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Characterization based Physical and Mechanical Properties of Brake Pad Materials for Railway Vehicle Applications

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Abstract

The friction material of brake pads needs to be selected wisely because there has a direct influence on the wear life of the mating disc or wheel used, which incur relatively high costs to be replaced and involve the safety of life. A study of the previous brake pads needs to be done to examine the physical and mechanical characteristics of the brake pads so that improvements can be made. For this study, three types of brake pad samples from actual railway vehicle applications are tested: Sideria(K) Sideria(M), and Class91 samples. Brake pad samples will first have to go through a preparation process, which includes cutting, assembling, scraping, and polishing until the desired size and shape of the sample are obtained. The mechanical properties tests that are carried out are the Rockwell hardness test, transverse breaking strength, and friction and wear rate. For physical features, x-ray diffraction (XRD) testing and microstructural characterization (SEM) are performed. It was found that the difference in materials used for the production of the brake pads greatly influenced the increase and decrease of physical and mechanical properties. In addition, the wear rate of the brake pads was strongly influenced by the hardness and carbon element composition factors. Finally, it can be concluded that the sample known as Sideria(M) is the optimal parameter sample and can be used as a benchmark to produce brake pads.

1. Introduction

Several crucial physical components can result in a train accident in the case of failure. The train brakes are powered by compressed air that is controlled and propelled. A transport train with an average of 90 to 120 cars moving at 55 mph will take between one and two miles depending on the weight of the cargo [1]. The locomotive engine is always at the very front of the train, leading or pulling the coach from the front. The engine on the train is generally powered by fuel [2]. In the 19th and 20th centuries, caboose used to be the staple on every train to mark the end of the train. The Flashing Rear-End Device (FRED) now marks the end of the train with the same mechanism. The first trains with working brakes were designed for transportation and long-distance travel. Some trains install special brake whistles famous for locomotives to alert passengers of applying the brakes. The amount of braking energy achieved is limited. It is also unreliable because the controllers' ability to use the brakes depends on their hearing and the speed with which they respond to the brake whistle.

The review of braking systems used in railways applications stated that the brake pads mechanism is the most important component in all brake systems in terms of safe operation, especially for freight and high-speed trains [3]. Brake pads were originally made of asbestos, a heat-absorbing material appropriate for the rate of wear and tear on the pads used. Asbestos, however, has been identified as an extremely potent carcinogen, and long-term exposure will result in cancer [4]. Ceramic brake pads are another material option to be used in brake pads. Fine copper fibres are also embedded in ceramic brake pads to help increase friction and thermal conductivity [5-6]. The other brake pad is the semi-metal brake pad, often called "metal brake pad". Metal brake pads are made up of 30% to 70% metal, including copper, iron, steel, or other composite alloys. The metal brake pad compounds available vary, each with its advantages for different situations. There have principal factors that dominate the selection of a friction material for railways application which are performance (friction and wear), environmental considerations and cost [7]. The material selection of the brake pads will influence the material behaviour, affecting the strength and durability of the structure. The pads product must fulfil the specific performance criteria over a range of speeds and braking efforts. In order to examine the capability and lifetime of each brake pads materials, the physical and mechanical properties of the brake pads need to be identified.

The motivation of this work is obtained, where the high cost of manufacturing and production such brake pads, including their formulation, materials supply and machinery, is strictly imported by foreign companies because not readily available by local light rail companies. Thus, extensive study and research need to be carried out to produce the brake pad locally following the standard that has been authorised. Therefore, in this study, three different brake pads materials will be characterised to determine the wear rate of the pads materials by referring to the hardness and carbon element composition analysis. Thus, the factor that affects the material behaviour of the brake pads can be recognised so that improvement can be made in future.

2. Materials and Method

The brake pad samples (provided by the local industry) will first have to undergo the preparation process depicted in Figure 1 before being used for the test. The samples consisting of three different materials brake pads, as shown in Figure 2, will be cut to a smaller size before being assembled for the sample preparation process.

