Mechanical Property Which Affect the Performance of Disk Brake Material

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Abstract: **Safety aspect in automotive engineering has been considered as a number one priority in development of new vehicle. Brakes convert friction to heat, but if the brakes get too hot, they will cease to work because they cannot dissipate enough heat. Ventilated disc brake is the state of the art technology in automobile brake system. This paper reviews work of previous investigators on transient thermal analysis on the vented disk rotor and rotor designs to evaluate and compare their performance. The brake system technological advance got great impulse due to the automobile industry necessity. Historically, the first material used to make brake discs was the gray cast iron, which is a material that fits the requirements it is intended for, such as: good thermal conductivity, good corrosion strength, low noise, low weight, long durability, steady friction, low wear rate, and a good price/benefit ratio. This research study that the affect mechanical and physical property of which affect the performance of disk brake material.**

Keywords: Ventilated disc brake, Heat Transfer coefficient, Heat flux. Brake discs, fatigue.

I. INTRODUCTION

Modern passenger cars have disc brakes on the front wheels, and there is a growing trend to have them on the rear wheels as well. The main purpose of a disc brake is to slow down a vehicle by transforming kinetic energy into frictional heat. A rotor (brake disc) is firmly fitted to and rotates with the wheel. Two brake pads (linings) are positioned inside a caliper mounted on the knuckle. The knuckle 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 rotor. The friction force between the brake pads and rotor exerts braking torque on the rotor, which is connected to the wheel, and the subsequent friction between the tire and the road makes the car slow down. This thesis examines a disc brake for the right front wheel of a typical passenger car. This disc brake assembly consists of a ventilated rotor, a sliding caliper with a single piston, and two brake pads. Most rotors used in passenger cars are made of gray cast iron. The brake pads can be made of many different material combinations, but are essentially constructed of four components: a binder, reinforcing fibers, fillers, and frictional additives.

The main task of the binder, which is made of polymer-based resin, is to hold the components of the brake pad together. The main task of the reinforcing fibers, which can be made of metal, glass, carbon, and ceramic fibers, is to give mechanical strength to the brake pad. Fillers are used partly to reduce cost and partly to alter the brake pad properties, for example, to reduce noise and improve thermal properties. They can be made of barium sulfate and mica. Frictional additives, such as graphite, metal sulfides, and metal oxides/silicates, are used to control the friction and wear. Brake pads are grouped into three categories: non-asbestos organic (NAO), semi-metallic, and low metallic. According to Sanders et al. [2].Rajendra Pohane & R.G.Choudhari[1] presented paper on Design and Finite Element Analysis of Disc Brake (2010) The objective of this research is to study disc brake system, to simulate disc brake assembly and to prepare the FEM model for

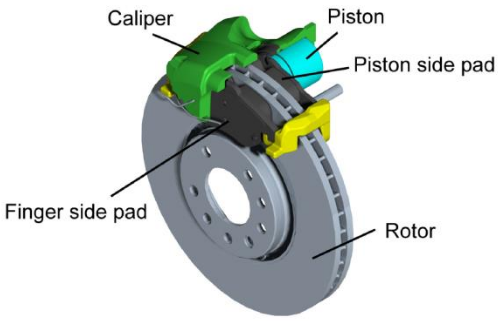

FIG 01: DISK BRAKE

contact analysis A three dimensional finite element model of the brake pad and the disc was developed to calculate steady state, and transient state analysis. The comparison was made between the solid and ventilated disc keeping the same material properties and constraints and using general purpose finite element analysis. It shows that how general purpose finite element analysis software can be used to analyze the stresses at disc to pad interface. A wear simulation routine has also been adopted. It is found that the total heat flux and thermal error is less in solid plate than in the perforated (ventilated) plate. The steady state thermal & Transient Thermal Analysis are carried out on the two types of disc brake i.e. perforated (ventilated) plate and Solid plate. The input conditions, boundary conditions & other analysis settings are same for both types of brakes.

