THE INFLUENCE OF BRAKE PADS THERMAL CONDUCTIVITY ON PASSANGER CAR BRAKE SYSTEM EFFICIENCY

by

Predrag D. MILENKOVIĆ [a*], Saša J. JOVANOVIĆ [a], Aleksandra S. JANKOVIĆ [b], Milan D. MILOVANOVIĆ [a], Nenad D. VITOŠEVIĆ [c], Milan V. ĐORĐEVIĆ [c], Mile M. RAIČEVIĆ [c]

[a] Zastava Automobili R&D Deparment, Kragujevac, Serbia

[b] Faculty of Mechanical Engineering, Uiversity of Kragujevac, Kragujevac, Serbia

[c] Fiat Automobili Srbija, Kragujevac, Serbia

Original scientific paper
UDC:
DOI:

In phase of vehicle braking system designing, besides of mechanical characteristics, it is also necessary to take under consideration the system's thermal features. This is because it is not enough just to achieve proper braking power, for the brake system to be effective but equally important thing is the dissipation of heat to the environment. Heat developed in the friction surfaces dissipate into the environment over the disk in one hand and through the brake linings and caliper, in the other. The striving is to make that greatest amount of heat to dissipate not threw the brake pads but threw disc. The experimental researching of heat transfer process taking place at vehicle brakes was made in the R&D Center of "Zastava automobili" car factory in order to increase the efficiency of brake system. The standard laboratory and road test procedures were used, according to factory quality regulations. The modern equipment such as thermo camera, thermo couples, torque transducers, signal amplifiers, optical speed measuring system and laptop computer were used. In this paper will be shown the part of the experimental researching, which refers to the thermal conductivity of brake pad friction linings.

Key words: *Brake, brake pad, heat, conductivity, measurement*

Introduction

The braking process is in fact the matter of energy balance. The aim of braking system is to transform mechanical energy of moving vehicle into the some other form, which results by decreasing of vehicle speed. The kinetic energy is transformed into the thermal energy, by using the dry friction effects and, after that, dissipated into the surroundings [1]. Some devices can be added to basic braking system for purpose of accumulating a part of braking energy and use it later for vehicle acceleration. On that way, the reduce of fuel consumption is achieved. Those devices known as retarders are very useful, but because of grate dimensions, their usage is limited on trucks and buses. It means that in the case of passenger cars, the whole vehicle's kinetic energy has to be transformed into thermal.

[*] corresponding author; e-mail: pmilenkovic1@sbb.rs

The energy transforming process takes place entirely on contact surfaces of disc and friction linings of brake pads. The heat carried out on this way transfers threw the parts in contact (disc and brake pad) at first, by means of conductivity and after that, dissipate into the surroundings, by convection and radiation [2], [3]. According to braking system efficiency it is very important thing how fast the heat transfer is going on. This is the important criteria for material of friction pair to be chosen.

This is just one part of the problem since it is necessary to take into account both the thermal as well as mechanical and tribological properties of materials. There are a few reasons to be cared about in the selection process of friction lining material:

– Friction lining should have the as large as possible coefficient of friction, in order to be satisfied the first condition of transformation of mechanical energy into heat;

– Friction lining, which should have as low as possible thermal conductivity in order to protect the sensitive elements of the damages caused by thermal treatment.

Brake pad is consisting of metal plate and friction lining. Metal plate is in contact with hydraulic piston of caliper and friction lining is in contact with disc (brake rotor). Friction lining is attached to metal support plate by some kind of adhesive material, during the process of vulcanization on high pressure and temperature. The tangent force resistance of that connection has to be very well, otherwise the braking system can be endangered. The temperature appears on disc and brake pad contact surfaces can be very high and, if thermal resistance of lining is poor, can lead to weakening of adhesive forces and brake pad destruction. That is why is important for brake lining to have poor heat conductivity, as much as possible.

Otherwise, the brake pads linings must have friction coefficient as high as possible because the brake efficiency directly depends on it. Brake pad manufacturers very often use metal shavings to improve the friction coefficient, but thus are the materials with extremely good thermal conductivity.

Table 1: Boiling points of brake fluids depends on absorbed humidity [1]

Brake fluid type	Boiling point (˚C) (0% of humidity)	Boiling point (˚C) (more than 4% of humidity)
DOT 3	205	140
DOT 4	230	155
DOT 5	260	180
DOT 5.1	270	191

So, there are two opposite demands to be compromised.

