Characterization of Friction Material Formulations for Brake Pads

Darius G. Solomon and Mohamad N. Berhan

***Abstract*— New friction material formulations are compared with a commercial brake friction material used in Light Rail Transit (LRT) operating in Malaysia. Characterization techniques such as SEM, TGA, XRD, friction and wear tests are used to characterize the formulations as well as the commercial material. Out of the 30 formulations made, two formulations viz., S1 and S2 closer to commercial material are presented in this work. Formulation S2 exhibits better thermal stability and better wear resistance. With the help of SEM analysis, physical properties and XRD spectrum analysis, it is shown that formulation S2 has same crystallinity as the commercial specimen and can be considered for replacing the commercial material in LRT brake pad applications. The cost of the brake pad would reduce by half if they are made locally in Malaysia.**

***Index Terms* — Brake pads, Characterization, Friction materials, Friction and wear.**

I. INTRODUCTION

The tribological application of phenolic resin-based friction materials is usually limited owing to the relatively poor stability and wear resistance. Therefore, it is imperative to incorporate various reinforcing and filling constituents such as reinforcing fibers, abrasives, binders, fillers, and friction modifiers (solid lubricants) into phenolic resin-based friction composites for the purpose of increasing the stability and wear resistance. [1].

Different kinds of fibers, e.g., metallic, glass, ceramic and carbon fibers, have been used to replace asbestos. Among the fibers mentioned above, the most frequently used metallic fiber material is low carbon steel. Due to their good thermal stability and high hardness, ceramic materials are also used. The presence of ceramic fibers composed of alumina and silica improves the wear resistance, insulating properties and high temperature performance. It seems obvious that the addition of different fibers could impose different effects on the tribological behavior of semi metallic friction materials [2].

Friction materials for brake systems typically contain metallic ingredients to improve their wear resistance, thermal stabiltiy, and strength. Various metals such as copper, steel, iron, brass, bronze, and aluminum have been used in the form of fibers or particles in the friction material, and it is known that the type, morphology, and hardness of the metallic ingredients can affect the friction and wear of friction materials [3].

In the past 20 years, rapid developments in the railway industry have been accompanied by increases of speed, loads, and engine power. The friction materials are required to provide a stable friction coefficient and a low wear rate at various operating speeds, pressures, temperatures, and environmental conditions. All of these requirements need to be achieved at a reasonable cost. A commercial brake lining usually contains more than 10 different constituents. They are often categorized into four classes of ingredients: binders, fillers, friction modifiers, and reinforcements. Selection of the constituents is often based on experience or a trial and error method to make a new formulation [4].

This paper reports the characterization carried out on the formulation S1, S2 and commercial specimen using the following tests: Shore Hardness, specific gravity, ESEM, EDX, X-Ray Surface mapping, TGA, XRD and friction and wear tests. Discussions are made on the suitability of the formulation S2 as a substitute for the commercial specimen in the light of the friction and wear tests. It is shown that formulation S2 can be further improved to substitute the commercial LRT brake pad friction material.

II. COMMERCIAL BRAKE PAD

A. Brake Pad

Fig. 1 shows a brake pad used in the PUTRA-LRT trains running in Kuala Lumpur. Two such brake pads are used in every hydraulic brake unit. There are 16 brake pads in every train. 35 trains operated by PUTRA-LRT in and around KL are fitted with this type of brake pads. These brake pads are non-asbestos, non-lead and semi-metallic.

B. New Formulations of Brake Friction Materials

New formulations of brake friction materials are made using the following ingredients: Resin, Iron oxide, Steel fiber, Ceramic fiber, Organic fiber, Magnesium Oxide, Aluminium Oxide, Barium, Sulphur, Graphite, Rubber, Novacite, Nipol and friction dust. Values of Hardness, Specific Gravity, SEM, TGA and XRD spectrums of these formulations are compared with

---

Manuscript received March 22, 2007. The Ministry of Science, Technology and Innovation, Malaysia is thanked for supporting this work through IRPA grant [03-02-01-0055-PR0066/04-03].

Prof. Madya Dr. Darius Gnanaraj Solomon is with Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor D.E., Malaysia. (phone: +603-5543-6281;+6013-301-2356 fax: +603-5543-5160; e-mail: darius598@ salam.uitm.edu.my).

Prof. Ir. Dr. Hj. Mohamad Nor Berhan is with Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor D.E., Malaysia. (e-mail: berhan@salam.uitm.edu.my).