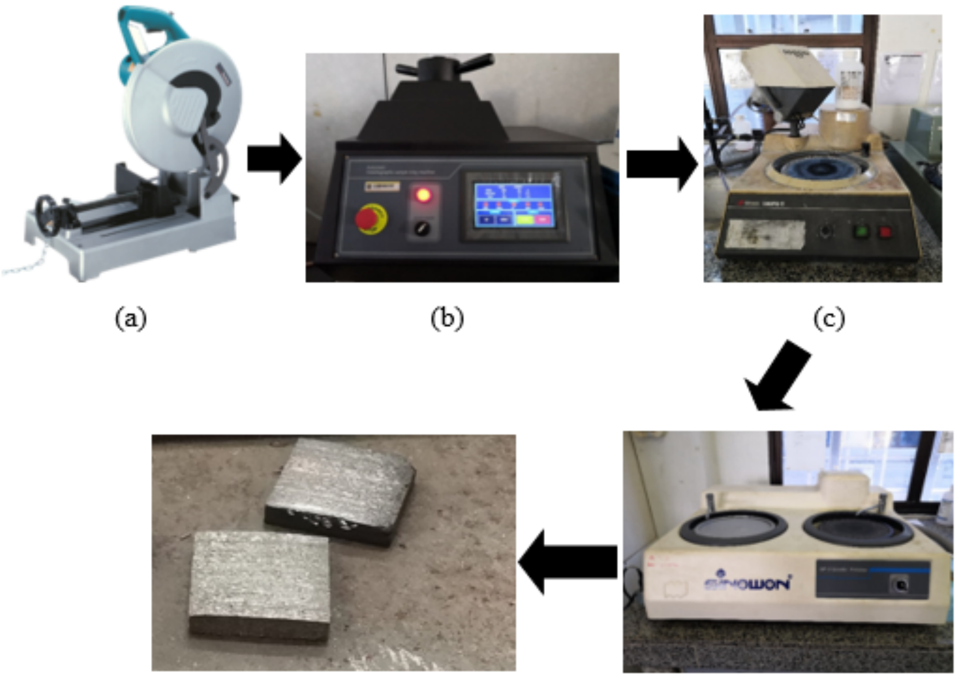


Figure 1. Samples preparation processes of brake pad (a) Cutting, (b) Mounting, (c) Scraping, (d) polishing and (e) samples upon completion

(a) (b) (c)

Figure 2. Type of materials brake pads tested (a) Sideria(K), (b) Sideria(M) and (c) Class91

The samples will then be scraped and polished until the desired size and shape are obtained. These three brake pads are brake pads that are used commercially by the industry throughout the train operation.

Following the completion of the sample preparation process, the sample will undergo physical and mechanical tests using the machine as shown in Figures 3 and 4 to obtain the characteristics behaviour of the brake pads. Two tests will be involved for the physical test: The X-ray diffraction (XRD) test using an XRD machine and the microstructural characterization test using a Scanning Electron Microscope (SEM). For the mechanical test, a hardness test will be performed using a Rockwell Hardness Tester machine. Meanwhile, to test the durability of the sample, the transverse rupture strength (TRS) test or standard three-point bend test will be used. Lastly, the friction and wear rate test will be explained using the critical review method.

(a) (b)

Figure 3. Mechanical testing for the brake pad samples (a) Rockwell hardness tester machine and (b) Universal testing machine (TRS)

3. Results and Discussion

3.1 Rockwell Hardness Test

Following the hardness test, the results revealed that the hardness of each sample of train brake pads is varied. Among the factors that can be attributed to the hardness of brake pads are the raw materials used and the method of production of brake pads. This is due to the fact that each material has a unique microstructure and characteristics that will have a significant impact on the manufacturing of the products [8].

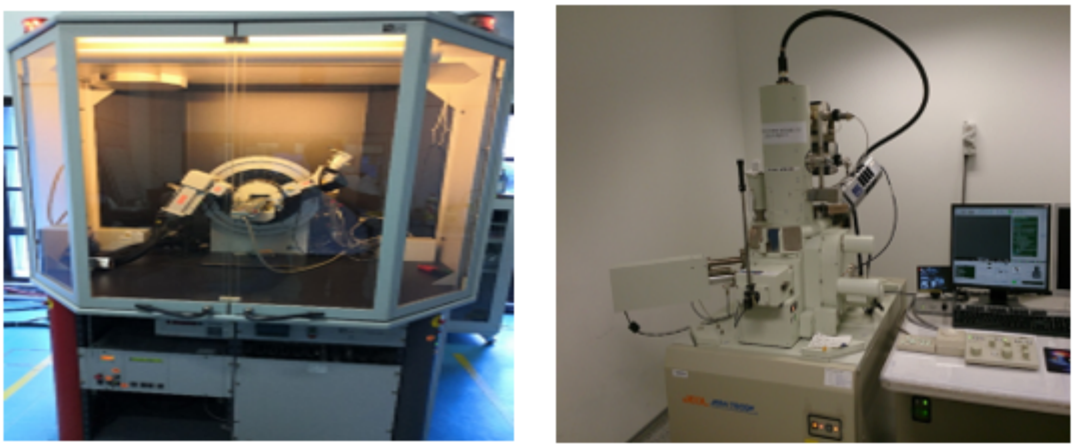


Figure 4. Machine for evaluation of sample characteristics for Physical testing for the brake pad samples (a) X-ray diffraction (XRD) machine and (b) Scanning electron microscope (SEM)

