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Burnishing Effect on Disc Brake Corrosion and Frictional Performance of Corroded Disk

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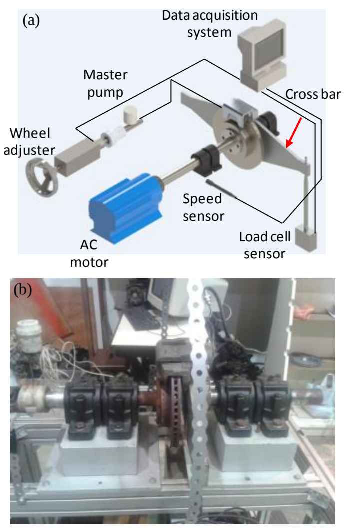
Graphical abstract



Abstract

This work examined the frictional force induced by the disc brake when the disc brake gets corroded. The corrosion process was carried out on two types of disc brake labelled disc A and disc B where both disc brakes were made from gray cast iron but having different design. Both discs were burnished with two types of friction materials labelled P-1 and P-2 before they were exposed to the open air environment to simulate the disc corrosion for a parked vehicle. The change in brake torque and friction coefficient was analyzed using a single-end brake dynamometer. The results showed that the burnishing effect of the friction material has significant effect on the formation of oxide layer. Oxide layer formed on disc burnished with friction material P-2 was more concentrated and thicker compared to the disc burnished with friction material P-1. Also, the results showed that brake torque and friction coefficient were closely dependent on the removal of the oxide layer and by the friction film on the burnished disc surface while applying the brake. Thus the composition of friction materials is critical to affect the formation of the oxide layer on the disc and consequently, the performance of the frictional force of disc brake system.

Keywords: Corrosion; friction material; frictional force; brake performance

Abstrak

Kajian ini bertujuan untuk mengenalpasti daya geseran pada brek cakera yang mengalami pengaratan. Proses hakisan dijalankan terhadap dua jenis cakera brek cakera berlabel A dan cakera B yang diperbuat daripada besi tuangan tetapi mempunyai reka bentuk yang berbeza. Kedua-dua cakera telah digosok menggunakan bahan geseran yang berlabel P-1 dan P-2 sebelum ianya terdedah kepada persekitaran udara terbuka untuk mensimulasikan hakisan pada cakera brek. Analisis menggunakan brek dinamometer untuk melihat perubahan tork dan geseran brek. Hasil kajian menunjukkan bahawa kesan penyapuan bahan geseran mempunyai kesan ketara ke atas pembentukan lapisan oksida. Lapisan oksida yang terbentuk pada cakera yang digosok dengan bahan geseran P-2 adalah lebih pekat dan lebih tebal berbanding dengan cakera yang telah digosok dengan bahan geseran P-1. Selain itu, didapati tork brek dan pekali geseran amat bergantung kepada penyingkiran lapisan oksida dan lapisan geseran pada permukaan cakera yang digosok semasa menekan brek. Oleh itu, komposisi bahan geseran adalah penting dalam memberi kesan kepada pembentukan lapisan oksida pada cakera brek dan penyumbang kepada prestasi sistem brek cakera.

Kata kunci: Hakisan; bahan geseran; daya geseran; prestasi brek

1.0 INTRODUCTION

The corrosion of the gray iron discs in a brake system has attracted much attention because the disc with corroded surface often causes high torque variation during brake applications [1]. The effect of corrosion on the brake performance has long been a concern by the brake manufacturer since the early stage of vehicle development. The important aspect of corrosion on gray iron discs brake is the oxide film that covers the disc surface which is easily removed after some brake applications [2]. The oxide layer on the disc often causes high torque variation and lead to corrosion induced friction stability problem [3]. The main factor that may affect the corrosion and performance of disc brake is the composition of friction material which is known as brake pads [4]. The composition of friction material may determine the wear particle generated and thus the formation of oxide layer on the disc brake surface. Thicker oxide layers on the corroded disc surface often cause high torque variation and different in surface roughness [2].

One of the methods to improve the corrosion resistance of gray iron disc is to control the metallurgical parameters and surface modification [5]. Corrosion resistance of gray irons can be improved by the addition of small amounts of alloying elements such as Ni, Cu, Cr, singly, combination, or by increasing the Si content more than 3 wt. % [6]. The compositional modification by changing the alloying elements will change the microstructure of the gray cast iron to provide protective layers on the surface of the disc [6-8]. However, traditional methods for reducing surface corrosion on brake discs are not very effective because the alloying elements for corrosion resistance often reduce the tribological properties of grey cast iron, and the protective surface layers are not durable enough during severe brake application conditions [6].