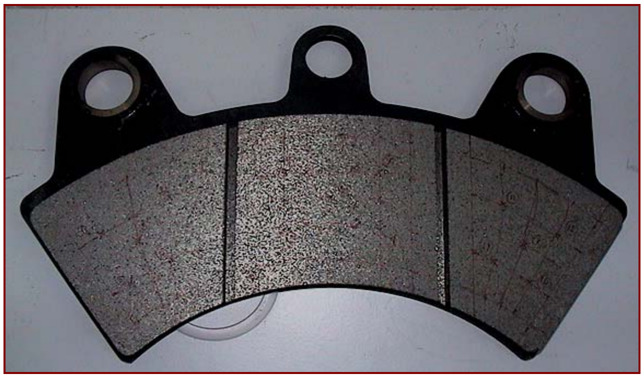

Fig. 1. A Railway Brake Pad (non-asbestos, non-lead and semi-metallic).

that of a commercial brake pad and the formulation which has its properties comparable with the commercial pad is identified. This paper reports the properties of specimen S1 and S2 and compares them with that of the commercial specimen

III. RESULTS AND DISCUSSIONS

A. *EDX Analysis*

Table-1 shows the elemental composition of commercial, S1 and S2. It can be seen that S1 & S2 have difference composition of elements compared to the commercial specimen. The amount of carbon in S1 and the amount of Al in S2 are comparable to the amounts present in the commercial specimen. Both S1 and S2 have higher amounts of C, O, Al, S, Ca and Ba compared to the commercial specimen. Correspondingly their properties are different from commercial specimen and we shall find which one exhibits closer behaviour compared to the commercial specimen using SEM, TGA and XRD spectrums.

Table-1: EDX Results Showing Elemental Composition of Commercial, S1 and S2

Element	Weight %		
	Commercial	Formulation S1	Formulation S2
C K	48.82	49.84	52.66
O K	11.45	14.17	14.96
Mg K	2.16	1.14	0.90
Al K	0.39	1.76	0.46
Si K	1.29	0.74	1.03
S K	0.54	2.19	0.86
Ca K	-	0.12	0.52
Fe K	33.15	27.18	25.04
Ba L	2.19	2.85	3.56
Total	100	100	100

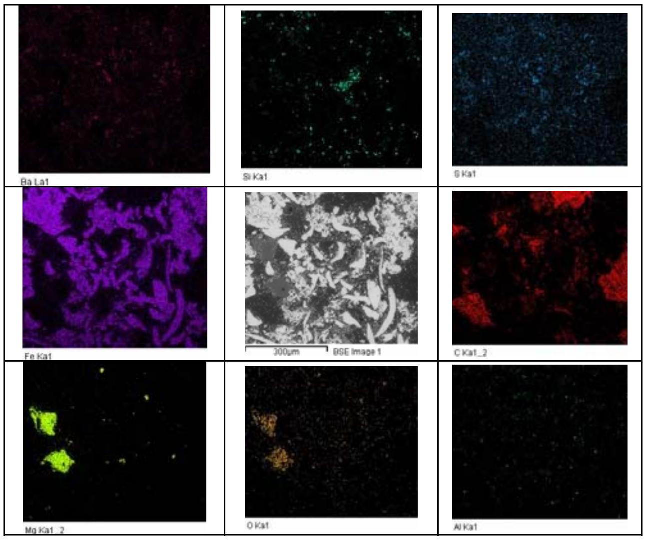

Fig. 2. ESEM and Mapping of Commercial Specimen

B. *Scanning Electron Microscopy*

ESEM and X-ray mapping of Commercial specimen, formulation S1 and formulation S2 are presented through Fig. 2, Fig. 3 and Fig. 4 respectively.

Fig. 2 shows the ESEM and mapping of commercial specimen. It is seen that Steel fibers, iron powders, iron oxide are distributed uniformly in the resin. Graphite, coke particles are evenly spread in the matrix. Clusters of Magnesium Sulfate are seen at random locations. Aluminium particles, Barium, Silica and Sulphur are uniformly spread. Even though the quantity of carbon is more or less same as the commercial specimen, it is uniformly spread in Specimen S1.

