ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc. THESIS

Gökhan BİLGİ

SIMULATING FRICTION AND WEAR BEHAVIOUR OF A BRAKE PAD USING DIFFERENT MATERIALS

DEPARTMENT OF AUTOMOTIVE ENGINEERING

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ABSTRACT

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The brake pads used in automotive brakes are made from the composition of many substances. The main features required from a brake pad are wear resistance in accordance with the standards, friction coefficient. The brake pads overheat due to friction during braking. In this study, the performance characteristics of the brake pad obtained by using the materials that make up the lining content were investigated in the simulation environment. In this context, brake disc and pads which are different contents are designed using CATIA V5 Program. The pads designed are simulated using ANSYS program and the wear rates, friction coefficient thermal behaviors and surface structure are examined.

Keywords: Break pad, Ansys, Friction, Wear, Thermal Analysis

ÖZ

YÜKSEK LİSANS TEZİ

FARKLI MATERYALLER KULLANARAK FREN BALATASININ SÜRTÜNME VE AŞINMA DAVRANIŞININ SİMÜLASYONU

Gökhan BİLGİ

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Otomotiv frenlerinde kullanılan fren balataları birçok maddenin bileşiminden yapılır. Bir fren balatasından istenilen temel özellikler, standartlara uygun aşınma direnci, sürtünme katsayısıdır. Frenleme sırasında sürtünme nedeniyle fren balataları aşırı ısınmaktadır. Bu çalışmada balata içeriğini oluşturan malzemeler kullanılarak elde edilen fren balatasının simülasyon ortamında performans özellikleri incelenmiştir. Bu kapsamda fren disk ve farklı içerikteki balatalar CATIA V5 Programı kullanılarak tasarlanmıştır. Tasarlanan balatalar ANSYS programı kullanılarak yapılan simülasyon testlerinde aşınma oranları, sürtünme katsayısı termal davranışları ve yüzey yapısı incelenmiştir.

Anahtar Kelimeler: Fren Balatası, Ansys, Sürtünme, Aşınma, Termal Analiz

EXTENDED ABSTRACT

Along with the evolving of the composite technology, organic friction materials have been starting to find a place for themselves in automotive market. They have been using a lot of areas in automotive market. The endurance and productivity of these parts, have been started to improve and still being analyzed as well.

One of the most important systems in automotive technology is the brake system. The brake system is the most important system that is used for, to be able to make a vehicle, that moves, slow down or stop; and make one stay where it is. This system's importance is very vital. There are a lot of parameters that shows the performance of the brake system. One of the most important is, the length of brake distance. The length of brake distance is directly related with the performance of the brake lining. For the brake system, brake lining is one of the most important part.

The brake lining needs to provide; regular friction factor, low wear ratio, low sound, vibrationless and temperature strain resistance etc. (Handa et al. 1996). For the last few years, the brake lining technology have been showed a big improvement to be able to provide all these specifications. The analyzes have still been going on to be able to reach maximum yield for a lot of friction materials for a lot of different methods.

Although the first thought about the brake system is only that it makes the vehicle stop at intented duration, it can be said that brakes has a lot of performance signs and they are more than make a vehicle stop. Nowadays, brakes are safe, vibrationless and ensured continuity.

For the last few years, automotive firms have started doing analyzes to improve pad lining materails on computer, along with the traditional methods. They have been trying to get real results on computer, instead of the cost of the test setups.

The goal of this study, to take a test and simulate it on computer for get quicker results. This analsis have been conducted on computer with using Ansys program. Free from the laboratory conditions, because there are a lot of factors that affect the pad lining, it is so normal that the received values is going to be different from the real values. The known values of the features of the friction materials have been processed on computer. Along with giving no certain results, the received values, it shows us the effect of the different friction materials on pad linings.

In this study, along with the effect of the different friction materials on pad linings, it also shows that the variables of the same friction materials at different medium conditions.

The conditions of the test that are needed this study to transfer to analysis environment, has been taken from different studies. Besides, the features of materials has also been taken those studies and tranferred to the computer. The brake disc facing that's been used is designed using Catia V5 on computer. The analysis have been made on workbench.

Besides, the general reasons for wear is; tribological, mechanical, metallurgical and thermal effects. About the wear, Archard's classical wear model have 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 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 caluculated that the weight that's been lost from the wear.

On the pad lining and disc brake, the rigidity behaviour that is required have been integrated. Moreover, the contact and friction conditions between the pad lining and the disc brake, have been processed on Ansys workbench. The thermal conditions have been provided. The amount of mass lost was recorded by multiplying the volume lost and the density of the material.

Aside from the regular test conditions, it has been analyzed the received values for different velocity stops. It is been observed that there is a scale between the velocity and and wear ratio.

There is a visuals of the results obtaine, the graphs of the volume loss related wear, the comparison of the analysis results with real values, the deformation on pad lining and wear areas visulas. Also, the graphs that shows the friction force from the real values, take part.

One of the results of this study is the ability to see on which surfaces the temperature distributions on the brake pad are.

The connections between the effect of the volume ratio lost due to abrasion on the density and the rate of abrasion were observed and it was aimed to approach the results of the experiment.

One of the results of this study is the ability to see on which surfaces the temperature distributions on the brake pad are.

In general, it has been observed that in a direct way there is loss of thermal along with the volume.

According to the results of the analysis, it has been obtained that the levels of the viscousness on the surface of the pad linings. Among 5 samples, it has been seen that the viscousness decreased from the centre of the pad lining to the surface that doesn't effected by the friction.

It has been observed that under the 1.05 Mpa, the pressure doesn't distribute equally on the pad linings surface with the contact of the brake disc. The sample of the pad lining is the place where the central pressure and the brake has been seen the most.

The wear on the pad lining does not distributed equally on the pad lining. In general, the wear is mostly occurred in the centre of the pad lining, to the external sides of the pad lining the wear ratio is decreased.

In this study, it has been observed that these kind of test can be processed on a computer environment yet to be able to get the most real results it has to be known that all the parameter spesifications.

According to the results, the values obtained are within the specific wear limits specified by TSE-555 Standards. However, differences were observed with the results of the experiments conducted in the laboratory conditions. In this study, the findings causing this difference are included.

The development of this work done in the computer environment will help to decrease the experiments carried out in the laboratory conditions and to reduce the costs depending on these reductions.

GENİŞLETİLMİŞ ÖZET

Kompozit teknolojisinin gelişmesi ile beraber, organik sürtünme malzemeleri de otomotiv sektöründe kendisine yer bulmaya başlamıştır. Özellikle otomotiv sektöründe birçok alanda kullanılmaktadır. Bu parçaların dayanımları, verimlilikleri de geliştirilmeye başlanmış ve incelemeleri devam etmektedir.

Otomobil teknolojisinde en önemli sistemlerden birisi, fren sistemidir. Hareket halindeki bir aracı yavaşlatmaya veya durdurmaya, duran bir aracın ise yerinde sabit olarak kalmasını sağlamaya yarayan en önemli sisteme fren sistemi denir. Fren sisteminin performansını gösteren birçok parametre vardır. Bunlardan en önemlisi frenleme mesafesinin uzunluğudur. Bu mesafenin uzunluğu fren balatasının performansı ile doğrudan ilişkilidir. Fren sistemi için en önemli parçalardan birisi balatadır.

Fren balatasından stabil bir sürtünme katsayısı, düşük aşınma oranı, düşük ses, titreşimsizlik ve ısıl deformasyon direnci gibi birçok önemli özellikler istenir (Handa et al., 1996). Bu özelliklerin sağlanması için balata teknolojisi son yıllarda büyük bir gelişim göstermiştir. Birçok sürtünme malzemesi de çeşitli yöntemlerle yapılan çalışmalarda, maksimum verime ulaşmak için incelenmeye devam etmektedir.

Frenleme işlemi başlarda sadece aracı istenilen sürede durdurmayı gerektirdiği düşünülse de frenlerin birçok performans göstergesi olduğunu ve sadece durdurmanın ötesine geçtiği söylenebilir. Frenler günümüzde güvenli, sarsıntısız ve sürekliliği sağlanmış bir sistem anlamına gelmektedir

Son yıllarda otomotiv firmaları balata malzemelerini geliştirmek için geleneksel yöntemlerle beraber, bilgisayar ortamında da yeni çalışmalara başlamıştır. Deney düzeneklerinin maliyetlerinin yüksek olması nedeniyle bilgisayar ortamında reel sonuçlara yaklaşma çabası içine girmişlerdir.

Bu çalışmanın amacı sonuçlanması uzun süren bir deneyi, bilgisayar ortamında tasarlayıp, simüle ederek daha kısa sürede sonuca ulaşmaktır. Bu inceleme bilgisayar ortamında, Ansys programı kullanılarak yapılmaktadır. Laboratuvar şartlarından bağımsız olarak, balata performansına etki eden bir çok etken olduğundan elde edilen değerler , reel değerlerden farklı çıkacak olması çok normaldir. Sürtünme malzemelerinin özelliklerinin, bilinen değerleri bilgisayar ortamında işlenmiştir. Elde edilen değerler kesin sonuç vermemekle birlikte, farklı sürtünme malzemelerinin fren balatası üzerindeki etkilerini bizlere göstermektedir.

Bu çalışmada farklı sürtünme malzemelerinin fren balatası üzerindeki etkileri ile birlikte farklı ortam koşullarında aynı sürtünme malzemesinin göstereceği değişkenlikler de gösterilmektedir.