The brake wear particle that made up the friction film that covers the disc surface is also another important factor for disc corrosion. This friction film act as coating agent and its thickness and morphology will influence the corrosion and removal rate of the oxide layer [9]. Nevertheless, there are few reports of the correlation between gray iron disc corrosion and brake performance [10,11]. Disc brakes using alternative materials, such as metal matrix composites, carbon-based composites, and ceramics matrix composites, have been developed as a substitute for gray iron discs. However, newly developed disc must go through a complete performance evaluation before can be accepted as commercial products because high production cost prevents commercial applications.

In this paper, the burnishing effect of two pad materials made by Bosch labelled P-1 and by OEM labelled P-2 on disc brake corrosion and its influence on the brake friction performance were studied. Several experiments were carried out using a single-end brake dynamometer test rig at different sliding speed and applied pressure in order to differentiate the changes in friction coefficient and braking torque at variable speed and variable brake pressure. Investigation was also carried out to find the relationship of the types of friction material with thickness of the oxide layer formed.

■2.0 EXPERIMENTAL

2.1 Test Rig

The experiment was conducted using a single-end brake dynamometer test rig. The schematic diagram with the photo of test rig is shown in Figure 1. The test rig consists of 11kW output power, variable speed motor driving a gray cast iron disc mounted vertically on the shaft. Vertical mounting of the disc allow for close simulation of the orientation of frictional contact encountered during the real brake operation.

The disc brake system was adapted from Proton Persona brake disc where the brake calliper is mounted to the solid cross bar that attached to the stationary shaft. The load cell sensor was attached at the edge of the cross bar which ease the sensor to read the braking torque during the brake operation.

The force was applied to the brake by using the master pump that attached nearby with the AC motor and the pressure was controlled by the wheel adjuster. The speed sensor was spotted perpendicularly to the white paper which marked at the shaft of the AC motor. All the sensors were attached to the data acquisition system which will obtain the result of brake test.

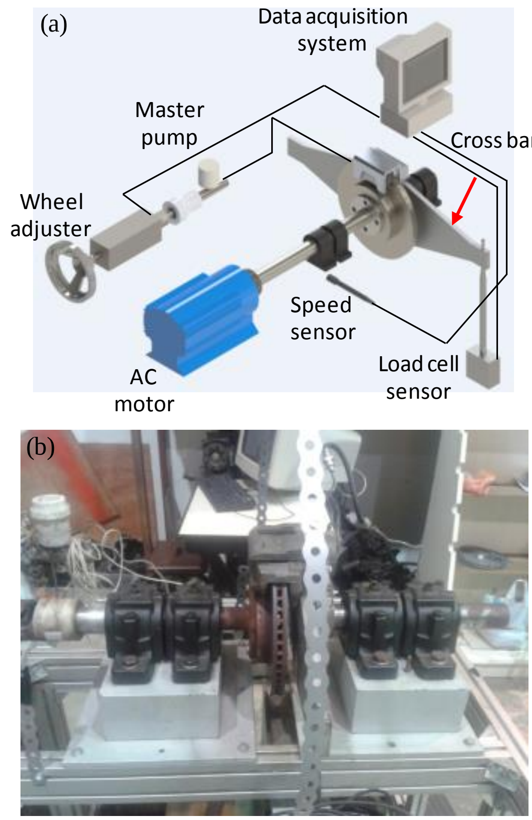


Figure 1 Schematic diagram (a) and picture of the test rig (b) used for the test

2.2 Specimen Materials and Testing Procedures

Two types of disc brakes and two types of commercial brake pads were used in this experiment. Both discs were made from the gray cast iron but having different design which labelled as disc A and disc B. The two types of commercial brake pads were produced by Bosch and OEM which labelled as friction material P-1 and friction material P-2, respectively. Table 1 shows composition of these two brake pads.

