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TRIBOLOGICAL, MECHANICAL AND NOISE PROPERTIES OF PROPOSED COMPOSITE MATERIALS FOR BRAKES OF HIGH SPEED TRAINS

[1]Moustafa, A. M., [1]Azzam, B.S., *[2]Ali Salah H.R. and [1]Osman, T.A.

[1]Mechanical Design and Prod. Dept., Cairo University, Giza 12211, Egypt
[2]Engineeringand Surface Metrology, National Institute for Standards, Giza 12211-136, Egypt

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ABSTRACT

High-speed train is a type of rail transporting vehicle that operates significantly faster than the traditional rail traffic, using an integrated system of specialized rolling stock and dedicated tracks. This type of trains has first begun operations in Japan during the sixteenth of the last century and is widely known as the bullet train. One of the most important systems in these trains is the braking system. With the continuous and improvement of this type of trains, disc brake pads are widely applied, due to their high speeds and reliable working of brake pads. In this paper, a new proposed composite material has been developed to achieve the requirements of these types of high speed trains. This new proposed material has been fabricated with various chemical compositions and tested tribologically and mechanically to measure its performance under different operating conditions. Moreover, surface characteristics of selected specimens have been performed using microscopic images. The results of tests showed that the new proposed material has satisfied the recommended values for the friction coefficient with maintaining a lower level of wear. The proposed material has also satisfied a good strength and stiffness properties. Additionally, the noise resulted from this new material is found to be in the reasonable range of friction noises. A comparison of tribological and mechanical properties with noise levels for commercial Egyptian brake pad, commercial Egyptian automotive brake pad and developed brake pad has been performed and showed the well performance of the proposed composite brake pad.

INTRODUCTION

The brake pads are part of important braking system structure in high speed trains. In this paper, the investigation will discuss manufacturing procedures of composite organic brake pad and a development of tribological, mechanical, surface, thermal conductivity and noise characteristics of a proposed composite organic brake pad which can be used in high speed trains. The proposed composite organic brake pad consists of five main constituents. The elements and functions of these constituents are as follows (Blau, 2001; Salah, 2003; Salah *et al*., 2010; Talib Ria Jaafa, 2012):

Friction additives (like: Silica, Aluminum oxide, Cast iron powder and Copper powder): The function of the friction additives is to increase the friction coefficient between the pad and disc,

Fibers and reinforcements (like: Rockwool fibers, Glass fibers, Aramid and Brass): It increases strength and tenacity,

Lubricant modifier (like: graphite and metal sulphides): It damps stresses and reduces noise level,

Filler (like: Barium sulphat, Cashew nut, Rubber filler and Ceramic filler).: The function of the filler constituent is to decrease the cost and increase the manufacturability,

Binder (like: Kaolin and Phenolic resin): It combines all the above contents with each other.

Required functional properties of composite brake pads

The brake pad material must satisfy some functional requirement in order to perform its function properly. Some of these functional advantages are (Deepika *et al*., 2013):

- High friction-coefficient stability.
- Low wear of the brake pad disc.

***Corresponding author: Salah H.R. Ali,**
Engineering and Surface Metrology, National Institute for Standards, Giza 12211-136, Egypt.

- Friction property can be adjusted according to requirement.
- Good wear resistance and long life span.

In this paper, a proposed composite material of reasonable tribological and mechanical characteristics for organic brake pad of high speed train is provided. The properties of the new proposed material are then compared tribologically and mechanically with properties of both of commercial Egyptian automotive brake pad and commercial Egyptian railway brake pad (AhmetAkkus, 2014) and (Jose, 2013).

Experimental Work

An experimental work has been performed to produce some samples of the proposed composite brake pads. This wok has included three stages, as follow:

Fabricating a Curing Mould

The mould used to produce the experimental samples for the new proposed composite material is illustrated below in figure 1. The mould consists of three parts; block, punch and base. The proposed specimens will be compressed in the mould under a defined certain pressure, temperature and time (Salah *et al.*, 2004).