TING-LONG HO Et al. (1974), Investigated on the effect of frictional heating on brake material (Aircraft)[3].Masahiro Kubota et al. (2000), presented paper on development of a lightweight brake disc rotor: a design approach for achieving an optimum thermal, vibration and weight balance[4]. This paper presents a parametric study that was conducted on the basis of an analysis of airflow through the ventilation holes as well as a thermal stress analysis and a vibration analysis during braking. Based on the relationships obtained between rotor weight, shape and each performance requirement, a method is presented for designing a lightweight disc rotor. Computational fluid dynamics analysis approach is used to visualize the actual process. Short and gourd shaped fins arrangement had been used and the results verified that ant squeal performance was improved, and also a substantial weight reduction was achieved compared with the baseline rotor shape without causing cooling performance and heat resistance to deteriorate. Choi and Lee, (2004) presented a paper on Finite element analysis of transient thermo elastic behaviors in disk brakes [5]. A transient analysis for thermo elastic contact problem of disk brakes with frictional heat generation is performed using the finite element method. To analyze the thermo elastic phenomenon occurring in disk brakes, the coupled heat conduction and elastic equations (cylindrical coordinates) are solved with contact problem. Material used is carbon composite and wear is assumed negligible. The numerical simulation for the thermo elastic behavior of disk brake is obtained in the repeated brake condition. The computational results are presented for the distributions of pressure and temperature on each friction surface between the contacting bodies. It is observed that the orthotropic disc brakes can provide better brake performance than the isotropic one because of uniform and mild pressure distribution. JIANG LAN et al. (2011), presented paper on thermal analysis for brake disk of Sci/6061 Al. Alloy co-continuous composite for CRH3 during emergency braking considering air flow cooling [6]. The thermal and stress analyses of SiCn/Al brake disk during emergency braking at a speed of 300 km/h considering airflow cooling were investigated using finite element and computational fluid dynamics methods. All three modes of heat transfer were analyzed. The highest temperature after emergency braking was 461 °C and 359 °C without and with considering airflow cooling, respectively. The equivalent stress could reach 269 MPa and 164 MPa without and with considering airflow cooling, respectively. The airflow through and around the brake disk was analyzed using the Solidwork2012 simulation software package. The results suggested that the higher convection coefficients achieved with airflow cooling will not only reduce the maximum temperature in the braking but also reduce the thermal gradients, since heat will be removed faster from hotter parts of the disk. Oder G. et al. (2009), worked on thermal and stress analysis of brake discs in railway vehicles [7]. Performed analysis deals with two cases of braking; the first case considers braking to a standstill; the second case considers braking on a hill and maintaining a constant speed. In both cases the main boundary condition is the heat flux on the braking surfaces and the holding force of the brake calipers. In addition the centrifugal load is considered. Finite element method approach is been used, 3D model has been modeled for analysis. Brake disc material is rounded graphite; two types of disc considered for studies one without wear and one with 7mm wear on both sides. Maximum speed is 250 km/hr and the ambient and initial disc and surrounding temperature is 50 C Temperatures and stress in discs under different loads is very high. Although they are fulfilling the buyer's requirements for safety, this investigation not considered shearing forces, residual stress and the cyclic loads during brake discs lifespan. The results need to be compared with experimental results. Talati and Jalalifar (2009), presented a paper on Analysis of heat conduction in a disk brake system[8]. Zaid, et al. (2009) presented a paper on an investigation of disc brake rotor by Finite element analysis. In this paper, the author has conducted a study on ventilated disc brake rotor of normal passenger vehicle with full load of capacity[9]. The study is more likely concern of heat and temperature distribution on disc brake rotor. In this study, finite element analysis approached has been conducted in order to identify the temperature distributions and behaviors of disc brake rotor in transient response. Modeling is done in CATIA & ABAQUS/CAE has been used as finite elements software to perform the thermal analysis on transient response. Material used is Grey cast iron, with maximum permissible temperature 550 C. For load analysis 10 cycles of breaking and 10 cycles without breaking (idle) operation is considered total of 350 seconds. Result provided during 1st, 5th and during 10th cycle. Thus, this sure study provide better understanding on the thermal characteristic of disc brake rotor and assist the automotive industry in developing optimum and effective disc brake rotor. Piotr Grzes & Adam Adamowicz (2011), presented paper on analysis of disc brake temperature distribution during single braking under non-axisymmetric load [11]. First step of the analysis based on the previously developed model where the intensity of heat flux was assumed to be uniformly distributed on the friction surface of disc during braking process, and the heat is transferred exclusively in axial direction, whereas during the second, the three-dimensional rotor is subjected to the non-asymmetric thermal load to simulate realistic thermal behavior of the brake action. Operation conditions, thermo-physical properties of materials and dimensions of the brake system were adopted from the real representation of the braking process of the passenger vehicle. Arbitrarily selected four values of the velocities at the moment of brake engagement were applied to the models so as to investigate theirs influence on the obtained solutions of the temperature evolutions on the contact surface of the disc volume referring to two separated finite element analysis. Two- and three-dimensional FE modeling techniques is used considering FEA approach. Finite element analysis and Fast Fourier transform been used to reduce computational time. Radiation heat transfer had been neglected and wear on the contact surface is negligible. We can conclude that the large amount of heat generated at the pad/disc interface during emergency braking indisputably evokes non-uniform temperature distributions in the domain of the rotor, whereas the pad element is constantly heated during mutual sliding.