Table 1 Composition of the friction material P-1 and P-2

Friction material P-1		Friction material P-2	
Composition	**Weight %**	**Composition**	**Weight %**
Carbon	51.138	Carbon	29.730
Oxygen	23.963	Oxygen	37.217
Sodium	0.461	Sodium	0
Magnesium	0.527	Magnesium	0.449
Aluminum	1.213	Aluminum	0.715
Silicon	3.069	Silicon	9.558
Sulfur	1.642	Sulfur	3.246
Chlorine	0.445	Chlorine	0
Potassium	0.364	Potassium	0.322
Calcium	1.880	Calcium	3.256
Iron	8.083	Iron	0.383
Barium	7.216	Barium	13.956
Titanium	0	Titanium	1.168

The disc corrosion process was evaluated after burnishing the disc with the friction material P-1 and P-2 at moderate sliding condition with a light pressure of 0.5 MPa applied to the brake for about 1 hour time period. The burnished disc was then water sprayed and exposed to the environment to simulate the presence of water and mist. The disc was exposed to the surrounding air at room condition for about 7 days. The corroded disc was then measured for their oxide layers thickness before undergone a brake dynamometer test to proceed with the investigation on the influence of oxide layers thickness on the frictional performance of the disc brakes.

The experiments were conducted by using a variable speed AC motor to rotate the disc at 50 rpm, 70 rpm, 80 rpm and 100 rpm. For every speed of motor, the brake pressures applied used were 0.5 MPa, 1.0 MPa and 1.5 MPa for each stops. These parameters were used for both specimens of friction materials and disc brakes. The main outcome of this experiment was the values of load cell where it was used to calculate the brake torque and friction coefficient values at the brake pads and disc interface. Data acquisition system by Dwesoft was used to record the result of the experiment during the test.

Table 2 Brake dynamometer testing details

	Disc type A and Disc type B burnish with:	
	Friction material P-1	**Friction material P-2**
Pressure (MPa)	0.5, 1.0, 1.5	0.5, 1.0, 1.5
Speed (rpm)	50, 70, 80, 100	50, 70, 80, 100

3.0 RESULTS AND DISCUSSION

3.1 Burnishing Effect of Friction Material P-1 and P-2 on corrosion

The burnishing effect on the discs corrosion by using different friction material was investigated. Disc A and disc B were undergone the burnishing process by using friction material P-1 for the first test and friction material P-2 for the second. Figure 2 shows the corrosion result of the two different type of disc after the burnishing process using friction material labelled P-1 and P-2.

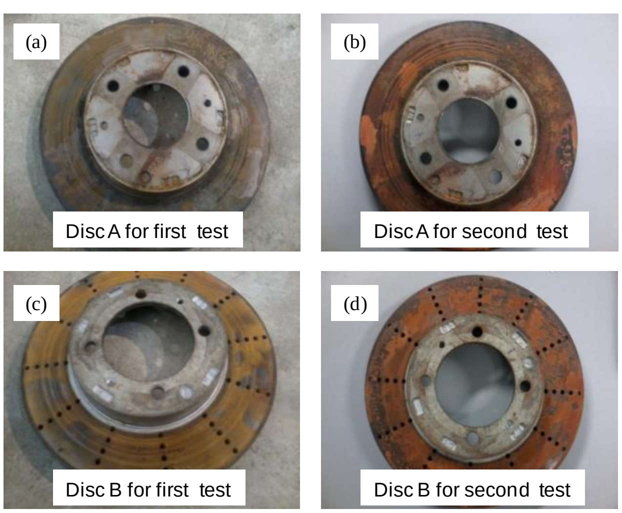


Figure 2 Result of corroded discs burnished with friction material P-1 and P-2 for both tests

The results from burnishing process on the discs shows obvious differences where more corrosion were produced on the second test when the discs were burnished with friction material P-2 compared to the discs burnished with P-1. This was due to the different composition capability of friction materials P-1 and P-2 used in the test to generate the wear particle and form third body on the encounter disc. For the first test on both discs, the formation of oxide layer was very little and not encouraging after both discs were burnished with friction material P-1. Meanwhile, for the second test, after both discs were burnished with friction material P-2 more corrosion patches can be observed on the surfaces of the two discs. This shows that the composition of friction material P-1 has better corrosion resistance characteristics than friction material P-2. The average thickness of the oxide layer for the second test for disc A was almost doubled the first test at about 113µm and this shows that the composition of friction material will significantly determine the thickness of the oxide layer formed. The complete measurement for the oxide layer thickness was recorded in Table 3 and Table 4. Thus, the composition of friction material P-1 can be said to have the element that can reduce the corrosion rate and oxide layer thickness compared to friction material P-2.