Punches Block Base

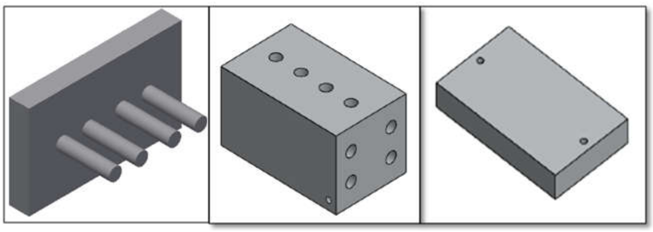

Fig.1. Fabricating mould parts

Production Procedures

The manufacturing processes for producing the proposed composite specimens are going as follows (Salah, 2003; Salah *et al.*, 2004; Ibrahim Ahmed *et al.*, 2006), (Salah, 2012), (Salah, 2014) and (Salah, 2013):

- Determining the percentage of each constituent in the composite material for each specimen and mixing them with each other perfectly.
- Filling the cavities of the mould with the mixture and then compressed it according to a specified pressure and temperature of 159MPa and 120^oC, respectively.
- Extracting the specimens from the mould after they have been dried in the mould.

The proposed composite pad compositions have been got after a lot of experimental trials on samples having different constituents with different ratios in order to obtain the best performance one.

Experimental Tests

Six tests have been performed for the three studied specimens of pads (commercial Egyptian automotive brake pad, commercial railway brake pad and the proposed developed composite frictional pad). These tests are:

- Chemical analysis test using, on EDX device, to determine the main components of the material.
- Tribological test (on Pin and Disc machine) to measure the fictional coefficient and the wear rate of each specimen.
- Mechanical test (compression test) to measure the strength and modules of specimens.
- Noise test by using a noise level meter to measure the noise level raised from specimens.
- Thermal conductivity test using a thermal conductivity meter to measure the coefficient of thermal conductivity of each specimen.
- Microscopic test using a metallurgy optical microscope to insurethat there is no crack orcavitation in the surfaces of specimens

Conditions of the tribologicaltest

Pin on disc machine device used to measure the tribological characteristics of specimens: as the coefficient of friction and wear rate. The machine has several conditions as follow:

- Max speed of disc = 400 rpm.
- Radial track of pin on disc is at radius of 20 mm.
- Effective Load of pin on disc =16 N.
- Time of test = 4 min.
- Used brake pad disc material is grey cast iron.

Test procedures

There are some steps should be done on specimen and machine to proceed the test as follows:

- Preparing a pin from specimens with 20 mm height and 8 mm diameter.
- Installing the pin in its position in the machine for rubbing it on the disc at specified values of speed, load, time and position.
- Running the machine and recording the outcome reading at intervals of 30 seconds, for a period of four minutes; each reading represents an instantaneous coefficient of friction.
- Calculating the average of the coefficient of friction, as:

μ (Average) = $\Sigma\mu_i$ / No. of readings.

- Weighing the specimens before and after the test (W_i, W_f).
- Calculating the wear rate of specimen as follows:

Wear rate= $(W_i - W_f) / (W_i \times t)$

RESULTS

The results of the six experimental tests performed on specimens (chemical analysis, tribological, mechanical, noise level, thermal conductivity, and microscopic photography tests are given in the following subsections:

Chemical Analysis Test Results

The main chemical elements of the specified specimens such as: filler, reinforcement, frictional materials and binder categories are given in Tables 1, 2 and 3.

Tribological Test Results

Friction coefficient and wear rate of the three tested specimens; commercial automotive, commercial railway and the developed high speed train pads are illustrated graphically in the following figure (2), respectively. Average friction coefficient and wear rate for the specified specimens are obtained from the previous figure and found to be as follows:

- μ=0.35 and Wear rate= 24.3×10^{-6}gm/gm.sec, for the commercial automotive brake pad specimen.
- μ=0.49and Wear rate=33.7×10^{-6}gm/gm.sec, for the commercial railway brake pad specimen.
- μ=0.41 and Wear rate=29.8×10^{-6}gm/gm.sec, for the developed brake pad of high speed train specimen.

Mechanical Test Results

The mechanical test results for the specified specimens to get the mechanical properties of the specimen; namely the ultimate tensile strength, strain and Young's modules are given below in table 4.

Noise Test Results

A noise test has been performed for all the specified specimens during the tribological test by using a noise level meter to measure the noise intensity results from the specimens, while rubbing with the disc. The results of tests are given in table 5.

Thermal Conductivity Test Results

Thermal conductivity test has been performed for all the specified specimens by using a thermal conductivity meter to measure the coefficient of thermal conductivity which reflects the ability of brake pad to dissipate the raised heat during the braking process. The results of this test are given in Table 6.

Test Results of Surface Characteristics

A microscopic photography test has been performed for the three specified specimens by using a metallurgy optical microscope, to make sure that there is no any crack or cavitation in the specimen surface. It shows in followed Figures (3-5).