Figure 5 compares the Rockwell hardness test results for the three samples in graph form for easier understanding. The Sideria (M) sample showed the highest hardness test readings, followed by Sideria (K) and Class 91 at the lowest position. The maximum hardness reading is 101.2 HRR, and the minimum is 71.0 HRR, indicating a relatively large difference in hardness. This could be because the material type and the uniformity of the material contained in the sample are not evenly distributed. Based on the observations, it is found that the Sideria (M) sample is the most suitable. This can be seen in terms of the hardness characteristics that make it the optimal sample to choose. Following the hardness test, an indentation will form on the samples and serve as a marker for the spot whose hardness has been tested, and it will be performed on multiple spots on the same surface [9].

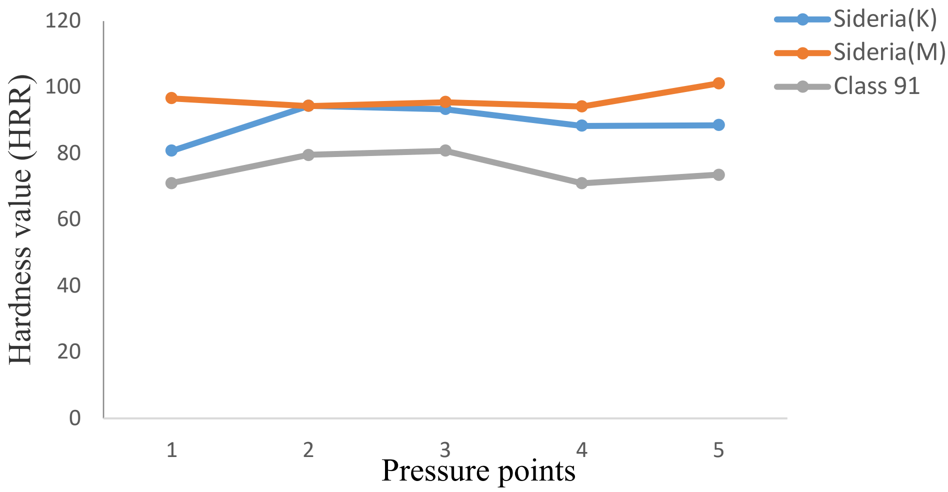


Figure 5. Hardness comparison for the three different material samples

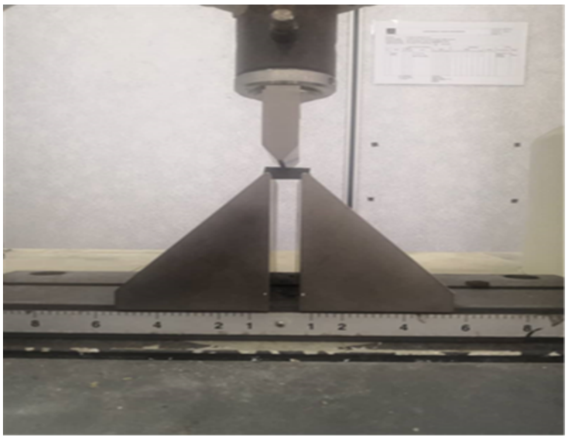
3.2 Transverse Rupture Strength (TRS) Test

TRS test is closely related to the hardness and durability of the brake pad samples. The particle size contained in the sample is the main factor impacting the sample's strength value. According to theory, a material's hardness and durability increase as its particle size decreases [10]. Table 1 displays the results of the TRS test performed on the railway brake pad samples. According to the results, Sideria (M) samples show the highest strength, followed by Class91 and Sideria (K) samples which recorded the lowest strength. This can be seen in the stress values obtained by each sample. The stress value of the Sideria (M) sample is stated at 33.6 MPa, which is the highest value, while the Class91 sample recorded only 25.48 MPa, which is the lowest value among the three samples.