Table 3 Thickness of oxide layer formed at Disc A for test 1

Reading	**Disc brake thickness (mm)**		**Thickness of oxide layer (µm)**
	Normal disc	**Corroded disc**	
1	22.13	22.21	80
2	22.15	22.22	70
3	22.15	22.20	50
Average	22.14	22.21	67

Table 4 Thickness of oxide layer formed at Disc A for test 2

Reading	**Disc brake thickness (mm)**		**Thickness of oxide layer (µm)**
	Normal disc	**Corroded disc**	
1	22.05	22.16	110
2	22.11	22.21	100
3	22.07	22.24	170
Average	22.08	22.20	113

Figure 3 shows the thickness of the oxide layer formed on the discs surface for both disc A and disc B for the corrosion tests.

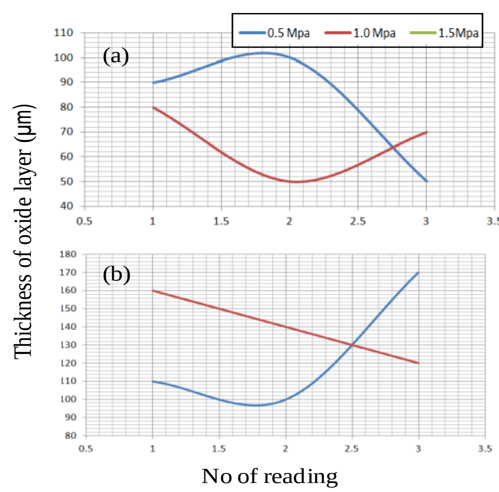


Figure 3 Thickness of oxide layer of both discs for first test (a) and second test (b)

3.2 Corrosion Effect on Coefficient of Friction (CoF)

The results of the CoF for test one and two for both discs are shown in Figure 4(a-d). In the first test for Disc A, the value of CoF for all three pressure lines shows similar pattern of increment with the speed with the pressure line of 0.5 MPa which is in blue colour was the highest compared to the other two lines. However, in the second test (Figure 4(b)), the blue pressure line recorded high CoF value of 0.37 compared to 0.26 at 50 rpm because of the presence of thicker oxide layer that the pad needs to counter.

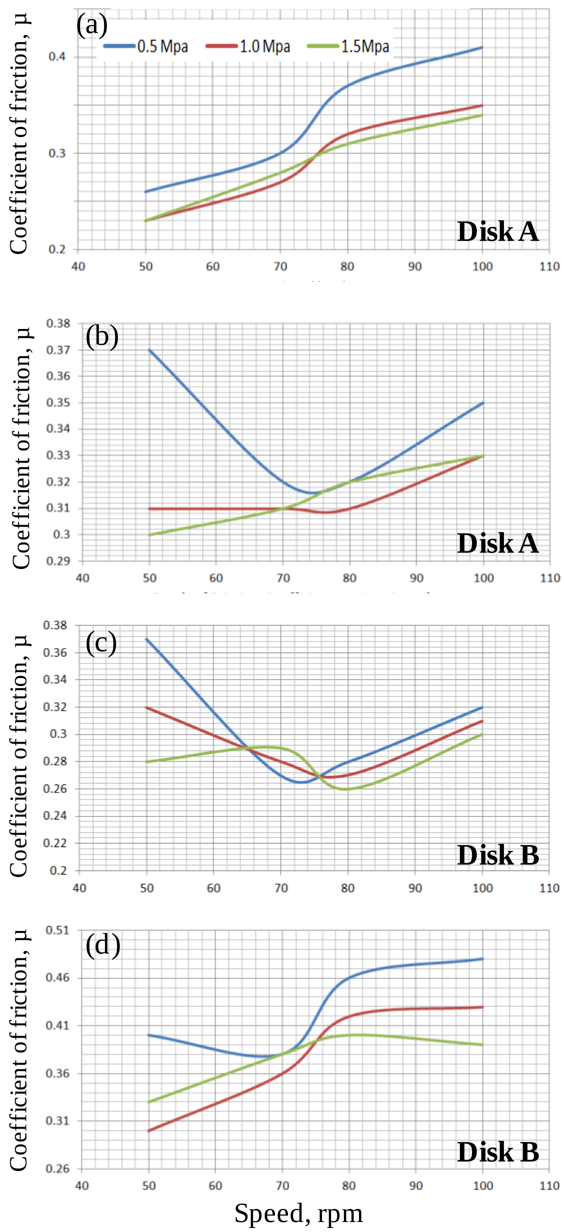


Figure 4 Result of CoF for the brake test using friction material P-1 (a),(c) and P-2 (b),(d)