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II. PHYSICAL AND MECHANICAL PROPERTIES

I. Diffusivity

Cast irons are indicated to produce brake discs because besides the low costs of the production, they have excellent thermal conductivity, which eases the dissipation of the heat generated by the friction of the pads during a stop, and the capacity of damping vibrations, which are prime characteristics of this kind of component. One of the ways to improve the heat transfer ability is to increase its thermal diffusivity. It describes the heat diffusivity during the transient process, and is also a fundamental parameter to the brake design. Thermal diffusivity may be used to calculate the heat conductivity, which is an inherent measure of how well the material transmits heat. Brake discs with improved thermal conductivity present increase in thermal fatigue strength (Jimbo et al. 1990), making it possible to increase its service life, that is, if the gray cast iron characteristic of conducting heat can be increased without sacrificing other objective criteria, the disc performance can be improved.

The main factors that influence the heat transfer in cast irons are distribution, size and morphology of the graphite phase, because graphite flakes have much higher heat conductivity than the matrices. The cast iron heat conductivity is proportional to the ratio between its surface area and its respective volume. Thus, cast irons with nodular graphite are worse conductors than the vermicular ones, which in turn are worse than the ones with graphite flakes. In 1983, Okamoto et al. (1983) reported that the cast iron thermal conductivity is proportional to the graphite flakes shape (or the graphite nodules). In 1990, Jimbo et al. (1990) described the benefits of using cast iron with high thermal conductivity in brake discs. However, the change in friction characteristics such as the friction coefficient value and the amount of particles generated by friction, analyzed as a gray iron microstructure function, has not been much discussed in literature. Little attention has been given to the correlation between the relative quantity of phases in gray iron and the performance under friction. In 1999, Hecht et al. (1999) observed that gray cast iron

TABLE 01: CHEMICAL COMPOSITION OF ALLOY

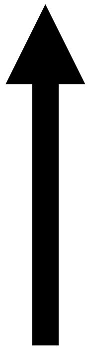
Chemical composition of grey cast iron base alloy				
Element	Metallic Alloy			
	A	B	C	D
%C	3.20-3.60	3.20-3.60	3.60-3.80	3.70-3.90
%Si	1.90-2.40	1.90-2.40	1.80-2.20	1.75-1.95
%Mn	0.60-0.90	0.60-0.90	0.60-0.80	0.50-0.80
%P	Max 0.20	Max 0.10	Max 0.10	Max 0.10
%S	Max-0.12	Max 0.10	Max 0.12	Max 0.13
%Cr	-	0.25-0.40	0.10-0.25	Max 0.20
%Mo	-	0.40-0.50	0.30-0.60	Max 0.10
%Cu	-	-	0.30-0.45	Max 0.40