Fig. 3 shows the ESEM and mapping of formulation S1. Steel fibers, iron powders, iron oxide are distributed in the resin. Graphite, coke particles are uniformly spread in the matrix. Silicon oxide and Barium oxide are randomly distributed. Fine particles of Sulphur and Aluminium Oxide are seen. Steel fibers

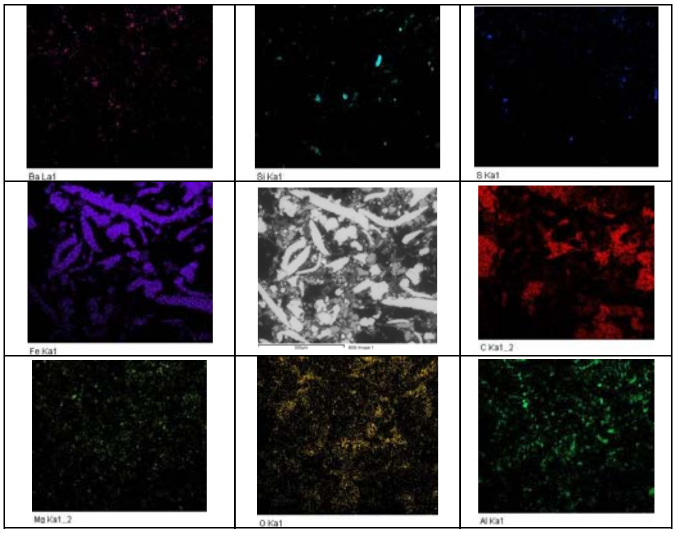

Fig. 3: ESEM and mapping of Formulation S1

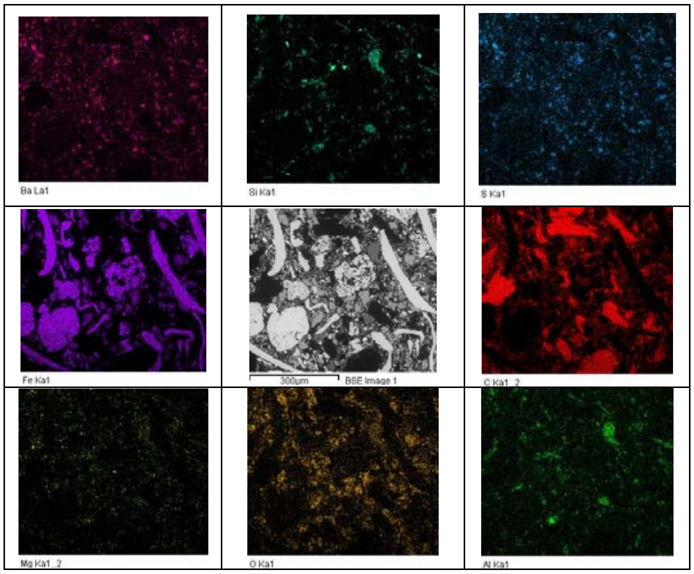

Fig. 4. ESEM and mapping of Formulation S2

are bigger and longer compared to the commercial specimen. Compared to commercial specimen, S1 has less quantity of iron powders. The Size and quantity of Aluminium seems to be more than that of commercial specimen. Table-1 confirms these observations; quantity of iron is lesser and quantity of Aluminium is more in Specimen S1.

Fig. 4 shows the ESEM and mapping of formulation S2. Steel fibers, iron powders, iron oxide are distributed uniformly in the resin. Graphite, coke particles are spread in the matrix. Aluminium Oxide, Silicon oxide and Barium oxide are randomly distributed. Fine particles of Sulphur and Magnesium are seen. The quantities of Steel fibers as well as iron powders are lesser in Specimen S2 when compared with the commercial specimen. More amount of carbon is seen in S2. Bigger particles of Aluminium Silicate are seen in S2. Magnesium Oxide particles are not seen in S2 as found in the commercial specimen.

C. *Shore hardness*

Hardness values of a commercial sample, formulation S1 and formulation S2 are tested using a Shore Hardness tester. Table-2 shows the minimum, mean and maximum shore hardness values of the commercial sample and the formulations. It can be seen that the hardness values of formulations S1 and S2 are equal and slightly higher when compared to the commercial sample.

D. *Specific gravity*

It is seen from Table-2 that, the specific gravity of the formulations S1 and S2 are lower than the commercial sample. However, the specific gravity of specimen S2 is higher than that of specimen S1.