Bu çalışmanın analiz ortamına aktarılmasında gerekli olan deney şartları farklı çalışmalardan alınmıştır. Ayrıca, malzeme özellikleri yine bu çalışmalardan bilgisayar ortamına aktarılmıştır. Kullanılan fren disk ve balatası Catia V5 kullanılarak bilgisayar ortamında tasarlanmıştır. Analizler ANSYS workbench üzerinde yapılmıştır.

Ayrıca, Aşınmaya genel olarak; tribolojik, mekanik, metalürjik ve termik etkiler sebep olur. Aşınmayla ilgili olarak, diskli frenlerle ilgili literatürde yaygın olarak Archard'ın klasik aşınma modeli kullanılır. Archard'ın aşınma yasası, aşınma oranının kayma hızıyla ve normal temas kuvvetiyle orantılı olduğunu gösterir. ANSYS workbench üzerinde yapılan çalışmalarda, aşınma kalınlığını hesaplamak için Archard'ın klasik aşınma kanuna göre, formüller entegre edilmiştir. Böylece, aşınmadan dolayı kaybedilen kütle miktarı hesaplanabilmektedir. Kaybedilen kütle miktarı, kaybedilen hacim ile malzemenin yoğunluğunun çarpılması ile kaydedilmiştir.

Fren balatası ve disk üzerinde, gerekli olan sertlik davranışları entegre edilmiştir. Ayrıca, fren balatası ve disk arasındaki kontak koşulları ve sürtünme şartları Ansys workbench üzerinde işlenmiştir. Termal koşullar sağlanmıştır.

Normal deney koşullarına benzer frenleme yaptırılmış olup elde edilen veriler yorumlanıştır. Hız ve aşınma oranı arasında bir orantı olduğu gözlemlenmiştir.

Elde edilen sonuçların aşınma kaynaklı hacim kayıplarının grafikleri, bilgisayar ortamında analiz sonuçlarının reel değerlerle karşılaştırılması, balata üzerindeki deformasyon ve aşınma bölgeleri görselleri yer almaktadır. Ayrıca, reel değerlerden alınan sürtünme kuvveti grafikleri de bu çalışmada yer almaktadır.

Bu çalışmanın sonuçlarındandın önemli bir kısmı da, fren balatası üzerindeki sıcaklık dağılımlarının hangi yüzeylerde olduğunun görülebilmesidir.

Aşınmaya bağlı olarak kaybedilen hacim oranının yoğunluk, aşınma oranına etkisi arasındaki bağlantılar gözlemlenmiş olup, deneye sonuçlarına yaklaşılması amaçlanmıştır.

Analiz sonuçlarına gore , analizlerden sonra fren balatasının yüzeyinde yapışkanlık dereceleri elde edilmiştir. 5 farklı numunede genel olarak fran balatasının merkezinden , sürtünme görmeyen yüzeylere doğru yapışkanlığın azaldığı görülmüştür.

Fren balatasının 1,05 Mpa basınç altında fren diskine teması sonucunda fren balatasının yüzeyinde basıncın eşit dağılmadığı gözlemlenmiştir.Fren balatası numunesinin merkezi, basıncın ve frenin en fazla görüldüğü yerdir.

Fren balatasının yüzeyindeki aşınmanın , balata yüzeyinde eşit dağılmadığı gözlemlenmiştir. Genel olarak balatanın merkezinde en fazla aşınma gerçekleşirken , balatanın dış yüzeylerine doğru aşınma oranının azaldığı gözlemlenmiştir.

Bu çalışmada, bilgisayar ortamında bu tip çalışmaların yapılabileceği ancak mevcut koşullara en yakın sonuçların alınması için tüm parametrelerin de bilinmesi gerektiği gözlemlenmiştir.

Sonuçlara göre, elde edilen değerler TSE-555 Standartlarının belirtmiş olduğu özgül aşınma sınırları içindedir. Ancak, laboratuvar şartlarında yapılan deney sonuçları ile farklılık gözlemlenmiştir. Bu çalışmada bu farklılığa sebep olan bulgulara yer verilmiştir.

Bilgisayar ortamında yapılan bu çalışmanın geliştirilmesi, laboratuvar şartlarında yapılan deneylerin azalmasına ve bu azalmalara bağlı olarak maliyet düşürme çalışmalarına yardımcı olacaktır.

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1. INTRODUCTION

One of the most important composite materials is the friction element of an automotive brake system and it generally consists of more than ten ingredients. The reason being a steady friction force, a reliable strength, and a good wear resistance in a broad range of braking circumstances must be provided by the friction materials. (G. Jacko, S. K. Lee, 1992). Failed brake systems is the reason that the most fatal accidents on the roads happen, some recent studies have shown. The tribological characteristics of the friction couple, composed of a gray-iron disk (or drum) and friction materials are the factors that determine the performance of a brake system in a vehicle. (Milenković, P.D. et all , 2010 & Akay ,2002).

In order to stop the motion of a machine, artificial frictional resistance is applied to moving machine member, which is the meaning of a brake that is a device. There is a growing trend to have disc brakes on the front wheels on the rear wheels as well in modern cars. Decreasing the speed of the vehicle is the result of the braking process which is the matter of energy balance and aim of braking system is to transform mechanical energy of moving vehicle into some other form. The brake cylinder pressure increases and the piston pushes the pads into contact with the disc, when the driver hits the brakes. and The subsequent friction between the tire and the road, which happens after the friction force between the brake pads and disc exerts braking torque on the disc, which is connected to the wheel, makes the car slow down. (G. Jacko, S. K. Lee, 1992 & Ericcson 2002) .

A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of a machine. Modern cars have disc brakes on the front wheels, and there is a growing trend to have them on the rear wheels as well. The braking process is in fact the matter of energy balance and aim of braking system is to transform mechanical energy of moving vehicle into some other form, which results in decreasing the speed of the vehicle. The kinetic energy is transformed into the thermal energy by means of dry friction effects, which then is, dissipated into the surroundings (Mikael Eriksson, Staffan Jacobson, 2000). A brake disc rotor is firmly fitted to and rotates with the wheel. Two brake pads are positioned inside a caliper mounted on the knuckle, which is mounted on the chassis. When the driver hits the brakes, the brake cylinder pressure increases and the piston pushes the pads into contact with the disc. The friction force between the brake pads and disc exerts braking torque on the disc, which is connected to the wheel, and the subsequent friction between the tire and the road makes the car slow down. An example of a disc brake assembly that consists of a ventilated disc, a cross-section of a sliding caliper with a single piston, and two brake pads is presented in Figure 1.1.

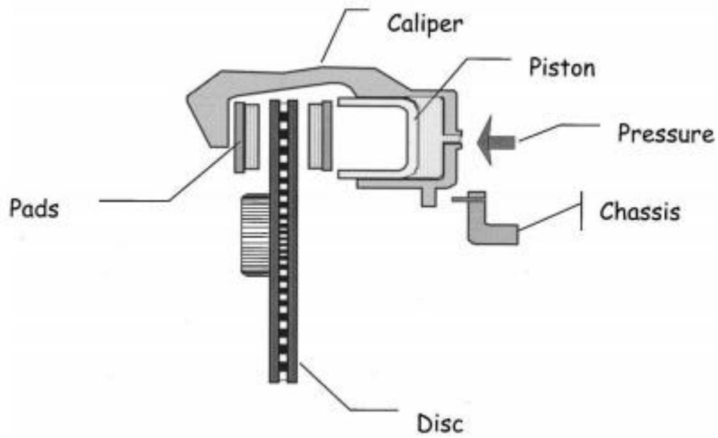


Figure 1.1. Disc and pad brake assembly with a single-piston and a ventilated disc (D Chan and G W Stachowiak , 1996)

Automotive brake system consists of three main parts (Eriksson, 2000).

a) Rotor (drum or disc); wheel with rotating part.

It forms the opposite surface part of the friction pair. Rotor material is usually gray cast iron.

b) Pad (shoe or pad); the friction surface portion of the friction pair.

At the moment of braking, the friction surface on the rotor via hydraulic piston Suppressed. Friction between rotating drum or disc and fixed lining forces convert kinetic energy to heat energy. Generally counter surface wear is allowed while the friction surface is allowed to wear.

c) Hydraulic system; Braking force on brake pedal in order to transfer to hydraulic piston and increase pressure is a system used. Hydraulic system ABS in modern brake systems system.

1.1. Brake Pads

As the brake pads ,which are among the most complex ever produced composite materials, contain the three main different types of materials, i.e., metals, ceramics and polymers. Finding the right composition and mixing, is very very difficult beacuse this chemical diversity and chemical-physical makes it so [Eriksson et al.,2000, Chan et al.,2004].

Figure 1.2. A commercial brake pad friction material

Wet lay-up, prepare lay-up, adhesive bonding, liquid composite moulding, continuous lamination, compression moulding and filament winding are the most commonly used sandwich production methods (Karlsson and Åström, 1997).

In general, the friction materials have to withstand conditions of high pressures and temperatures throughout their use, certainly these materials should be of durability, comfort, affordability and above all ensure safety at all times that they can perform their function braking efficiently. In particular, the properties that are required to friction materials are:

- Resistance to wear.
- Resistance to thermal fatigue.
- Resistance to shear and compression that are generated during braking.
- Low sensitivity to environmental conditions such as water, oils and corrosive salts.
- Thermal stability and oxidation.
- Workability and ease of production.
- No or very little vibration and noise during operation.
- Ensure a stable friction coefficient under different conditions and time. [Mukesh et al., 2014]

1.2. Tribology

Tribology is the "science and technology of interacting surfaces in relative motion and of the practices related thereto" or, in other words, the study on lubrication, friction, and wear of moving or stationary parts in physical contact (essentially rolling, sliding, normal approach or separation of surfaces) (Bernard J Hamrock et all , 2004 & Gwidon Stachowiak and Andrew W Batchelor 2013). Both mechanical phenomena and several topics in materials science and chemistry, making it a greatly interdisciplinary field that are comprised by tribology. Tribology comprises not only mechanical phenomena, but several topics in materials science and chemistry, making it a greatly interdisciplinary field.

