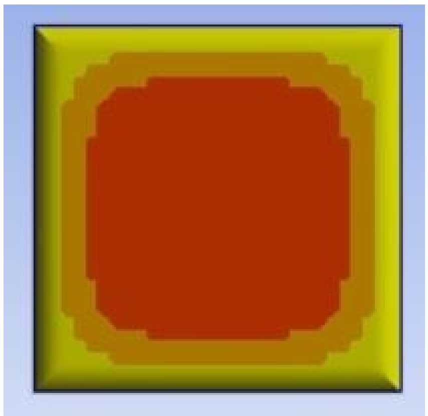

Fig. 9. Sticking distribution of the pad surface

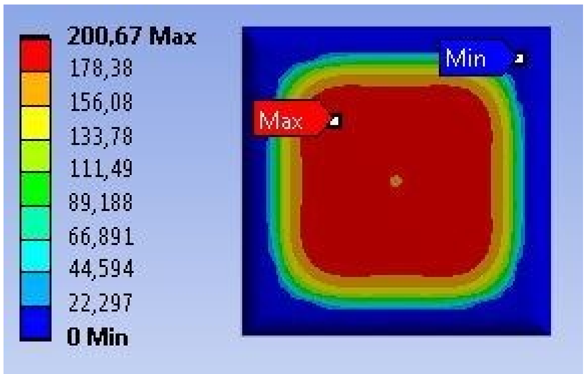

Fig. 10. Pressure distribution of the pad surface

5. Conclusions

The following results have been found;

- According to the received values, it has been observed that there is a direct proportion between the density and the wear ratio.
- Density and hardness are the most important factor for loss of volume due to wear.
- In this study, it has been observed that these kinds of tests can be processed on a computer yet to be able to get the most realistic

results it has to be known that all the parameter specifications.

- Material specifications can improve. Material properties need to be entered more accurately to get closer to real results. We need to define the material library.
- The wear distribution is generally concentrated in the center of the material. We get such a result because it is applied as the center of pressure on the lining.
- The wear ratios that's been found with the received values on Ansys are in the TSE-555 boundary.
- The results are founded approximately between +%9 and -%14.

Archard's equation mainly depends on surface pressure and speed but, wear depend on all of the different features such as hardness of the material, density, etc.

CRediT authorship contribution statement

Gökhan Bilgi: Methodology, Resources, Visualization
Mustafa Atakan Akar: Investigation, Writing - original draft, Supervision, Writing - review& editing.
İlker Sugözü: Investigation, Methodology, Conceptualization,
Umut Kumlu: Investigation, Visualization, Writing - original draft, Writing - review& editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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