E. *Friction and Wear*

Talib et.al [5] have studied the friction and wear properties of these formulations and reported the following results: Table-2 shows the co-efficient of friction and average thickness loss values for the commercial as well as the formulations. It can be seen from Table-2 that the friction coefficient of formulation S1 is higher and the wear is lower compared to that of the commercial specimen. Lower wear rate would increase the life of the brake pad and higher friction coefficient would offer a better performance compared to the commercial specimen. But the wear of formulation S2 is negligible and the coefficient of friction is slightly lower than the commercial specimen. The thickness loss is only 0.01%, which indicates the integrity of the formulation S2 is high.

Fig. 2, Fig. 3 & Fig. 4 show the SEM pictures of commercial, formulation S1 and formulation S2 respectively. Table-1 shows the elemental distribution of commercial, S1 and S2. The carbon content is more or less same in both commercial and formulation S1 whereas formulation S2 has more carbon content which indicates that the amount of resin is probably more which enhances the integrity of this formulation and reduces the wear drastically. The iron contents of S1 and S2 are lower than the commercial specimen, which explains the reason for the lower specific gravity. Also the coefficient of friction offered by formulation S2 is low due to the lower content of iron fibers in the formulation resulting in lower interlocking between the pad and the disc. Presence of Aluminium Oxide and larger steel fibers would contribute for the higher coefficient of friction offered by S1, whereas Lower amount of steel fibers coupled with smaller sized fibers would contribute for the reduction in the coefficient of friction offered by S2. The presence of Aluminium Silicate in the formulation S2 would decrease the average thickness loss in formulation S2.

F. *TGA of Commercial, S1 and S2*

Thermogravimetric analysis of commercial, S1 and S2 are presented through Fig. 5, Fig. 6 and Fig. 7 respectively.

Table – 2: Shore Hardness, Specific Gravity, Friction and Wear Values of Commercial and Formulations.

	Shore Hardness			Specific Gravity	Friction coefficient	Ave. Thickness loss (%)
	Minimum	Mean	Maximum			
Commercial	72.0	76.2	82.0	3.30	0.332	1.68
Formulation S1	73.0	76.8	82.6	2.72	0.374	0.56
Formulation S2	71.0	76.8	85.0	2.91	0.316	0.01