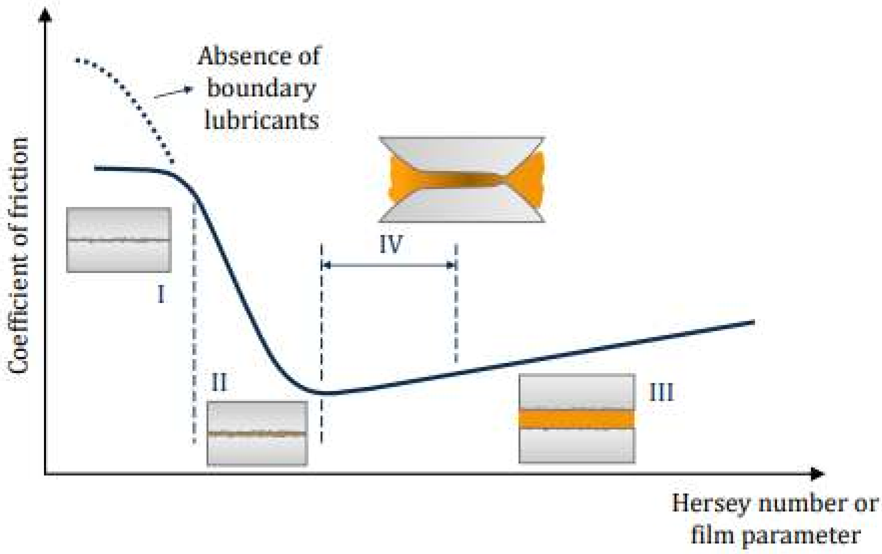


Figure 1.3. Stribeck curve showing the behaviour of friction for different lubrication regimes along with scheme of physical cases; I: Boundary, II: mixed, III: hydrodynamic, IV: EHL (non-conformal contact only). (Mikael Eriksson, 2001)

1.3. Wear

Abrasive wear, a harder material/body removes material from a softer body, which can occur by cutting, microfracture on brittle abraded materials, pull-out of individual grains, or repeated deformations by subsequent grits .Cutting refers to the classical model, resulting in wear grooves, micro-machining, or scratching. The abrasive particles can be present in the microstructure, enter as contaminants, or generated as wear debris, the abrasive action can be in terms of ploughing, i.e., plastic grooving without material removal, or in terms of cutting. The process can be thought of consisting of three stages mechanical deformation and stresses at a contact area; action of the frictional forces; rupture of material.

Adhesive wear occurs during sliding due to the continuous sticking and tearing of the adhesive junctions, thus it is related to interfacial wear and friction due to shearing of the junctions. Abrasive wear, on the other hand, is related to the ploughing phenomenon. This overview follows the concept of the two-term friction model, i.e., that the energy dissipation of the two frictional terms results in two general modes of damage and consequent wear: interfacial, and cohesive The balance between interfacial bonding and cohesive forces of the material determine how the fracture will occur.

2. PREVIOUS STUDIES

There are many studies concerning friction and wear behavior of a brake pad. Sugözü , Mutlu and Keskin (2015) investiagated friction and wear behavior of a brake pad using ulexite and cashew. Aim of this study , composites mixed different rates and testing with their method . It is achieved that wear and friction behaviour same conditions such as pressure, velocity etc. . The braking tests were realized at a pressure of 1.05 MPa, a velocity of 6 ms–1 and at temperatures from 50 °C to 400 °C for 500 s. The materials used to produce sample of pads are attached.

Table 2.1. Ingredients of the samples (w/%) (Sugözü et all , 2015)

Sample code	UC-4 UCH-4	UC-8 UCH-8	UC-12 UCH-12	UC-16 UCH-16	UC-20 UCH-20
Phenolic resin	22	22	22	22	22
Steel fibers	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

Samie and Sheridan (1990) studied the effects of friction using the finite element technique. In this study , calculated results without the friction forces (static case), they reach to different the inboard and outboard pressure distributions. Aim of this study , compare with effect of frictions with friction and no-friction case.

Dhami, Thiyagarajan and Mathur (2004) investigated reseraching the hardness and tribological behaviour that which is non-asbestos brake pad materials for automobiles such as Fiber Glass. In that study, hardness of the brake pad has been controlled using suitable reinforcement materials like glass, carbon and

Kevlar pulp. Brake pad formulations were made using CNSL (cashew net shell liquid) modified phenolic resin as a binder, graphite or cashew dust as a friction modifier and barium sulphate, talc and wollastonite as fillers. The materials used are ;

Table 2.2. Materials Proporties (Dhami,Thiyagarajan and Mathur (2004))

Sample No.	Phenolic Resin HR-6152	Glass Fibre (3 mm)	Friction Modifier CD-25	Copper Powder	Barium Sulphate	Wollastonite
A_1	20	6	15	10	25	24
A_2	25	6	15	10	22	22
A_3	30	6	15	10	20	19
A_4	35	6	15	10	17	17
A_5	40	6	–	–	27	27

Sugözü et al. (2011) studied to impact on the performance of lining of heat treatment time from lining produce parameters was investigated. Samples with the same content were produced in 18 MPa pressure, at 150oC temperature in 10 minutes hot pressing time, at 200ºC temperature in different heat treatment time such as 1 (HTT-1), 3 (HTT-3), 5 (HTT-5) hours and friction performance were investigated.

Imam, Syafa'at (2012), presented paper on Prediction of Sliding Wear of Artificial Rough Surface. When two surfaces are brought in contact, deformation takes place at asperity level. The local pressure distribution and deformation of the contacting surface are importance with respect to wear. This paper describes a wear model to predict the wear of rough sliding contacts. The wear model is based on the general Archard's wear equation in combination with finite element analysis (FEA). In this paper the roughness is represented by uniformly distributed spherical asperities. The proposed model, FE in combination with Archard's wear law, has proven to be a powerful tool in predicting wear of rough surfaces.

Alen, John (2014), presented paper on Stress Analysis of Polyoxymethylene which Leads to Wear in Pin on Disc Configuration using Finite

Element Method. The wear is defined as the progressive loss of substances from the operating surface of a body occurring as a result of relative motion at the surface. The simulation of the stresses which leads to wear in pin on disc configuration having the pin made of polyoxymethylene having the NC010-150 designation in sliding contact with the rotating steel disc was performed using finite element software ANSYS Workbench11.0. The three dimensional geometry of the required configuration was made by using the modeling software CATIA. Using the boundary conditions the analysis were done. Rotation of 3000 rpm was provided for the disc. Then with analysis software he was analyzing the wear by varying the pressure acted up to the tensile yield strength of the material and assuming that the region of the pin where maximum equivalent stress occurred is failing or wearing out, since he had no provision for finding out the wear analysis in the available software packages.

Boz M.(1999) investigated during the braking, if the thermical stability temperature goes high than expected for the brake sysem and pad lining material, the friction factor on the pad lining goes down. The performance drop for the brakes resulted by working errors, quick pad lining wear and the sound. The increase of the temperature makes the pad linings wear resistiviy reduce. After a specific temperature, the wear on the pad lining rise fastly. It is called the temperature of the wear of the pad lining. It is good that the temperature is high. During the temperature of braking, the pad linings that stays under the boundary temperature of the wear of the pad lining, do their normal duties. In practice, the temperature of the pad lining and the disc needs to be below this temperature.

In TEKELİ S. , (2004) study, he subjected that the calculation of three point curving test and the fracture toughness of the samples of glass epoxy which composite material that’s been analyzed, with modelling on ANSYS and ABAQUS which are the three dimensional analyses and design programs.

(Sugözü I. , 2009) Studied boron minerals, boron derivatives and cedar conedust have been used for the production of the pad lining which is free from asbestos and fiber. To find out the effect of the pad lining performance, it has been applied a variety of parameters. In this way, it's been analyzed that the parameters that affect the pad lining performance. To specify the optimum ratio for boron minerals in components, it's been created different types of pad linings. In order to find out the fricton factor-time-friction surface temperature of the pad linings that's been produced, a lot tests were done and with the received values the graphs has been made. The wear, toughness, density values and resistance to the other liquids of the samples have been evaluated and took SEM pictures. The received values and datas have brought up a new appoach for the friction materals about the physical, chemical and mechanical features that's wanted from the pad linings.

If we concentrate on the studies in the computer environment, (Pais et. All 2003) defined new algorithmical teory. His aim of study , decrease calculate time and find stress density for wear ratio. Also , he used Archard's model and created flowchart. (Figure 2.1.). This teory show to us wear calculate with software.