Thermal diffusivity is influenced by a subtle change in chemical composition and presented a linear relation between thermal diffusivity and equivalent carbon (or maximum length of graphite flakes), as observed in Figure 5. Linear dependence was expected, because increasing C or CE amounts is the fastest way of improving gray cast iron graphitization. There was a 25% increase of diffusivity in brake discs with a increase of 0.40% of EC (Yamada & Kurikuma, 1998). Hecht et al. (1999) also noticed that in gray cast irons, diffusivity is reduced with the increase of the temperature until 500ºC. Above this temperature, the difference noticed in diffusivity of alloys with similar values in 500ºC is reduced. These data suggest that high diffusivity and thermal benefits can be reached by controlling the casting process of brake discs in gray cast iron with longer graphite flakes.

II. Abrasion strength

The diffusivity value on ferrite phase is higher than the one presented by the pearlitic microstructure. Thus, it could be concluded that best iron alloy to brake discs production would be a gray iron presenting longer graphite flakes on a ferritic matrix. This is not true because the matrix type influences diffusivity just a little (Fitzgeorge & Pope, 1959; Omerod, 1978) and the disc must present good mechanical strength, especially regarding abrasion. This is why most brake discs used in passenger cars are produced with cast irons whose microstructure presents graphite flakes on pearlitic matrix. Pearlite, consisting of intercalated lamellae of ferrite phase and cementite phase (Fe3C), results in a matrix with higher mechanical strength (Omerod, 1978). To avoid producing the components from gray cast iron alloys with identical chemical composition and different mechanical properties, it is necessary that the solidification rate is the same, so that the microstructure is not modified. As a consequence, molding, fusion and casting parameters have to be strictly controlled at every new production. If the chemical composition is modified by means of adding alloy elements, the mechanical properties

Table No 02 : HARDNESS EFFECT

Harding Effect of alloying element.	
Element	Hardening Effect
C,N	
P	
Si	
Ti	
Al	
Cu	
Mn	
Mo	
V	
Ni	
Cr	

will be changed. In other words, to modify mechanical properties, two factors are really important: cooling speed and chemical composition. Despite being possible to produce good quality cast irons without adding alloy elements, just controlling the carbon, silicon and manganese contents and the production technique, it is usual to add alloy elements to obtain not only higher strengths with higher equivalent carbon, but also because microstructures are less susceptible to thickness variation of the parts.

Practically all alloy elements tend to increase the tensile and toughness strength, and the most efficient to gray cast iron are manganese, vanadium, molybdenum, chrome and copper. Manganese promotes the pearlitic microstructure formation, increasing mechanical strength and toughness; vanadium is a strong pearlite former and graphite refiner; molybdenum increases mechanical strength to heat, creep and corrosion, Cr increases corrosion and abrasion strength and Cu is a strong pearlite stabilizer.

III. Hardness:

The hardening effect produced by alloy elements in solid solution in ferrite can be seen schematically in Table (Milan et al., 2004). Notice that despite all elements increase the alloy strength, the ones that form interstitial solid solution have a stronger effect than the substitution ones. Besides the direct way, by forming a solid solution and second-phase precipitates, alloy elements can indirectly act upon the increase in strength through grain refining, dessulfuring or globalizing sulfides, stabilizing carbides, degasifying and also increasing the material harden ability. Rhee et al. (1972) pointed that a change in the disc chemical composition affected very strongly both mechanical properties and the lining/disc wear rates. Libsch & Rhee (1979) related the effects of variation in chemical composition upon the disc. They showed that small changes on alloy elements level changed the lining and disc wear level. Anderson (1992) stated that thin graphite flakes reduce lining and disc wear. Zhang et al. (1993) studied cast iron triblological properties in terms of phosphorus concentration and graphite morphology and observed that cast iron with phosphorus and compact (or vermicular) graphite morphology presented high friction coefficient and low mass loss due to wear. Cho et al. (2003) investigated gray cast iron features regarding phase quantities, graphite and ferrite, and the micro constituent pearlite, controlling the microstructure by the carbon quantity variation (equivalent carbon) and cooling speed. They noticed the free ferrite quantity and the pearlite quantity in the gray iron disc do not affect the friction coefficient. Additionally, they observed a friction coefficient increase with a higher graphite area perceptual.