Comparisons of Results

The analysis of results show gradient values of tests results for developed of brake pad of high speed train specimen (a), commercial Egyptian railway brake pad specimen (b), and commercial Egyptian automotive brake pad specimen (c) as given in the followed Figures (6-10).

Table 1. Chemical analysis of commercial Egyptian automotive brake pad specimen

Sc%	V%	K%	Ca%	Cu%	Fe%	Ti%	Zn%
0.65	0.69	0.80	14.64	19.90	19.36	23.86	20.1

Table 2. Chemical analysis of commercial Egyptian railway brake pad specimen

Sc%	Zr%	Cr%	Ca%	Ba%	Fe%	Zn%
0.37	4.13	15.2	10.51	23.3	20.87	25.55

Table 3. Chemical compositionofdeveloped brake pad for high speed train specimen

Brass Fiber +Rockwool%	Phenolic Resin%	Graphite%	Barium Sulphat%	Cashew Nut%	Cast Iron + Copper%	Aluminum Oxide%
9	14	12	15	15	25	10

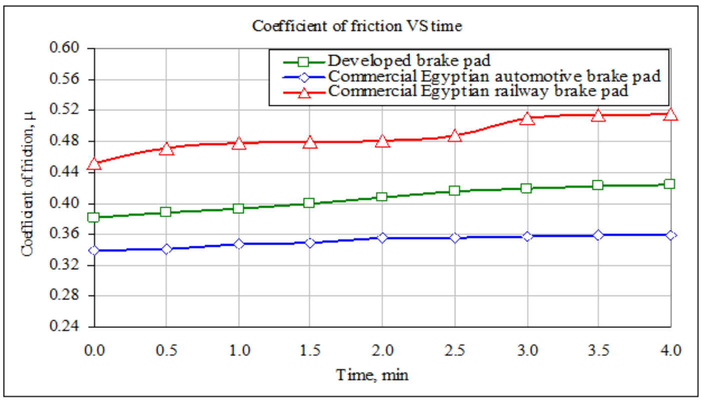

Fig. 2. Comparison of coefficient of friction of the specified brake pads

Table 4. Test results of the specified brake pads

Specimens \ Properties	Strength (MPa)	Density (Kg/m^3)	Young's Modulus (MPa)
Developed Brake Pad Specimen of High Speed Train	50.327	2300	2879.79
Commercial Railway Brake Pad Specimen	85.696	1633.3	8920.75
Commercial Automotive Brake Pad Specimen	34.733	2100	2532.94

Table 5. Test results of the specified brake pad (period of test is 30 seconds)

Specimens \ Properties	Developed Brake Pad Specimen for High Speed Trains	Commercial Railway Brake Pad Specimen	Commercial Automotive Brake Pad Specimen
Noise(dB)	66	71	69

Table 6. Test results of the specified brake pads

Specimens \ Properties	Developed Brake Pad Specimen for High Speed Trains	Commercial Railway Brake Pad Specimen	Commercial Automotive Brake Pad Specimen
Thermal Conductivity factor (W/ m. K)	13.8	10.7	15.4