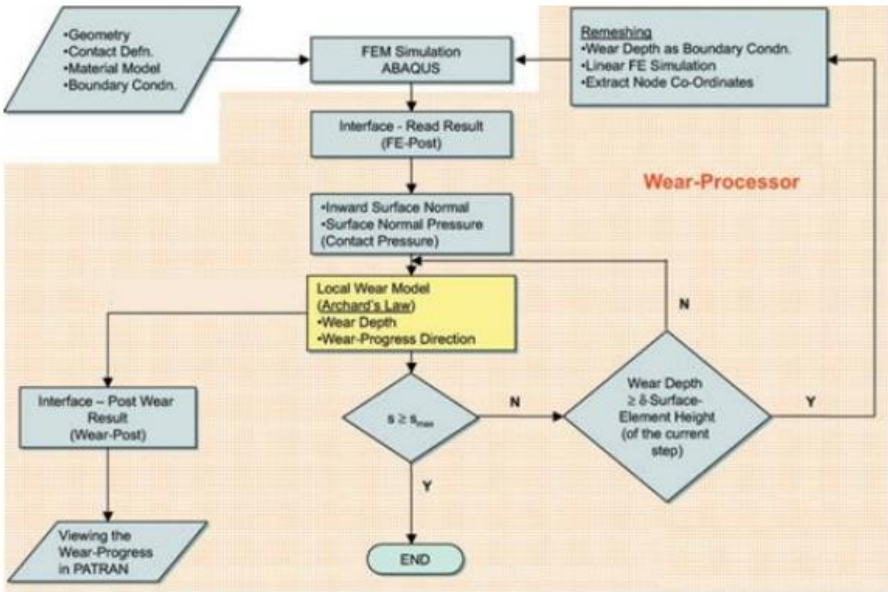


Figure 2.1. Flowchart for wear modelling using Archard's model

Abu-Bakar and Ouyang (2008) made numerical approaches on static, dynamic and thermal analysis in his works. They examined the thermal and wear effects on the pad and disc during braking. They used complex eigenvalue analysis in their studies. Figure 2.2. shows the authors' recent numerical methodology to study car disc brake squeal.

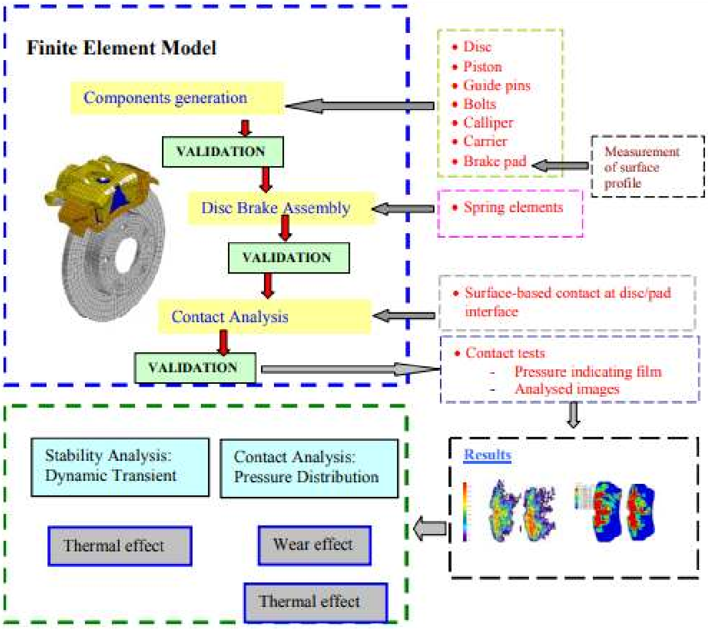


Figure 2.2. Overall simulation scheme (Abu-Bakar and Ouyang,2008)

Molinari J.F. (2000) studied on finite-element method about dry sliding wear indeed metals. He tried to solve specifications of wear process such as contact boundary layers. Also , used to Archard's method for analysis method. He reached to relationship between hardness and wear process. His study included ; surface evolution due to wear , finite-deformation , thermal analysis and heat transfers each other to surfaces. (Molinari J.F. , 2000)

Podra, P. & Andersson, S. (1999) , had studied wear analysis about commercial finite element method. They used to Euler integration scheme for modeling and simulating process. Analyzed pin on disc connections on wear simulation FEA.

Cannon R.J. and Howell L.L.They performed analytical calculations according to the false-rigid-body method for a flexible contact-assisted spherical joint (CCAR), which can perform the functions of a planar mechanism consisting of a bearing and a spring, and checked the accuracy of the results with 2-dimensional finite element analysis. With the results they obtained, they found that the values obtained with the false-rigid-body method were quite close (5.4%). However, detailed information about the analysis is not included in the article. (Howell L.L., Cannon J.R., 2005)

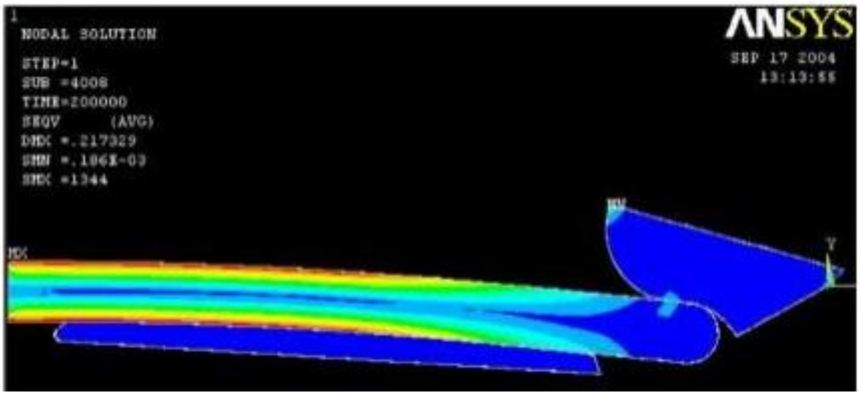


Figure 2.3. Connections Analysis FEA (Howell L.L., Cannon J.R., 2005)

As a result of the experiment, it was said that the air ducts on the disc prevent the temperature of the disc from reaching the damaging dimensions of the disc, reduce the internal stresses of the disc and can be used for a longer time and safely.(Figure 1.7.) It is said that a better disc cooling will be achieved by changing the geometric structure of the disc. (Belhocine, A., Bouchetara, M,2013)

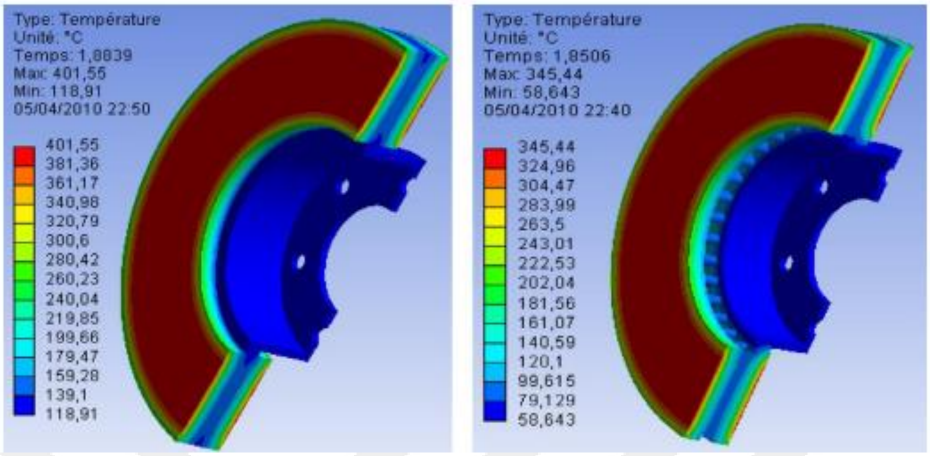


Figure 2.4. Disturbition of Temperatures on Ansys (Belhocine, A., Bouchetara, M, 2013)

The 3D modeling of the thermal and stress analysis of the air duct brake disc used in Locomotives by (Ghadimi et al. 2013) The heat generated during braking is said to cause losses and thermal cracks in braking. These thermal cracks can affect braking performance and disc thickness. Temperature braking time is important to determine the increase. Also, this temperature increase may vary depending on the pad and the disc material, the disc and the pad's area. In this study, a disc with ventilation ducts with a diameter of 920 mm was used. Assuming the braking pressure is proportionally distributed. It was calculated. Then it was examined in thermal analysis on the disc. (Figure 1.8.)

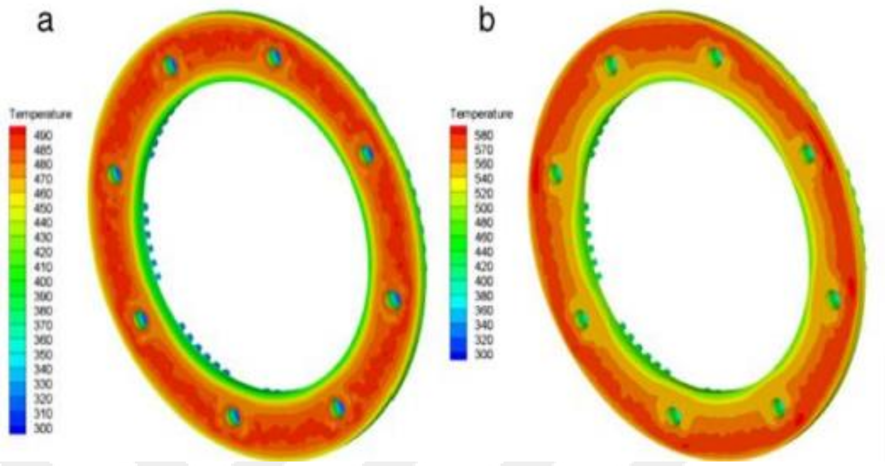


Figure 2.5. Distribution of temperature on disc (Ghadimi et al. 2013)

The effects of cooling channel brake discs on braking forces and heat exchange were investigated by Düzgün &Yıldız. In this study, discs with different cooling channels have been tried and the heat changes and results have been analyzed. It has been observed that there are different abrasions in the longitudinal and transverse channel discs. It is said that different cooling design patterns can remove more heat from the surface. It has been explained that channeled discs create more abrasion than solid disks. The disks are drawn in the same dimensions and solved using the finite element method in the Ansys program. Braking forces increase in cooling channel discs due to the discharge of heat. (Düzgün M. & Yıldız Y., 2009)

The brake mechanism fatigue test by Pektaş was simulated with the FEA method. In this study, deformation caused by fatigue of heavy vehicle brakes under real operating conditions was observed. Quantitative observations using strain-gage, considering that qualitative observation will not be sufficient in the observation.