IV. Fatigue

It is known that the brake disc form and physical properties can affect the braking performance and cause problems such as vibration, material loss during the stop and noise (Metzler, 1990; Rhee, 1972). This happens because gray cast iron physical properties, such as thermal conductivity, vibration weakening, thermal expansion coefficient and the specific heat, change according to the phases present in gray cast iron (Chapman & Mannion, 1982). In the last decades, great attention has been given to improve brake discs performance concerning its behavior when there is friction with the brake pads. This great effort led to materials development, such as: non-ferrous copper alloys, aluminum matrix composites and, nowadays, carbon composites (Wycliffe, 1993; Rhee, 1970). However, gray cast iron is still very used in automobile disc brakes because, as mentioned earlier, besides having good physical and mechanical properties, it is cheap and easily produced. Nevertheless, a more detailed characterization of these alloys is necessary, especially concerning the wear strength to determine which one of them is more appropriate to braking because, with trucks and passenger cars performance improvement, there is a growing increase of the demand for brake discs technological improvement. Because it is, perhaps, the most important piece of the disc brake system, the brake disc is submitted to three types of fatigue: thermal, where the component is only submitted to abrupt temperature variations with no load; isothermal, where the temperature is stable and the load, variable; and thermo mechanical (in or out-of-phase), where temperature and load are changeable. The most important, for representing better the conditions the disc is submitted to during the braking process, is the out-of-phase thermo mechanical fatigue, where the maximum load is applied when the temperature is the lowest possible and vice-versa. The discs exposed to high thermal stresses require materials that offer better strength to thermal fatigue. In these cases, gray cast irons with nickel, chrome and molybdenum have been used (Yamabe et al., 2002), as the ones used by General Motors, for example, which posses 12% nickel, more chrome and molybdenum(Sakamoto et al., 1993). However, the disadvantage of these alloys is, without a doubt, the high cost.Yamabe et al. (2002) studied the possibility of producing truck discs with a cheaper cast iron alloy with high thermal fatigue strength. They used prototypes of different alloys with variable quantities of elements and some of them had cerium inoculated. They verified the connection between the material thermal fatigue strength, its physical and mechanical properties, and its corresponding microstructure. They noticed that the higher graphite quantity is distributed on a matrix with refined grains, the lower the crack propagation rate is, and that the number of graphite flakes increases with nickel addition and some cerium inoculation. They also observed that the thermal fatigue limit is not severely affected by the number of cycles before the beginning of the crack, but after it. From this survey, a low cost brake discs alloy was developed, equivalent to the one used nowadays. Conclusion It is noticed that, historically, despite all the evolution that took place during the 20th century, brake discs of automobile vehicles are still produced with the centennial and very cheap gray cast iron, which still offers the best price/benefit ratio, even after receiving some alloy elements addition. From the technological point of view, along the time a great number of experiments were accomplished, especially after 1938, with the beginning of the Second World War. However, as experimental projects like the ones described above are really expensive and slowly executed, nowadays the advance of the development of materials and brake discs project has been almost exclusively based on modeling in terms of low cost and speed. In modeling, one tries to predict the component behavior (life), through finite elements, simulating several parameters under thermal, isothermal, and especially thermo mechanical fatigue, which is the one that represents best the real braking. Although this type of analysis presents meaningful results, there is the need of experimental works to validate them, i.e., it is necessary to study the component under real rather than only virtual conditions.

III. CONCLUSION

The material which is used for disk brake having required intended property such as: good thermal conductivity, good corrosion strength, low noise, low weight, long durability, steady friction, low wear rate, and a good price/benefit ratio. These researches study show the over view of mechanical and physical property which affect the performance of disk brake material. For the smooth performance of disk brake optimum value of these property is essential. By considering these optimum property developed the new material which satisfied the all requirement of disk brake at optimum cost.

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