The thicker oxide layer caused higher pad surface roughness and more effective area contact resulting in high CoF value. The CoF then decrease across the speed as the oxide was removed before its value was again increase when the speed reached 80 rpm. Meanwhile, the pressure line of 1.0 MPa and 1.5 MPa shows similar behavior where its position on the graph is almost the same. Also, the overall CoF increase with speed for test two was reduced due to the removal of oxide layer to form third bodies and assist friction.

Figure 4(c) shows similar behavior as Figure 4(b). It can be seen that the CoF for 0.5 MPa pressure initially was high and reduce with the speed, before it increases when the speed reached 80 rpm. This behavior was similar to the red curve line of 1.0 MPa but a little bit different for green line of 1.5 MPa. However, there was an obvious difference in term of CoF value for test two of disc B. It can be seen in Figure 4(d) that the CoF value of disc B is higher compared to test one with bigger overall CoF increase with speed. This was also due to the removal of thicker oxide layer but with higher surface roughness of disc B where it affects the initial value of CoF when brake was applied. Overall, the CoF for disc A was in the range of 0.3 to 0.4 and CoF for disc B was in the range of 0.3 to 0.5.

Figure 5(a-d) shows the brake torque results for the three pressure lines where the maximum pressure which is 1.5 MPa was the highest followed by pressure line of 1.0 MPa and 0.5 MPa. The curved lines in Figure 5(a) shows increasing braking torque when the speed increased. As the disc increase in speed, the braking torque to resist the rotation of speed also increase and this caused the torque generated on the disc to increase. The braking torque also increases when the pressure of the brake application was increased. In Figure 5(b), the brake torque curve line behaviour was like a concave shape with small decreased and increased with speed. This happened due to the presence of uneven oxide layers on the disc surface and in addition, it was not uniformly distributed. Therefore, it was affecting the braking torque of the brake where high torque was generated at the initial brake application.

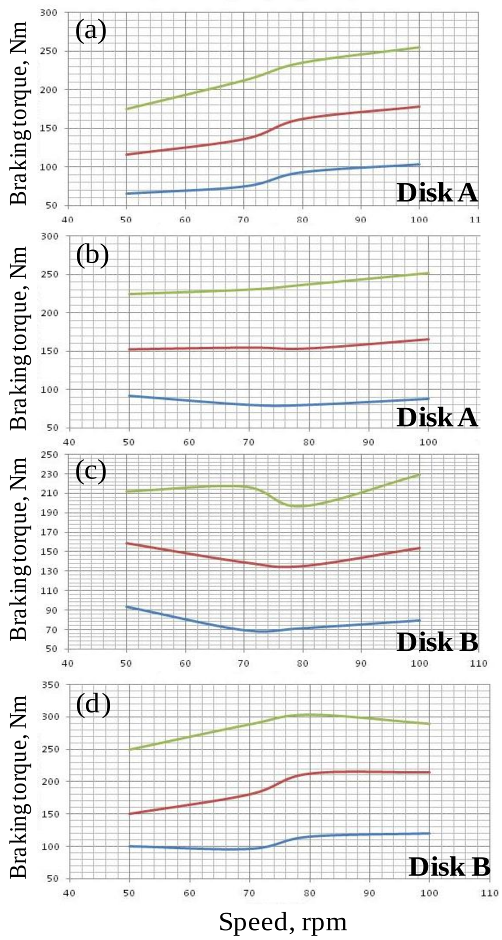


Figure 5 Result of Braking torque at variable pressure for test with P-1(a),(c) and P-2(b),(d)

Comparing Figure 5(a) and 5(b), the value of braking torque generated by disc A was lower at the initial stage and increasing across the speed. Compared to disc B, the braking torque induced is higher at the initial stage and decreased across the speed but increased back when reached the medium to maximum speed. It can be assumed that during the initial brake application, the braking torque induced by disc A was less compared to disc B because the oxide layer formed was less and thinner and the oxide layer on the disc surface of disc A was easily removed. However, the friction materials need to induce a little bit more torque to remove the thicker oxide layer on the disc B. So, that was the reason braking torque for disc A is lower than disc B at the initial stage.When the oxide layer has completely removed from the disc, the brake performance was back acting with normal braking.