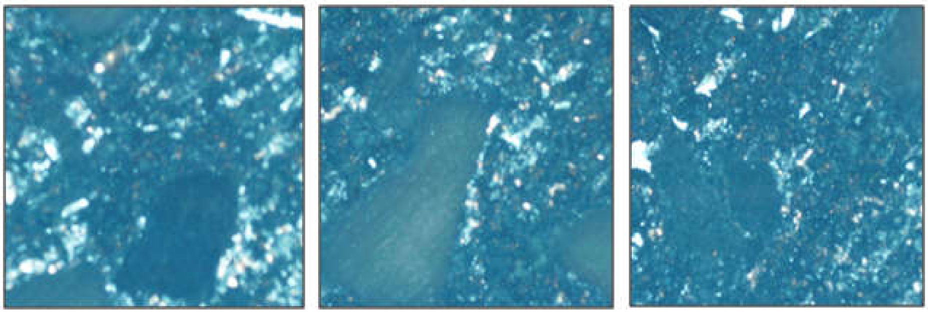

Fig. 3. Developed brake pad of high speed train specimen surface microstructure

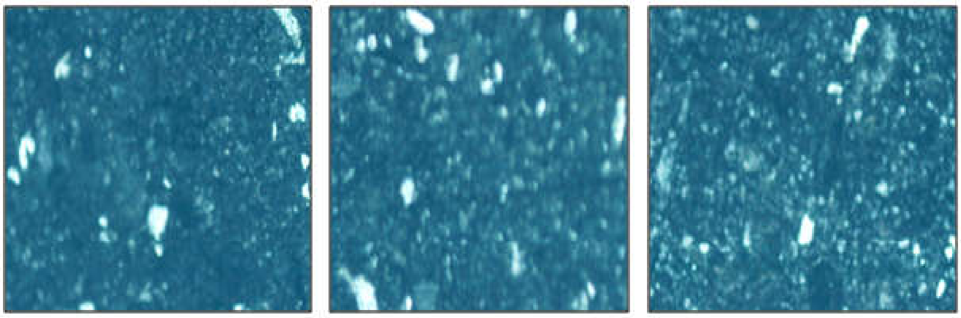

Fig. 4. Commercial railway brake pad specimen surface microstructure

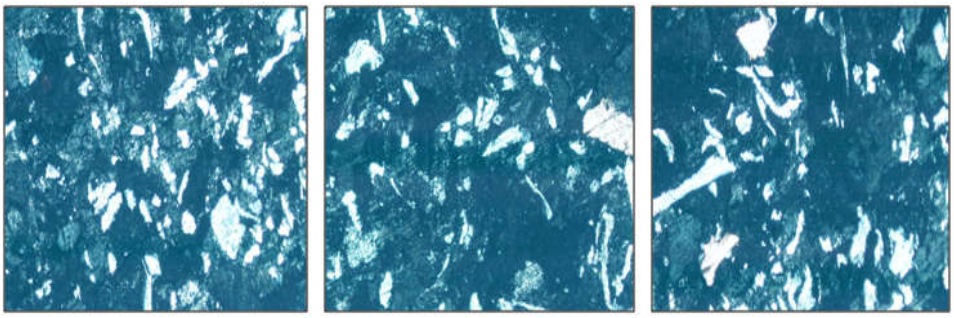

Fig. 5. Commercial automotive brake pad specimen surface microstructure

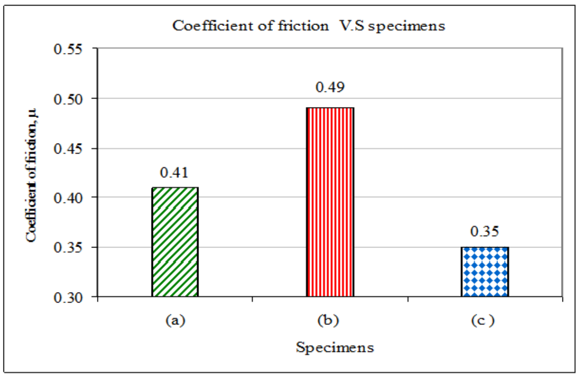

Fig.6. Coefficient of friction of the specified specimens

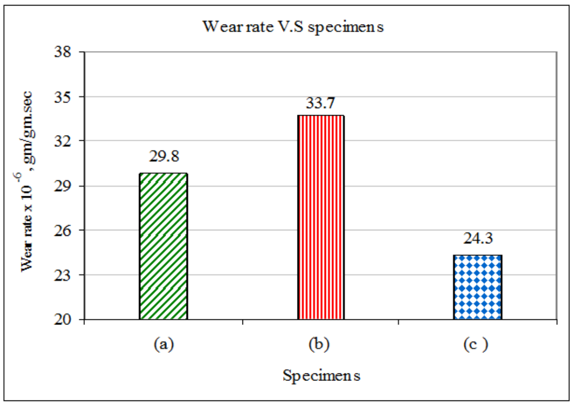

Fig.7. Wear rate of the specified specimens

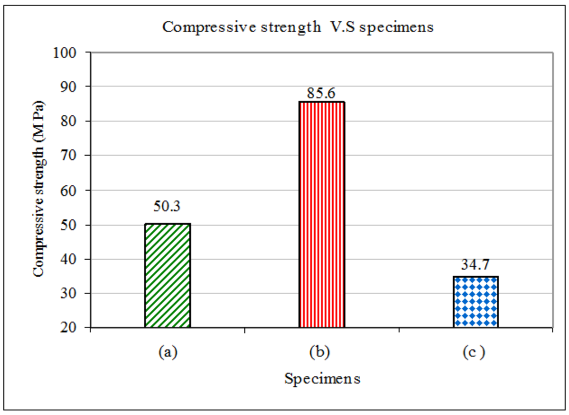

Fig. 8. Compressive strength of the specified specimens

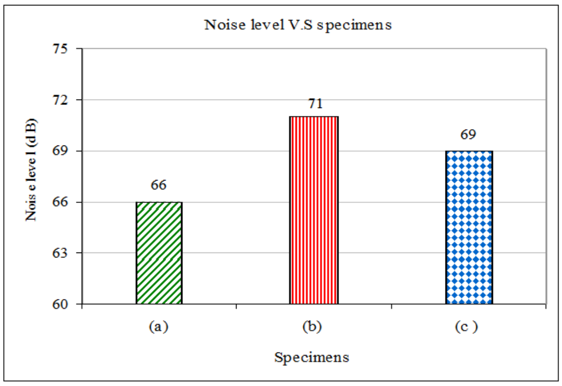

Fig.9. Noise level of the specified specimens

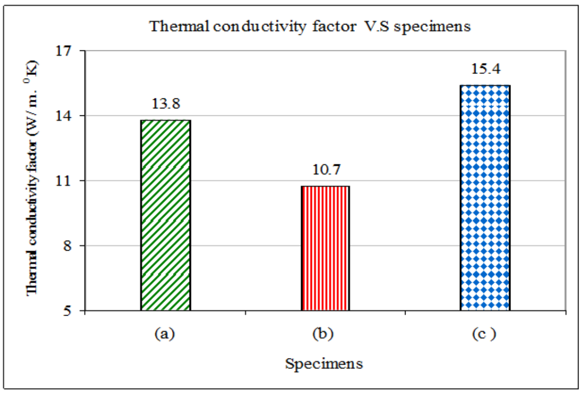

Fig.10. Thermal conductivity factor of the specified specimens

DISCUSSION

Throughout the results of the experimental tests, this performed on the three specified brake pads specimens. The well properties of this proposed material can be referred to the selected types and ratios of its compositions. Where, its content ratio of abrasive material as; cast iron powder and Aluminum oxide could lead to an increase in the friction coefficient with maintaining the wear rate at minimum levels. Also, the presence of the reinforcement material as; Rockwool fibers could lead to an increase in the strength of specimen. Additionally, the content of the lubricant modifier materials; graphite with the specified ratio could lead to a decrease in the noise level of specimen. Finally, the thermal conductivity of the proposed material could be increased due to the presence of the metallic materials in the pad one can deduce that developed composite brake pad specimen could give well acceptable tribological properties as; it has satisfy coefficient of friction, it is enough to braking the train through satisfy time and braking force. It also gives well mechanical properties as; it has satisfied compressive strength, it is enough under braking force, without cracks and damage. It has also lower noise level than the other due to existing of graphite which is safe to human. Commercial Egyptian railway brake pad has higher coefficient of friction than the other due to existing of satisfied percentage of abrasive materials; it is enough to braking the train in satisfy time and braking force, it has lower density than the other, it has higher noise than the other, and it also has lower thermal conductivity factor than the other. Commercial Egyptian automotive brake pad has lower coefficient of friction than the other and it also has higher thermal conductivity factor due to existing of satisfied percentage of copper and iron, this lead to dissipate heat.