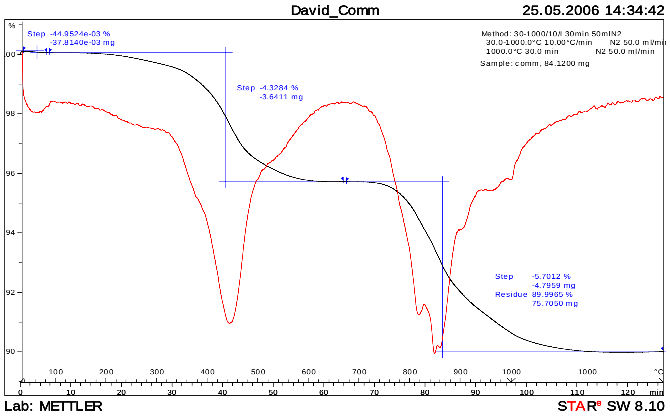

Fig. 5: Thermogravimetric Analysis of Commercial Specimen

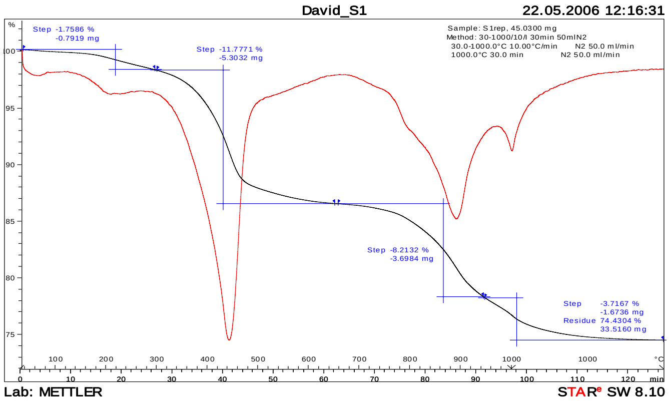

Fig. 6: Thermogravimetric Analysis of Specimen S1

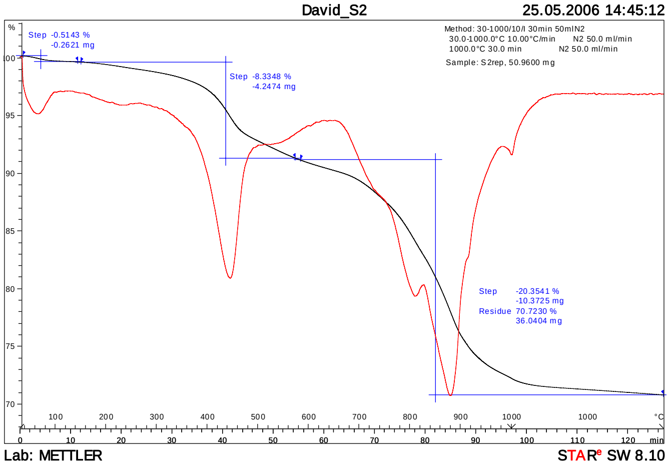

Fig. 7: Thermogravimetric Analysis of Specimen S2

In Fig. 8, a comparison is made between the thermal stability of formulations S1 and S2 with the commercial specimen. The commercial specimen exhibits a good thermal stability even up to 1000°C. Specimen S1 loses weight drastically between 200°C and 800°C. Specimen S2 has better thermal stability in this range compared to specimen S1, but disintegrates faster beyond 800°C. Since the braking temperature of LRT brakes are found to be around 500°C, specimen S2 is found to be thermally more stable than specimen S1 until this temperature.

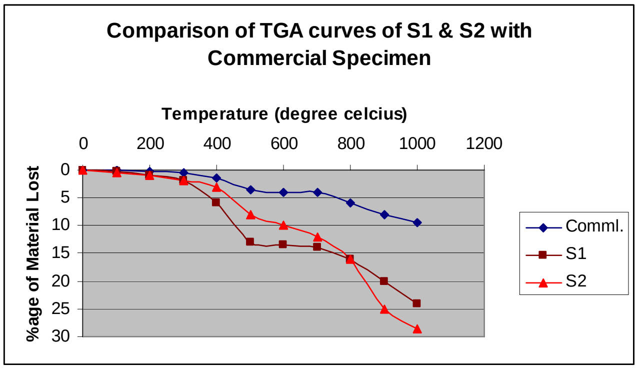

Fig. 8: Comparison of TGA curves of S1 and S2 with commercial Specimen

G. *XRD Analysis of Commercial, S1 and S2*

Fig. 9, Fig. 10 and Fig. 11 show the XRD spectrums of commercial, S1 and S2 respectively. Commercial specimen shows a strong peak at a 2θ angle of 26.8°. Specimens S1 and S2 also exhibit strong peaks at the same angle. The intensities of peaks are more or less same for specimen S2 and commercial which suggests that the crystallinity of specimen S2 is more or less similar to that of the commercial. Specimen S1 gives a much stronger peak indicating that it is more crystalline compared to the commercial specimen.