Transmission mechanism for the braking systems of passenger cars is the hydraulic type and as such has limitations that are related to its operating temperature. From this point of view, the weak points are gaskets and brake fluid. Namely, the caliper seals may work properly if operating temperature does not exceed 200 ˚C, which is significantly lower than the temperature develops at the contact surfaces of the disc and brake pad. Damaged seals can lead to brake fluid leakage and/or caliper piston jam, which causes dysfunction of brake system. Boiling points of different brake fluids are shown in table 1.

In the case of the boiling point exceeding, at least locally, the steam bubbles in the brake fluid comes to appearance, which leads to increased brake pedal stroke when acting on it. This pedal stroke increase can cause the impairment or total loss of braking efficiency.

These are the reasons why it is necessary the greatest amount of heat developed in the contact surfaces to be taken out by the disc and at the same time as small as possible transferred to the caliper. This means that the thermal conductivity of brake pad needs to be much lower than the thermal conductivity of the disc.

Experimental research

To make claims about the influence of brake linings thermal conductivity on the brake characteristics can be verified, a number of tests were done, both on samples of brake linings and brake assembly devices. As a basis for testing were used the standard procedures in automotive industry quality control processes. This way of testing provides a very high repeatability of tests, which is an important prerequisite for the accuracy of results. Changes in relation to these standard methods are made only in order to increase the accuracy of measurements, which are achieved by using the latest measurement equipment and by increasing the sampling frequency.

In laboratory tests the thermal infra-red (IR) camera was used as basic measuring instrument.

About thermography

In the automotive testing world the IR is an extremely useful tool. Some projections for the near future implementation of innovative thermal imaging to the solution of automotive design verification problems are offered, along with their potential benefits to the auto industry.

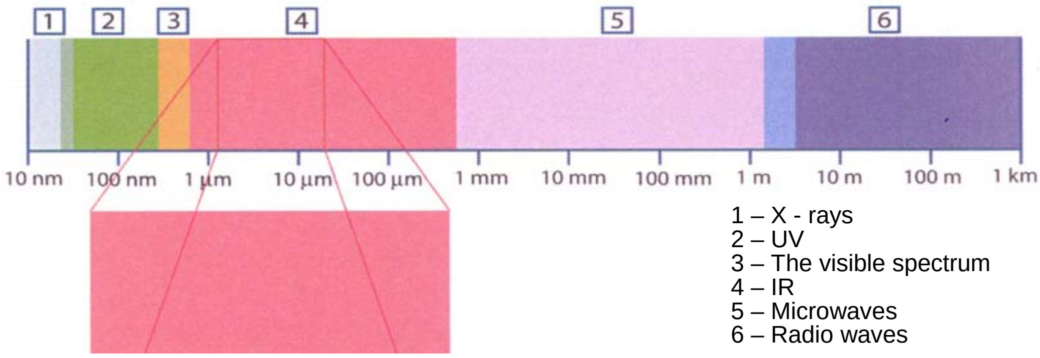


Figure 1. The basic principles of IR thermal camera function [4]

An infrared camera creates an image by converting radiant heat energy into a signal that can be displayed on a monitor (and later printed).

The infrared energy emitted from an object is directly proportional to its temperature. Therefore temperatures are accurately measured by the infrared camera.

An infrared camera is a non-contact device that detects infrared energy (heat) and converts it into an electronic signal, which is then processed to produce a thermal image on a video monitor and perform temperature calculations. Heat sensed by an infrared camera can be very precisely quantified, or measured, allowing you to not only monitor thermal performance, but also identify and evaluate the relative severity of heat-related problems. Recent innovations, particularly detector technology, the incorporation of built-in visual imaging, automatic functionality, and infrared software development, deliver more cost-effective thermal analysis solutions than ever before.

Thermal imaging is a kind of infrared imaging science that can detect radiation in a certain infrared range of the electromagnetic spectrum and produce radiation images. Thermal imaging works because infrared radiation is produced by every object and it's based on its temperature. The higher the temperature, the higher the amount of radiation is emitted from the object. According to the blackbody radiation law, thermal imaging allows you to see your environment without any visible light or illumination. Thermal imaging has the ability to see warm objects against cooler background.