It was formed. The deformation values were compared with the actual values by the end of the elements method with the help of computer 4 program. These two values are shown to be close, given the approximate errors. (Pektaş , H.S. 2006)

In this study, ABAQUS was modeled with a finite element program, 5 different pad materials were studied for 300 s, with continuous braking process, temperature distributions and stress conditions. 4 different thicknesses of the same pad were taken into consideration in the analysis in order to reveal the condition of the pad caused by wear. (Koç et al. , 2009)

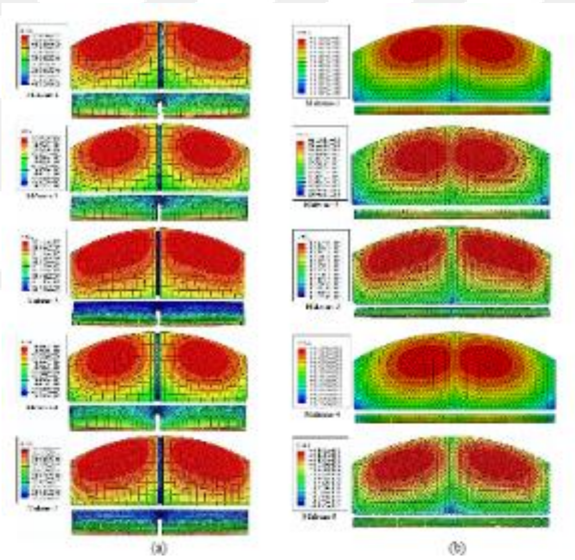


Figure 2.6. Deformation Status after brake (Koç et al. , 2009)

2.1. Aim of the Study

To investigate the effects of different composite materails on brake pad on simulating with ANSYS and that will be calculate to the specific wear rate according to reel and simulation datas is the purpose of this study.

To reach a result in a shorter time by designing and simulating a long experiment in a computer environment is the aim of this study. This examination is carried out in computer environment using Ansys program. There are many factors affecting the performance of the lining, it is normal that the values obtained will be different from the real values, regardless of the laboratory conditions.

In computer environment, the known values of the properties of friction materials were processed. The effects of different friction materials on the brake lining show us, although the results obtained do not give an exact result.

3. MATERIAL AND METHOD

3.1. Design to Braking Pad And Disc Brake

In this thesis , braking pad and disc created using Catia V5. Sugözü, Mutlu and Keskin (2015) [7] studied experiment 116 HB (41.86 HRA) hardness and 280 mm brake disc made of gray cast iron used.

Pad samples are designed to be 25.4x25.4 mm and 6 mm thickness. Different specimens are assigned on the pad on Ansys workbench.

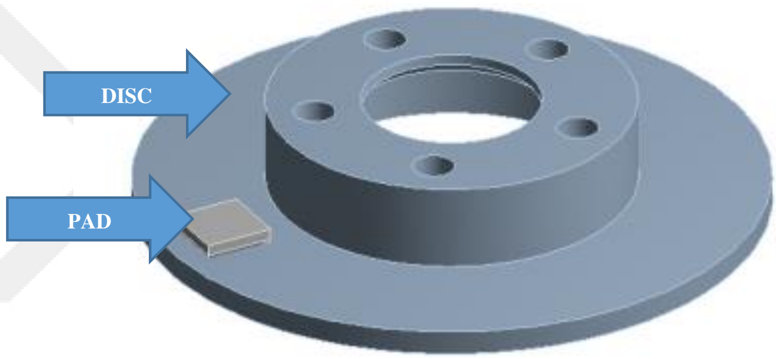


Figure 3.1. Designed Pad & Disc

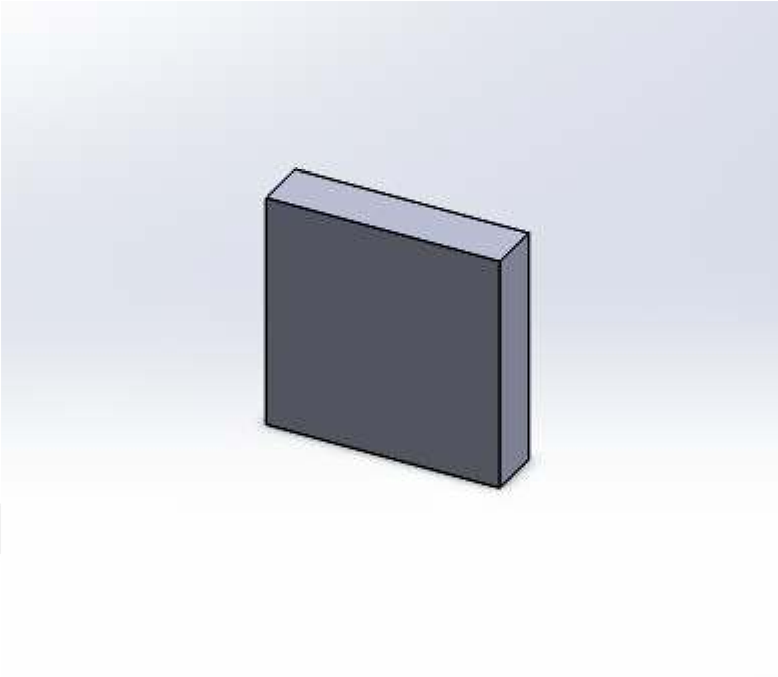


Figure 3.2. Pad Sample

3.2. Prepared to material properties on ANSYS

In this thesis , used ulexite, cashew powder as substance mixed at different ratios.

All of these materials will be prepared on Ansys modüle. Features will that need to be entered. These features used are ;

- Density
- Mass of brake pad before testing
- Friction distance calculated by using the number of revolution and radius of the disc
- Hardness
- Friction Coefficient of samples
- Friction Force

Table 3.1. Material Proporties (Sugözü , İ. 2016)

Sample	Mean coefficient of friction	Standart Deviation	Density (g cm-3)	Hardness (Brinell)
UC-4	0.394	0.0182	1.935	18.2
UC-8	0.401	0.0172	1.842	16.2
UC-12	0.420	0.0192	1.765	15.9
UC-16	0.427	0.0216	1.704	14.7
UC-20	0.437	0.0223	1.680	13.9

3.3. Prepared to Conditions of Simulating on ANSYS

3.3.1. Descriptions

Before the simulations, defined some datas software on Ansys. There are;
The disc rotate with Velocity: V rpm

Pressure applied on the top of face the pad: P

Temperature at the face between the disc and the pad: T^{o} C

Archard wear parameters;

Wear coefficient: K

Hardness (HB): H

Material;

The brake disc: Gray Cast Iron

The Pad: Different Samples.

Friction Coefficient: Differents according to samples.

3.3.2. Step By Step Conditions of Simulation on Ansys

After adding the features of materials, to be able to process statically and thermally, on Ansys, there has to be some data added step by step. The most important one is specify the behaviours of the materials. In this way, the disc is solid and were selected as pad flex.

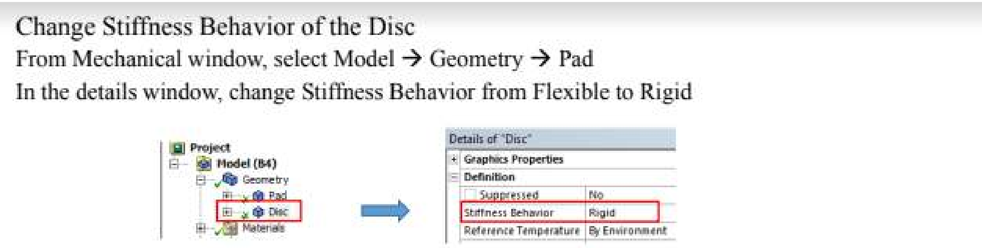


Figure 3.3. Change Stiffness Behavior of The Disc

And then, the change about the assumed axises must be done and these changes were added on commands line.

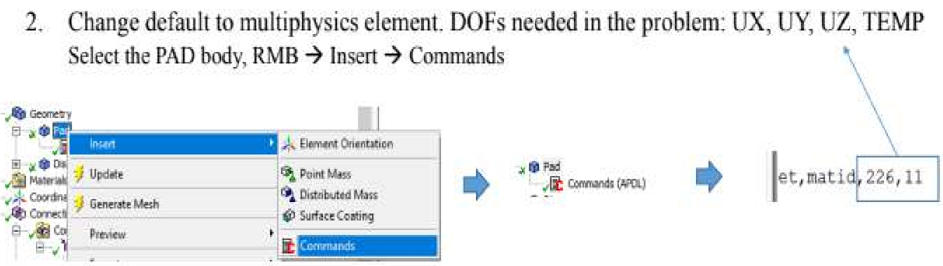


Figure 3.4. Change Default To Multiphysics Element

One of the most important steps is that the pad lining and dics's contact surface must be defined. In this step, the contact surface and the surface that is going to contacted were chosen. Furthermore, the friction factor is determined in this step. The friction factors that are used in this test were taken by Sugözü.