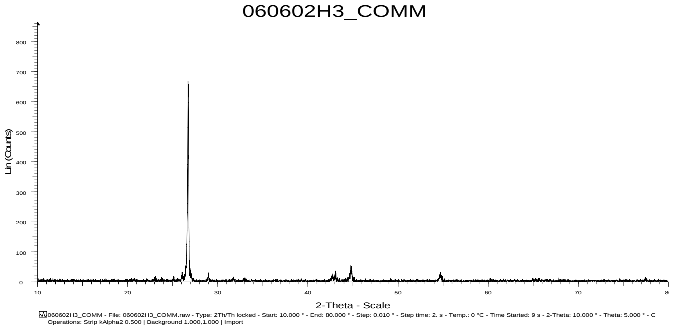

Fig. 9: XRD spectrum of Commercial Specimen

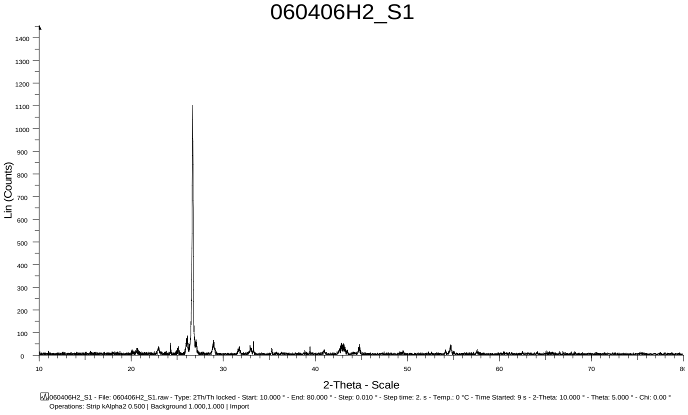

Fig. 10: XRD spectrum of Specimen S1

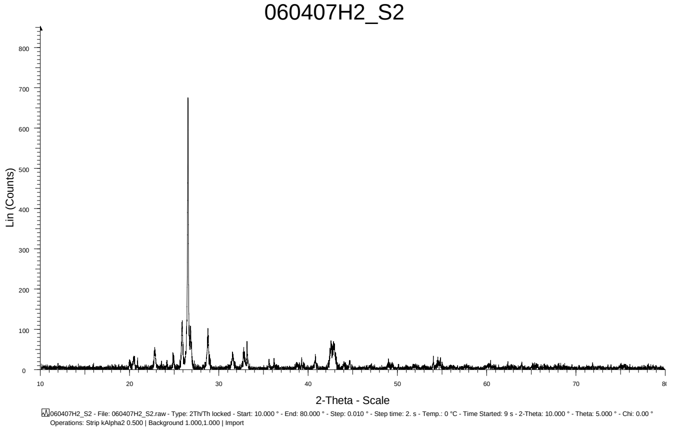

Fig. 11: XRD spectrum of Specimen S2

Based on the discussions given above, it can be concluded that Specimen S2 is better that specimen S1. Since specimen S2 has properties closer to the commercial specimen, formulation S2 can be further improved and considered for manufacturing brake pads locally for use in LRTs operating in Malaysia. One imported brake pad costs about £ 200-00 in Malaysia. The cost can be approximately reduced by half, if the brake pads are produced in Malaysia.

IV. CONCLUSIONS

Lower coefficient of friction and negligible thickness loss make formulation S2 a better alternative to the commercial brake pad. Formulation S2 can be improved further and considered for manufacturing brake pads locally

Equal amount of carbon is present in specimen S1 and in commercial specimen whereas specimen S2 has higher amount of Carbon which indicates that it has the right amount of resin to impart more integrity. Formulation S2 is able to offer better wear resistance.

Thermogravimetric analysis of the formulations revealed that Formulation S2 has better thermal stability up to the operating temperature of 500°C.

The cost of brake pads can be approximately reduced by half, if they are produced locally in Malaysia.

ACKNOWLEDGMENT

We thank Prof. Dr. Azni Zain Ahmad, Assistant Vice-Chancellor and Prof. Madya Dr. Mohd Hanafiah Abidin, Research Head (Science & Technology), IRDC, UiTM Shah Alam, Malaysia. We thank Prof. Madya Ir. Dr. Hj. Abdul Rahman Omar, Dean of the Faculty of Mechanical Engineering, UiTM Shah Alam for his support. The authors are thankful to to Dr. Mohmad Soib Selamat (AMREC, Kulim, Kedah), Dr. Talib Ria Jaafar (AMREC, Kulim, Kedah) and Dr. Mustafar Sudin, (Universiti Teknologi Petronas) for their support. Mr. Andrew, Miss Mardiana of COMBICAT, University of Malaya, KL are thanked and all those who helped in this work in one way or other are thanked for their contribution to this work.

REFERENCES

[1] Gewen Yi and Fengyuan Yan, “Mechanical and tribological properties of phenolic resin-based friction composites filled with several inorganic fillers” Available: www.elsevier.com/locate/wear

[2] S.C. Ho, J.H. Chern Lin and C.P. Ju, “Effect of fiber addition on mechanical and tribological properties of a copper/phenolic-based friction material”, *Wear* 258, 2005, pp. 861–869.

[3] H. Jang , K. Koa, S.J. Kima, R.H. Basch and J.W. Fash, “The effect of metal fibers on the friction performance of automotive brake friction materials”, *Wear* 256, 2004, pp. 406–414.

[4] K.W. Hee, P. Filip, “Performance of ceramic enhanced phenolic matrix brake lining materials for automotive brake linings” *Wear* 259, 2005, pp. 1088–1096, doi:10.1016/j. wear. 2005.02.083

[5] R.J. Talib, M.S. Shaari, W.M.A.W. Ibrahim, S. Kemin, K. Ramlan, “Suitability of Friction Materials for LRT Based on Friction and Wear Characteristics”, 3rd Malaysian Brake Friction Materials Colloquium 2006, Universiti Teknologi Petronas, Lumut, Perak, Malaysia, 23-24 February 2006.