Conclusion

The experimental analysis and tests performed in this paper lead to the following conclusions:

- Commercial Egyptian railway brake pad has higher coefficient of friction, wear rate, noise level and compressive strength than the other; it has also lower thermal conductivity coefficient, and noise level.
- Commercial Egyptian automotive brake pad has higher thermal conductivity coefficient than the others, it has lower coefficient of friction, wear rate, compressive

strength than the others, it has also higher thermal conductivity factor than the others, and noise level.

- Developed brake pad of high speed train has lower noise level; it also has satisfied coefficient of friction , compressive strength and thermal conductivity factor equal.
- Surface characteristics of developed brake pad of high speed train are; there are not any cracks or cavitations in the surface, composites materials distribution is homogenous on the surface. The surface photograph show that; there are brown color, it are cashew nut particles, there are metallic silver color, it are cast iron particles, there are bright gold color, it is copper fiber and there are also black areas, these are graphite particles.
- Surface characteristics of commercial Egyptian railway brake pad are; there are not any cracks or cavitations in the surface, composites materials distribution is homogenous on the surface. The surface photograph show that; there are metallic silver color, itare Sc, Zr and Fe_2O_3particles, there are gray color, it are Cr particles, and there are also black color, it are Zn particles.
- Surface characteristics of commercial Egyptian automotive brake pad are; there are not any cracks or cavitation in the surface, composites materials distribution is homogenous on the surface. The surface photograph show that; there are big metallic silver color, it are Fe_2O_3fibers, and small metallic silver color, it are Ti, there are bright gold color, it are copper fibers, and there are also black color, it is Zn.

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