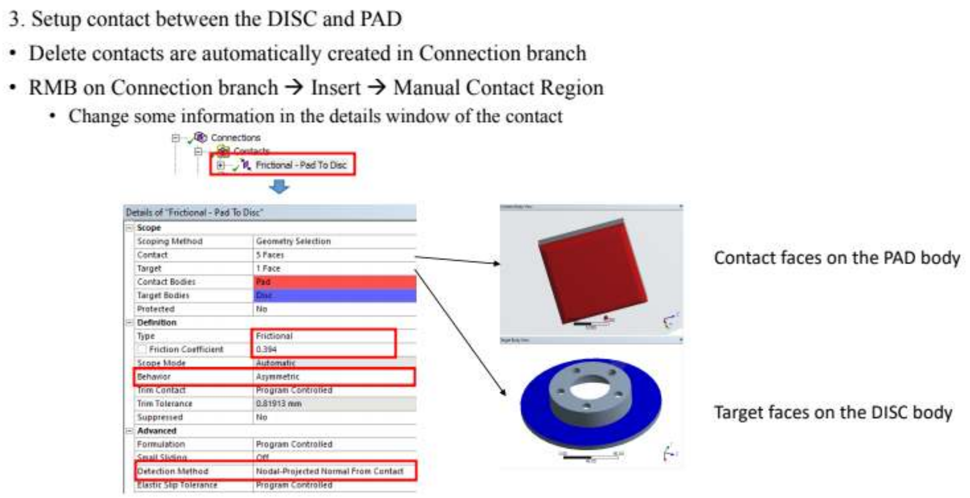


Figure 3.5. Setup Contact Between the Disc and Pad

After entering the contact properties, the disc rotation axis has been defined.

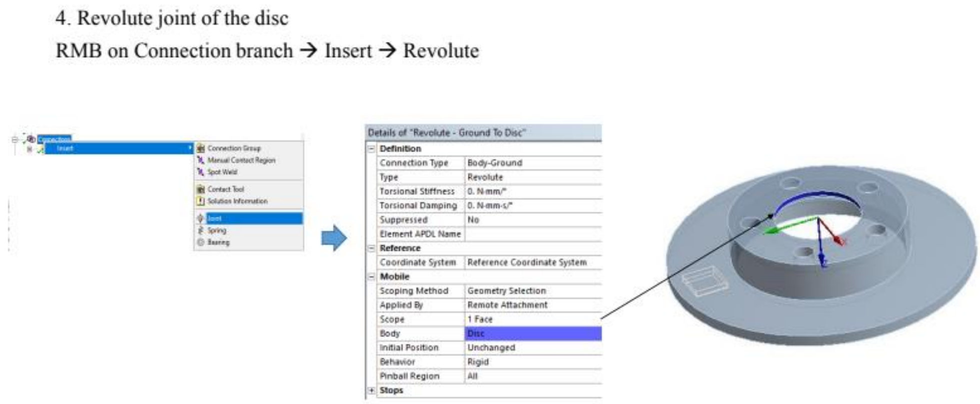


Figure 3.6. Revolute Joint of The Disc

For the pad and disc there was a mesh assignment. The mesh assignment were done in an automatically

- See details in the project

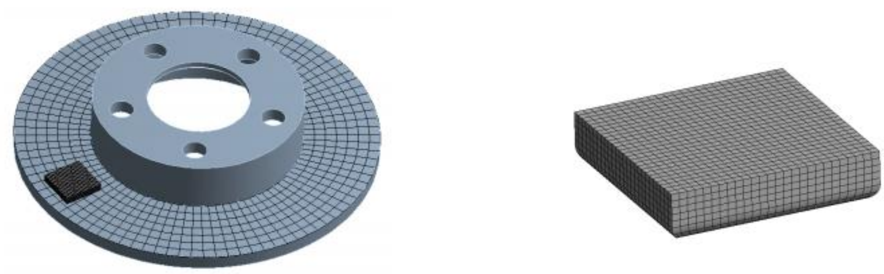
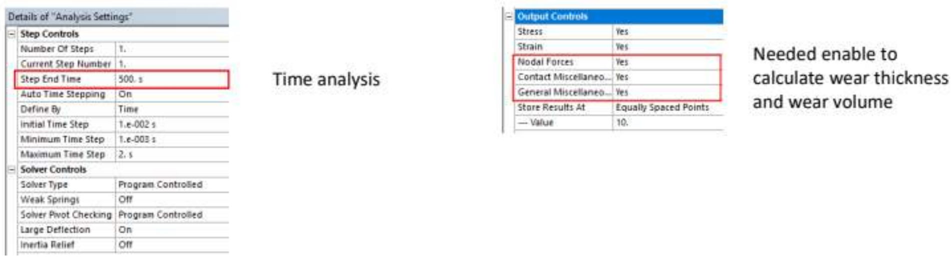


Figure 3.7. Meshing

The data about the analysis were given. To be able to do the calculation and finding the wear ratios, needed data were processed.



Details of "Analysis Settings"	
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	500. s
Auto Time Stepping	On
Define By	Time
Initial Time Step	1.e-002 s
Minimum Time Step	1.e-003 s
Maximum Time Step	2. s
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Off
Solver Pivot Checking	Program Controlled
Large Deflection	On
Inertia Relief	Off

Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	Yes
Contact Miscellaneo...	Yes
General Miscellaneo...	Yes
Store Results At	Equally Spaced Points
— Value	10.

Figure 3.8. Analysis Settings

The pressure applied in the real experiment was also applied on the analysis.

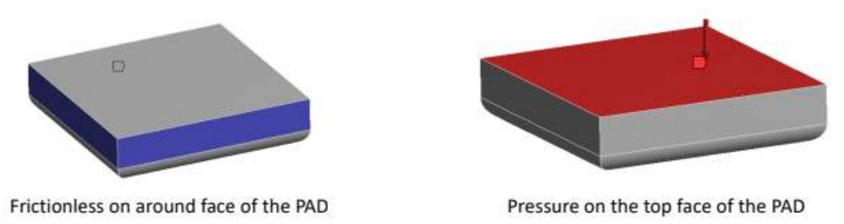


Figure 3.9.Boundary Counditions and Load

The values that show the thermal change depending on time, were processed on the analysis.

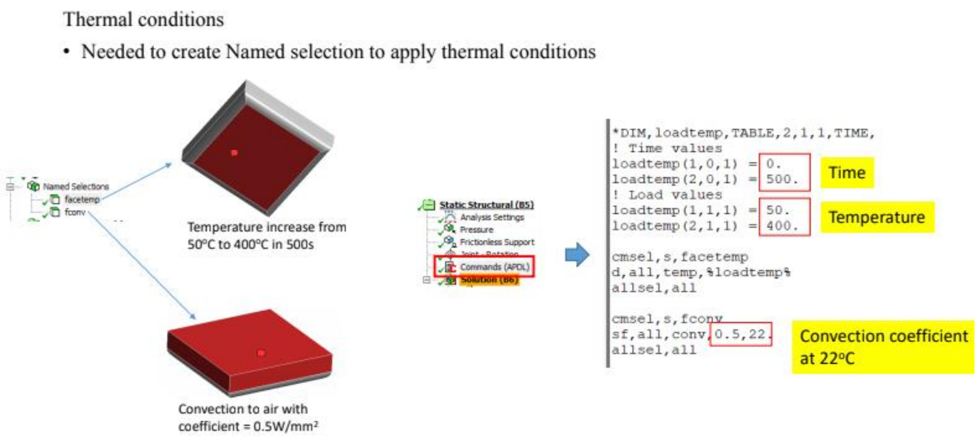


Figure 3.10. Thermal Conditions

To Sum up in this study, the braking tests will be carried out at a pressure of 1.05 MPa,differenet velocities of 6 ms–1, and at temperatures from 50 °C to 400 °C for 500 s.