The measuring of brake pad friction lining thermal conductivity

The measurements of thermal conductivity of brake pads friction leanings was made in the laboratory as a part of extensive researching in aim to improve the characteristics of braking system of vehicles made by „Zastava automobili“ factory, according to manufacturing standards TU 9.02122 [6]. For the test the steel heating plate was used. After stabilization of hot plate temperature at desired value, the tested brake pad samples were put on the plate by the friction material surface down, as shown on figure 2. The heat conduction process was started between two isothermal surfaces – surface of lining with higher temperature and surface of metal plate with lower temperature. The increasing temperature gradient of metal brake pad plate was observed by using infra red thermo camera. Temperatures were measured and recorded in interval of five seconds. After repeated tests on more samples, to further analysis those with the lowest and highest thermal conductivity were subjected, so that the difference was noticeable.

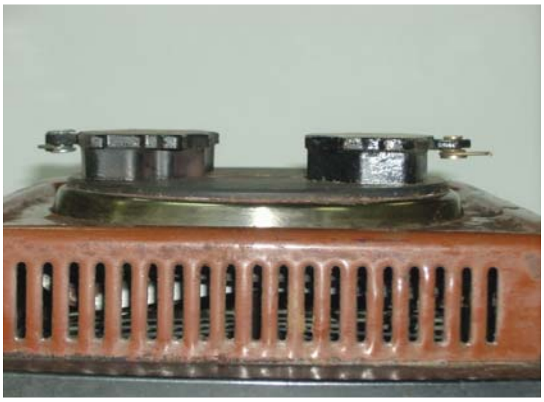


Figure 2. The brake pad samples on the heating plate [6]

According to the temperature fields in the figures 3 and 4 [4] the difference in heat conductivity between the sample *A* and sample *B* is easy to be noticed.

At the figure 5 is shown the graphic of compared values of measured temperatures in thermal conductivity testing, for brake pad samples *A* and *B*. It is obvious that the sample *B* is the one with much better conductivity.