Figure 5(c) shows the three pressure lines for braking torque against friction material P-1 for disc type B. The braking torque generated during brake application is slightly high initially, then reduce at medium speed before increase slightly at maximum speed for pressure 0.5 MPa and 1.0 MPa. For pressure of 1.5 MPa, the braking torque tends to increase at medium speed and drop at 80 rpm before again increase at maximum speed of 100 rpm. The higher pressure applied was assumed to be the main reason for the braking torque to experienced consistent increased during the test. Figure 5(d) shows the braking torque generated during brake application with P-2. For pressure of 1.5 MPa and 1.0 MPa the brake torque increase slightly at medium speed before they stabilized. For pressure of 0.5 MPa, the braking torque tends to reduce slightly at medium speed and increase at 80 rpm before stabilized at maximum speed of 100 rpm.

By comparing Figure 5(c) and (5(d), it can be seen clearly the different trend between both graphs. The brake torque generated for test with friction material P-2 tends to be higher compared to test with P-1in terms of brake torque value and overall increase. This is in relation to the thicker oxide layer that the friction material P-2 need to overcome and counter compared to P-1. So, it was assumed that the braking torque was having little bit more resistance to stop the disc. This also explained why the coefficient of friction for friction material P-1 is less than friction materials P-2.

■4.0 CONCLUSION

The burnishing effect on corrosion and the corroded discs effect on the frictional performance were investigated using a single-end brake test rig. The following conclusion can be made:

- The type of disc used has small effect on the disc corrosion compared to the friction material composition that gives significant effect on the disc corrosion.
- Oxide layer formed on disc burnished with friction material P-2 was more concentrated and thicker compared to the disc burnished with friction material P-1.
- Higher values of CoF and brake torque were related to the higher pressure and speed applied besides the amount and thickness of the oxide layer presence on the counter disc that the friction materials need to abrade.

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References

[1] Y. Suganuma, F. Howse, C. Thornton. 2001. Dynamometer Simulation Study for Market Brake Judder. SAE Technical Paper 2001-02-3191.
[2] K. H. Cho, J. M. Han, H. Jang, S. J. Kim, J. Y. Lee, H. D. Park, J. S. Oh and J. D. Lim. 2005. Corrosion Induced Brake Torque Variation; The Effect From Gray Iron Microstructure and Friction Materials. SAE International.
[3] M. W. Shin, K. H. Cho, S. J. Kim, H. Jong. 2010. Friction Instability Induced by Corrosion of Gray Cast Iron. *Tribology Letter*. 37: 149–157
[4] G. Ohira, T. Kusajawa, E Niyama (ed.). 1988. Physical Metallurgy of Cast Iron IV. Proceedings of MRS Symposium.
[5] C. V. White. 1990. Metal Handbook. vol. 1, 10th Edition. Properties and Selection: Irons, Steels, and High-performance Alloys, ASM.
[6] H. Jang, J. H Yoon, S. J. Kim, J. Y. Lee, H. D. Park. 2003. The Effect of the Composition and Microstructure of Gray Cast Iron on Preferential Wear during Parasitic Drag and on Intrinsic Damping Capacity. SAE Technical Paper 2003-01-3313.
[7] W. F. Smith. 1993. *Structure and Properties of Engineering Alloys.* 2nd Ed. New York, MacGraw-Hill.
[8] M. H. Cho, S. J. Kim, R. H. Basch, J. W. Fash, H. Jang. 2003. Tribological Study Of Gray Cast Iron With Automotive Brake Linings: The Effect Of Rotor Microstructure. *Tribology International.* 37: 537–545.
[9] S. J. Kim, S. J. Park, R. H. Basch, J. W. Fash, H. Jang. 2004. High Temperature Wear Properties of multiple Composite: The Role of Transfer Film. *Material Science Forum.* 449–452: 81–84.
[10] M. K. Abdul Hamid, A. M. Kaulan, S. Samion, A. R. Abu Bakar. 2013. Frictional Characteristics under Corroded Brake Discs, Procedia Engineering. Malaysian International Tribology Conference 2013.
[11] M. K. Abdul Hamid, S. Samion and G. W. Stachowiak. 2012. Effects of Hard Particles on Friction Coefficients and Particle Embedment in Brake

System during Hard Braking, AIP Conference Proceedings, 1440. 905– 913.