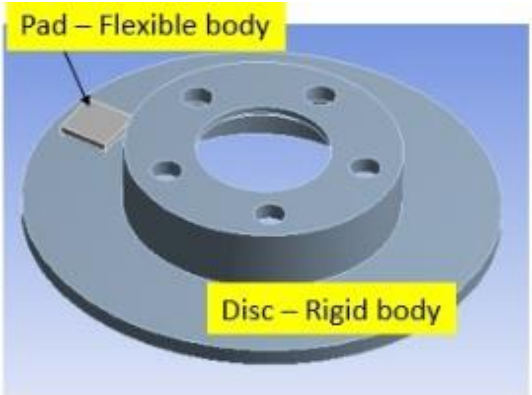


Figure 3.11. Brake Pad and Disc

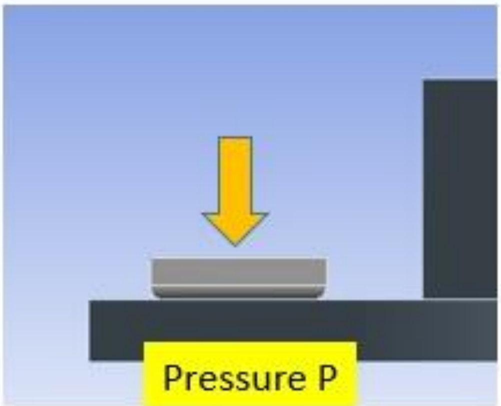


Figure 3.12. Pressure

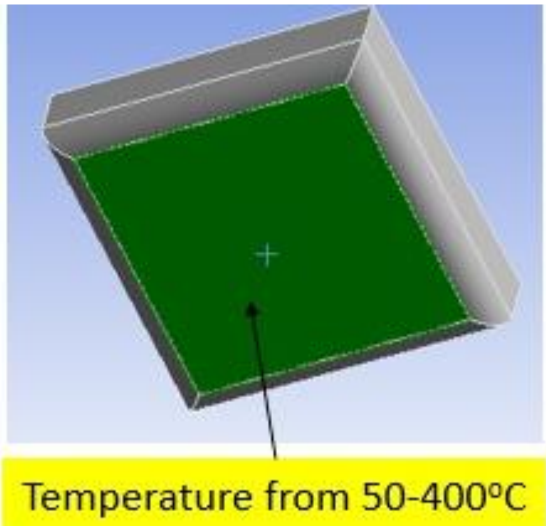


Figure 3.13. Temperature Disturbution

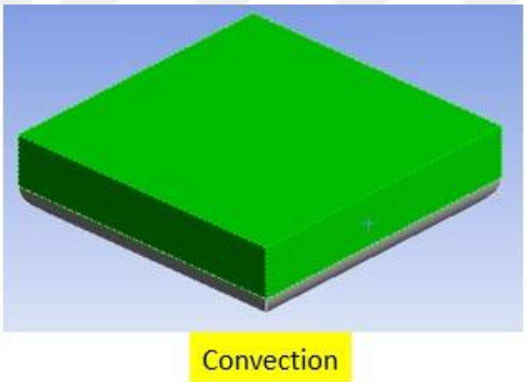


Figure 3.14. Convection Sample

3.4. Investigated Solutions

According to ANSYS solutions that there will be calculate to specific wear rate on brake pad.

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 [11,12]:

$$V = \frac{(m_1 - m_2)}{L\ f_m \rho}$$

where V is specific wear (g/mm-1),

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

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

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

fm – average friction force (N),

ρ – the density of brake pad (kg/mm3) .

In this formula , mass of brake pad before testing (m_1) and mass of brake pad after testing (m_2) with Ansys solutions. Friction distance calculated by using the number of revolution and radius of the disc (m) for 500s. Average friction force (N) and the density of brake pad (ρ) taken from previous studies.

4. RESULTS AND DISCUSSION

The volume loss of the pad linings have been received from Ansys environment. The most volume loss is the sample UC-20, has been observed. The less volume loss has been seen UC-4. Generally volume losses are approximately 0,625-0,952 (x10^-6) mm3.

It has been calculated the volume values on mm3 at Ansys environment.

As in the method section, the volume losses occurred from the thermal and dynamic movements after 500 seconds. In this study, the analyses were processed properly as the base from Archard's wear theory

Also , while wear ratio calculating, the K constant was created by approaching. K constant is calculated 0,018.

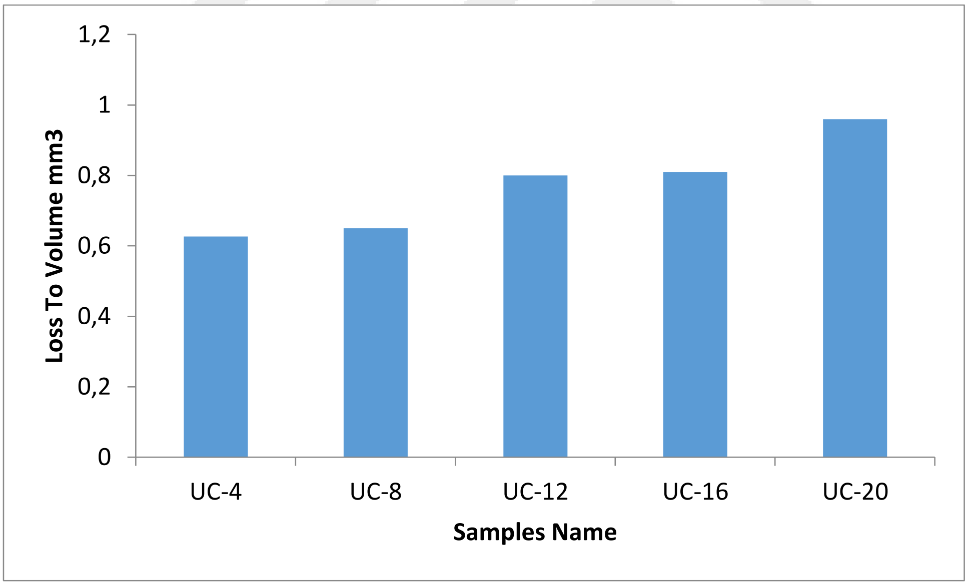


Figure 4.1. Loss To Volume Due To Wear

It has been observed that there is a direct proportion between the volume loss and the density, according to the received values. The sample UC-20 has the less density, has been seen also the most volume loss, from detections. Likewise, the sample UC-4 has the more density, shows that the less volume loss from wear.

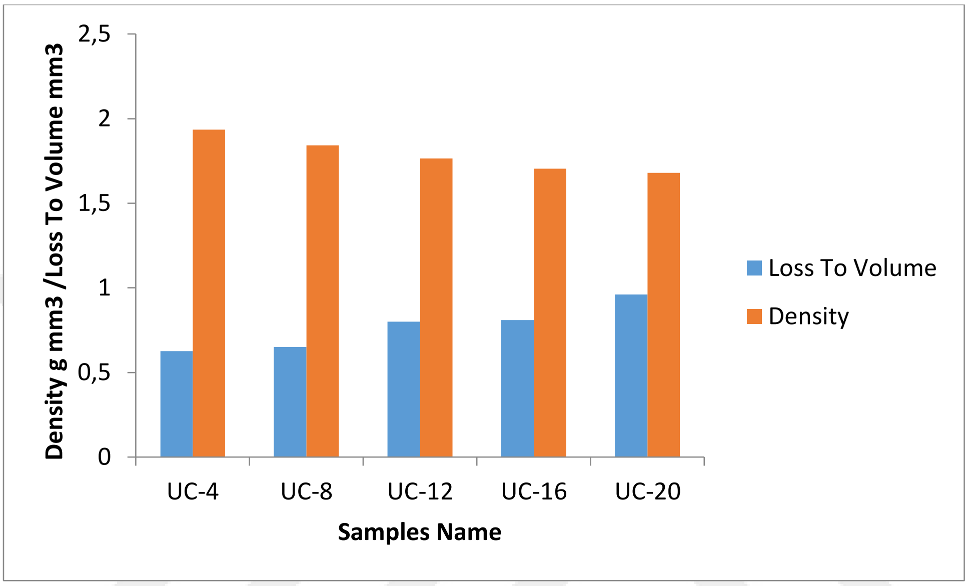


Figure 4.2. Compare Between Loss to Volume and Density

In below, there is graph that shows the volume that's lost from the wear ratio. According to these data, there is a direct proportion between the volume loss and the wear ratio. The sample UC-4 which has the most less ratio, the volume loss is the maximum. The sample UC-20, has the most wear ratio, so the volume loss is minimum. Exceptionally, UC-12 has shown a different value related to the other samples.

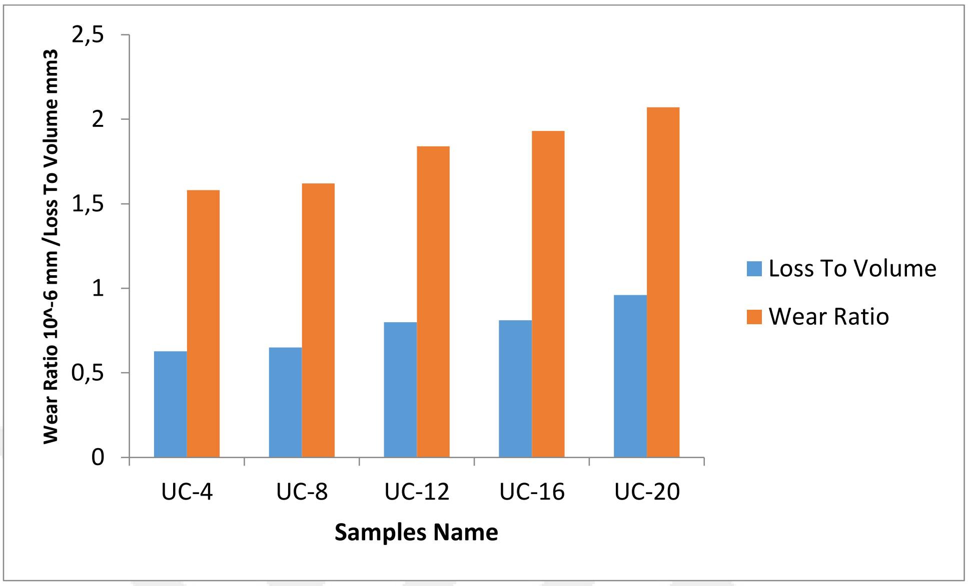


Figure 4.3. Compare Between Loss To Volume And Wear Ratio

In below, there is graph that shows wear ratios and sample densities. It has been observed that there is a direct proportion between the density and the wear ratio. The sample UC-4 which has the less wear ratio, is the most dense one. UC-20 is the less dense one , which has the most wear ratio.