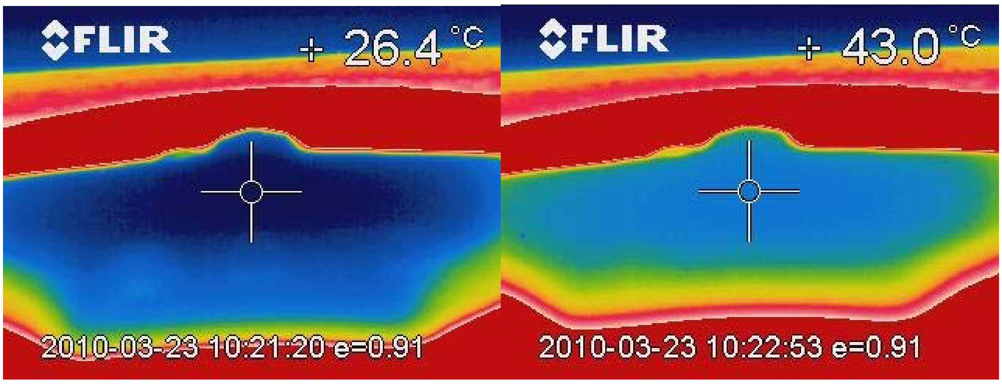


Figure 3. The sample *A* at the beginning and at the end of test

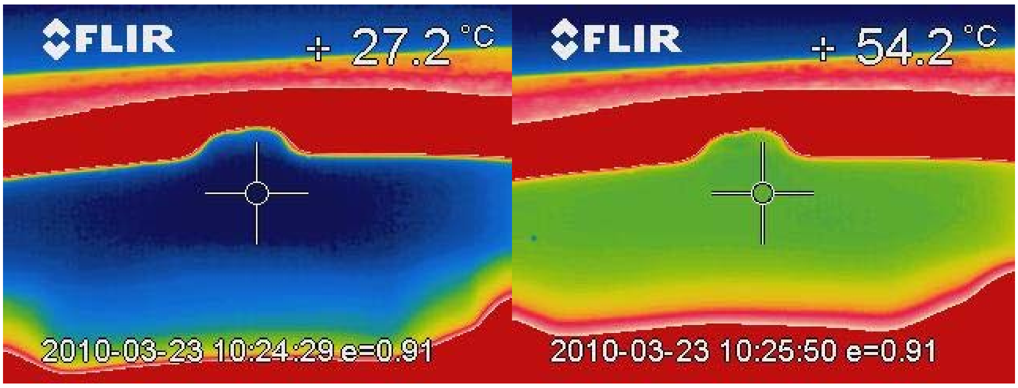


Figure 4. The sample *B* at the beginning and at the end of test

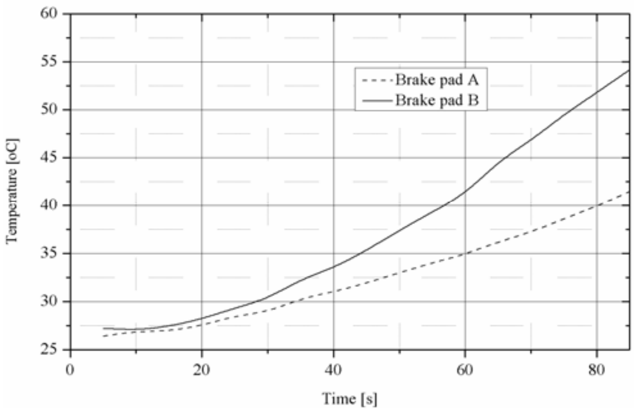


Figure 5. The compared thermal conductivity diagrams [6]

Based on graphics shown at fig. 5, the relationship between temperature and time was obtained:

$T = -4.75 \cdot 10^{-6} t^3 + 1.93 \cdot 10^{-3} t^2 + 0.05 \cdot t + 26.69$, for brake pad ***A***, and
$T = -2.85 \cdot 10^{-5} t^3 + 7.2 \cdot 10^{-3} t^2 - 8.8 \cdot 10^{-2} t + 27.34$, for brake pad ***B***.

It is easy to conclude that the conductivity of brake pad ***B*** is grater than the one of brake pad marked as ***A***.

Tests on dynamometric test bench

Only the samples 1 and 2, chosen by previous criteria, were tested on test bench, according to manufacturing standard 7.H2000.

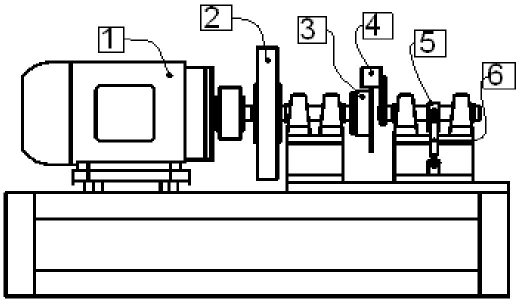


Figure 6. Dynamometric test bench (drawing and the photography)[4]

The test bench (figure 6) is consisting of electromotor (1), set of flywheels (2), supporting elements (6) for brake assembly (3, 4) montage and torque measuring device (5). On this test bench is possible to simulate the real conditions of vehicle brake function. The mass of flywheel has to be chosen from set in the way to correspond to the mass of vehicle which the brake assemble belongs to. Electromotor drives flywheel and make them rotates with energy corresponding to vehicle driven at demanded speed. The kinetic energy of flywheel has to be absorbed and flywheel stopped by one wheel brake, at the same way as the disc brake functioning on real vehicle. The velocity of „vehicle", braking torque, applied hydraulic pressure and temperature inside of brake pad, temperature on the outside brake pad surface, and temperature of brake fluid inside the caliper are the measured physical characteristics. For this purpose the whole standard was not under consideration but only the parts putting foreground the correlation of temperature and braking efficiency.

The temperature of brake pad was measured by thermocouple (Ni-CrNi) put in small hole 2 mm under the brake lining contact surface, at the same way for both samples.

The brake pad metal surface temperature was measured by thermocouple tightly pasted on the back of metal plate of outside brake pad.

The brake fluid temperature inside of caliper was measured by thermocouple built inside of caliper threw the air drain bolt.

At figures 7. and 8. [4] the temperatures measured during the test are shown. The thermal characteristics of brake pad sample *B* causes the higher temperatures of brake fluid inside of caliper (figure 8). According to Table 1, the brake fluid boiling point could be easily reached in brake system with brake pad *B* built in.

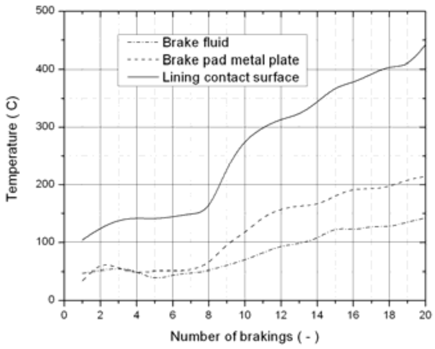


Figure 7. Measured temperatures during the test on dynamometric test bench, sample *A*

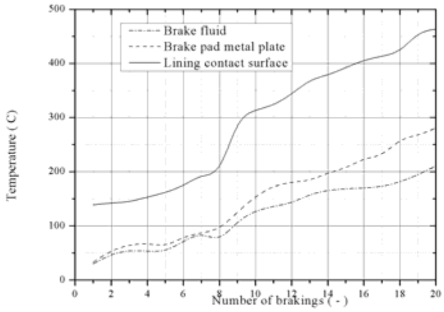


Figure 8. Measured temperatures during the test on dynamometric test bench, sample *B*

The figure 9. [4] shows IR photography of disk brake assembly on test bench at the end of 20th braking cycle, first with brake pad ***A*** and, after that with brake pad ***B***. The photos captured by common digital camera while the experiment was running are shown at figure 10.

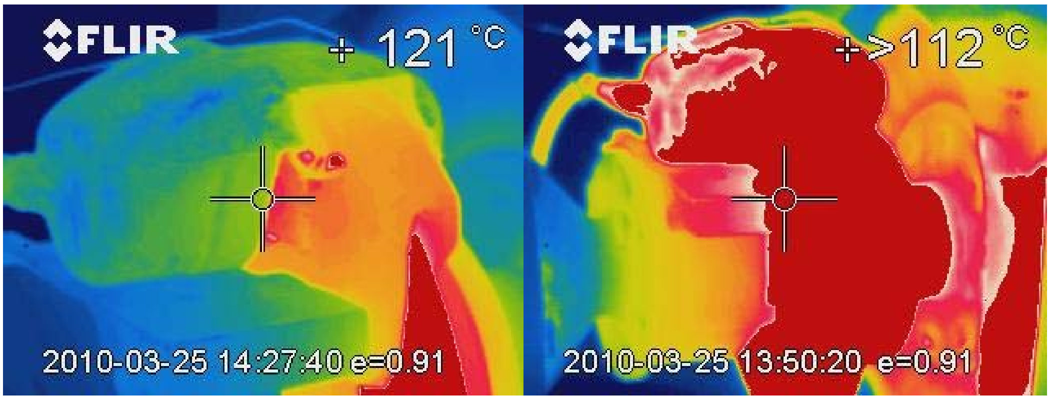


Figure 9. IR photography of brake with brake pad *A* and brake pad *B*

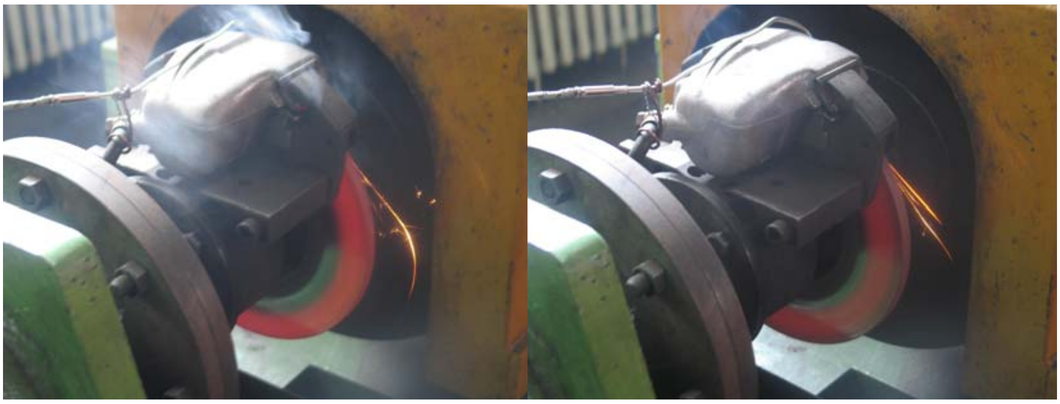


Figure 10. Photo of experiment at test bench [4]