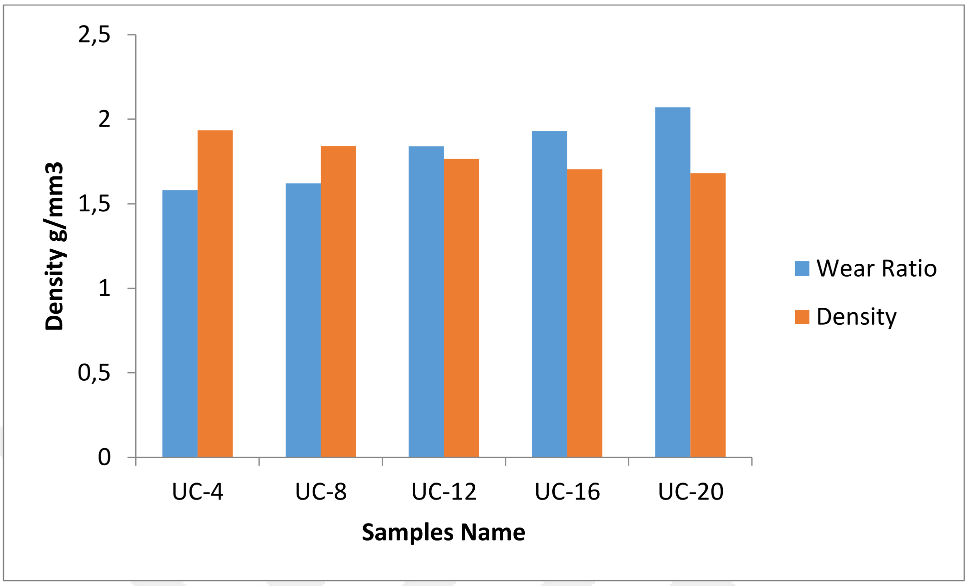


Figure 4.4. Compare Between Density and Wear Ratio

Also ,The graphs of volume losses due to time is shown below. In general, it has been observed that in a direct way there is loss of thermal along with the volume

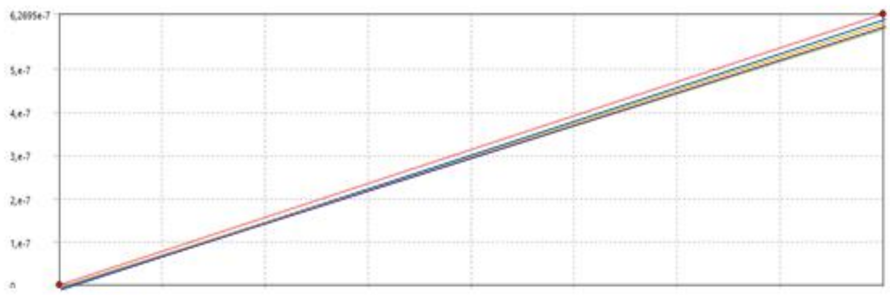


Figure 4.5. Ansys- Loss to Volume Graph of Samples

According to the results of the analysis, it has been obtained that the levels of the viscousness on the surface of the pad linings. Among 5 samples, it has been seen that the viscousness decreased from the centre of the pad lining to the surface that doesn't effected by the friction.

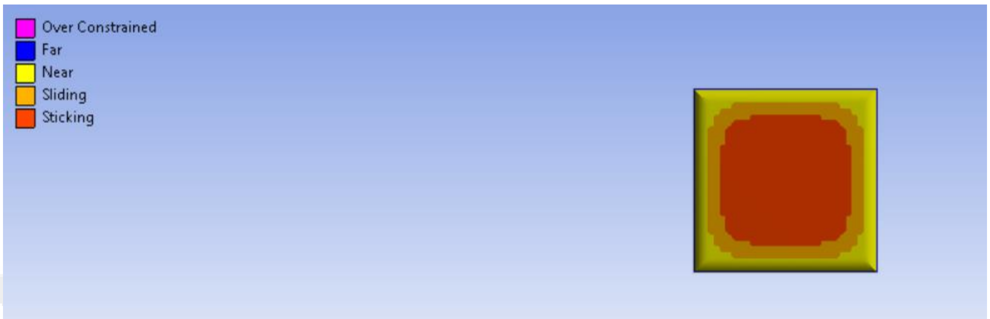


Figure 4.6. Behavior of Adhesive Surface of Brake Pad

It has been observed that under the 1.05 Mpa, the pressure doesn't distribute equally on the pad linings surface with the contact of the brake disc. The sample of the pad lining is the place where the central pressure and the brake has been seen the most.

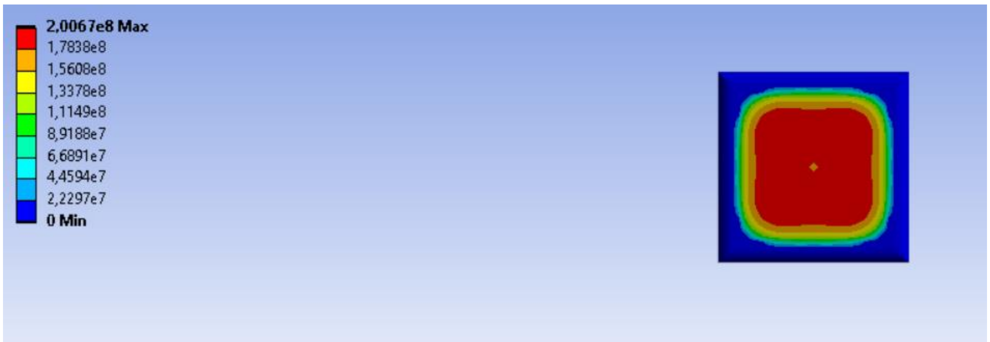


Figure 4.7. Effect of Adhesive Pressure of Brake Pad

The wear on the pad lining does not distributed equally on the pad lining. In general, the wear is mostly occurred in the centre of the pad lining, to the external sides of the pad lining the wear ratio is decreased.

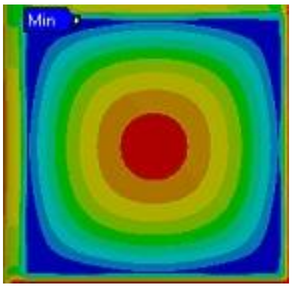


Figure 4.8. Disturbution of Wear Surface of Brake Pad

The change of the temperature along with the time has been observed according to the analyses results. The maximum temperature is from the central to the edges of the pad lining, the minimum temperatures is in general, on the external sides of the pad lining

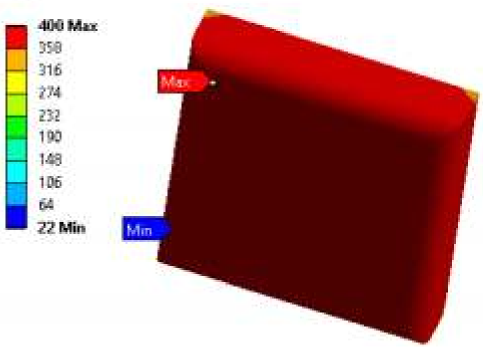


Figure 4.9. Disturbution of Wear Surface of Brake Pad

In his study, İlker Sugözü (2016) has found the wear ratios in the bellowing graph. It is the comparison of the values from computer environment and the İlker Sugözü's values(Sugözü et all 2016). The mean friction factor has taken from İlker Sugözü's studies(Sugözü et all 2016).

According to the results, the wear ratios that's been found on computer environment is more than the others. This kind of difference is normal because, the mean friction factor could not been calculated out of analyses. The results that are found on computer environment, approximately between +%9 and %-7.

Table 4.1.Samples properties (Sugözü İ. et all , 2016)

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	0.26×10^{-6}
UC–8	0.401	0.0172	1.842	16.2	0.27×10^{-6}
UC–12	0.420	0.0192	1.765	15.9	0.34×10^{-6}
UC–16	0.427	0.0216	1.704	14.7	0.37×10^{-6}
UC–20	0.437	0.0223	1.680	13.9	0.38×10^{-6}

Table 4.2. Compare Simulation Results Table

Material	Wear Ratio	Test Results	Density	Percentage Of Tolerans	K Constant
UC-4	2,84116E-07	2,60E-07	1,935	+%9	0,018
UC-8	2,91916E-07	2,70E-07	1,842	+%8	0,018
UC-12	3,30351E-07	3,40E-07	1,765	-%3	0,018
UC-16	3,47391E-07	3,70E-07	1,704	-%7	0,018
UC-20	3,72334E-07	3,80E-07	1,68	-%3	0,018

5. CONCLUSIONS

In this study, it has been analyzed that to transfer the tests of the pad lining to Ansys environment and the received values' scale to the real values. Furthermore, it also been analyzed that the viscousness ,which resulted from thermo, of pad lining.

The following results have been found;

1. According to the received values, it has been observed that there is a direct proportion between the density and the wear ratio.
2. It has been detected that there is direct proportion between the friction factor and the wear ratio.
3. It also been detected that there is direct proportion between the weight loss of pad linings and the specific wear ratio.
4. It has been observed that along with the increase of the temperature on the pad linings, there's been an increase of viscousness.
5. It has been seen that among the pressure distribution on the pad linings, the central area has the most force.
6. It has been detected that there is 2 or 3 ratio between the wear ratio of the tests that's been conducted on laboratory environment and the wear ratio of the values that's been received from Ansys environment. It's been thought that the difference between these values is that the laboratory environment is not the same with the computer environment. The temperatures is not the same with the day that the tests were conducted and the unknowing of the material features is the main reasons for that.
7. It has been added the features of the materials on Ansys environment. In addition, to be able to get the most reliable values, it has to be

known that the refraction of the young model, the position model etc. of features of materials.

8. In this study, it has been observed that these kind of test can be processed on a computer environment yet to be able to get the most real results it has to be known that all the parameter spesifications.
9. The results that are found on computer environment, approximately between +%9 and %-7.
10. The wear ratios that's been found with the received values on Ansys environment, is in the TSE-555 boundary.

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