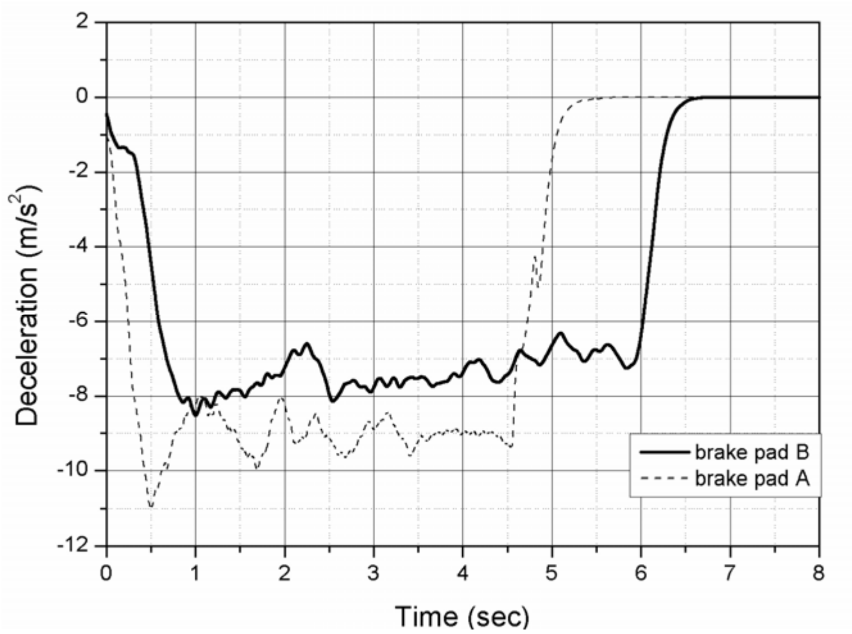
Road tests

After the conclusions of brake pads conduction were made according the laboratory tests, the researching was continued by vehicle testing in on-road conditions. The experiment was done according to ECE 13 regulation and valuation of brake system efficiency was made by measuring of vehicle brake distances and/or deceleration. Figures 11 and 12 respectively show test vehicle on the polygon and the test results [5], [6].

Figure 11. Test vehicle on the test polygon

The differences in brake efficiency were not noticed during the low temperature tests whit no regard on vehicle speed than test begins with, brake pedal force or other conditions.

The problem was occurred in test of consecutive braking when the capability of brake system to dissipate the heat was fully expressed. It has been noticed that the deceleration rise time was longer with brake pad ***B***. At first, it seams like measuring fault, but by repeating of experiment the conclusion was made that the braking fluid boiling point has been achieved. Also, the average maximal deceleration is inferior at brake pad ***B***, because of friction coefficient weakening caused by linings overheating.



If the brake system is not able to transmit the thermal energy to surroundings fast enough, the overheat will emerge and all mentioned poor consequences.

Figure 12. Vehicle deceleration at road fade test

Conclusions

In the process of brake pad quality control the thermal conductivity does not treat as primary characteristic. Experimental researching proved that characteristic of conductivity must not be avoided. Brake system is even more effective if the thermal capacity of brake is greater and if the thermal conductivity is better, i.e. if it possible to provide better heat dissipation. By those examinations only the brake pad, as one part of friction pair, was taken under the consideration. Brake disc, as a very important part of brake so as caliper, deserves complex long term examination for heat transmission studies to be made. This research is made by car manufacturer for cause of making choice between a few brake pad suppliers. The next step in researching should be involving the brake pad producers in tests of this kind to make the mathematics relationship between thermal conductivity and row material composition. The results described in this paper can be used for mathematic model verification.

References

[1]. Breuer B., Bill K.: Brake Handbook (in German), Vieweg & Sohn Verlag, Wiesbaden, Germany, 2003.
[2]. Zaharim et al.: Study of the Temperature Distribution in Disc Brakes by the Method of Order-Of-Magnitude Analysis, *Regional Conference on Engineering Mathematics, Mechanics, Manufacturing & Architecture (EM3ARC) 2007.*
[3]. Khong Keng Leng: Simulation of Temperature Distribution in Brake Discs, In partial fulfillment of the requirements for the Degree of Bachelor of Department of Mechanical Engineering, National University of Singapore.
[4]. Milenković P., Milovanović M., Djordjević M.: The Brake Pad Laboratory Testing (in Serbian), Report No 15OIA-06/10, Zastava automobile, R&D Department, 2010.
[5]. Djordjević M. Jovanović S.: The Road Testing of Brake Pads (in Serbian), Report No 20OIA-041/07, Zastava automobile, R&D Department, 2007.
[6]. Milenković P. et al.: The Improvement of Passenger Brake System Efficiency (in Serbian), Report No 15OIA-08/06, Zastava automobile, R&D Department, 2006.

Paper submitted: May 05, 2010
Paper revised: Jul. 02, 2010
Paper accepted: Jul. 06, 2010