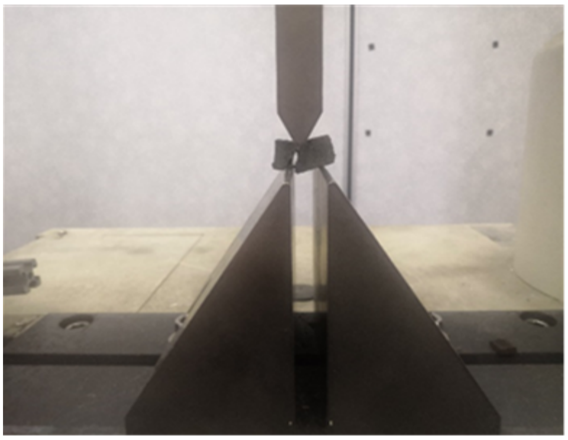
Table 1. The results for TRS test

Reading / Sample	Displacement (mm)		Load (kN)		Stress (MPa)		Strain	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Sideria(K)	0.8256	0.7491	0.9615	1.080	27.04	30.36	0.2201	0.1997
Average	**0.7874**		**1.0208**		**28.70**		**0.2099**	
Sideria(M)	1.118	0.8087	1.482	1.211	37.05	30.27	0.2980	0.2157
Average	**0.9634**		**1.3465**		**33.66**		**0.2569**	
Class91	0.728	1.080	1.497	1.111	29.25	21.70	0.2330	0.3455
Average	**0.9040**		**1.3040**		**25.48**		**0.2893**	

The TRS test is closely related to the durability factor. This means that the Siberia(M) samples have the highest durability with respect to the highest transverse rupture strength reading. The durability of the brake pads is indicated by the readings of the load that the brake pad sample can accommodate. Based on the results obtained, the Sideria(M) samples have the highest load reading, followed by the Class91 and Sideria(K) samples. This proves that Sideria(M) samples have the highest durability when compared to other samples. Inconsistent reading results are due to errors that occur, such as measurement errors and varying sample thicknesses. Figures 6(a) and (b) show the condition of the samples before and after the TRS test was performed.



(a)



(b)

Figure 6. The condition of the sample (a) before the transverse rupture strength (TRS) test was performed and (b) after the transverse rupture strength (TRS) test was performed

3.3 Friction and Wear Test

For friction and wear rate tests, a critical survey method is used to gather information. The results for this test are associated with a number of factors, namely hardness, durability, and the percentage of carbon content in the samples. The material content greatly influences the physical features of the sample, particularly the carbon element. Therefore, references and in-depth studies have been conducted in literature to strengthen further the evidence regarding the influence of the percentage of carbon element on the hardness and durability of samples, as shown in Tables 2 and 3.

Table 2. The results of Disc-On-Balltribotester test [11]

Sample	Carbon Composition (%)	Hardness	Wear Rate at 1000°C ($10^{-5} mm^3$/N.m)
CMC0	0	485	2.75
CMC1	0.3	512	1.25
CMC2	0.6	523	1.20
CMC3	1	468	0.50

Table 3. The results of small scale dynamometer disc brake system test [12]

Sample	SiC(%)	Hardness (BHN)
LC-A	10	75
LC-B	15	90
LC-C	20	100

As can be seen in Table above, the wear rate of the sample decreases as the hardness of the sample increases. However, if the carbon content is too high, carbon will accumulate at the particles' metal interface, resulting in a drop in the sample's hardness. In Table 3, the wear rate for each sample is not specified. The samples were treated with different percentages of silicon carbide (SiC) and carbon compositions. Based on this table, the same conclusion can be expressed that the carbon content strongly influences the hardness of the sample. It can be seen in the table that the hardness of the sample increases as the carbon composition increases. Therefore, it can be concluded that the carbon composition has a big impact and influences the behaviour of the sample's hardness. In addition, Table 4 shows the friction and wear rate test results for each material specimen.

Table 4. The results for the brake pad samples

Sample	Carbon Composition (%)	Hardness (HRR)	Wear Rate
Sideria(K)	74.82	89.8	Medium
Sideria(M)	78.11	96.4	Low
Class91	51.74	75.2	High

Based on the results, increasing carbon composition will cause the hardness of the sample to increase. The sample's hardness and carbon composition values are inversely proportional to the sample's wear rate. Thus, it can be concluded that the Sideria(M) sample has the lowest wear rate among the three samples that have been studied, while the Class91 sample has the highest wear rate.

3.4 X-Ray Diffraction (XRD) Test

A graph is generated in the x-ray diffraction test through the x-ray alignment process derived from the material atoms in the brake pad sample. The variation of the resulting graph peaks is due to the different types of materials. Each of the resulting lines represents its respective material element. It indicates the presence of more than one type of phase, such as amorphous and crystalline. This is most likely due to the fact that the materials in the amorphous phase have less thermodynamic stability than the crystalline ones. This causes amorphous materials to change into known crystalline phases or potentially unknown crystalline phases [13]. The compatibility between the graph peaks and the type of material selected from the library contained in the system will be obtained if the two lines (lines of differing colours) are in a state of overlapping with each other. Based on Figures 7(a), (b) and (c), the XRD test results for the three brake pad samples: the main elements of Sideria(K) are carbon and silica carbide, carbon and carbon aluminium oxide for Sideria(M) and calcium carbonate for Class91.

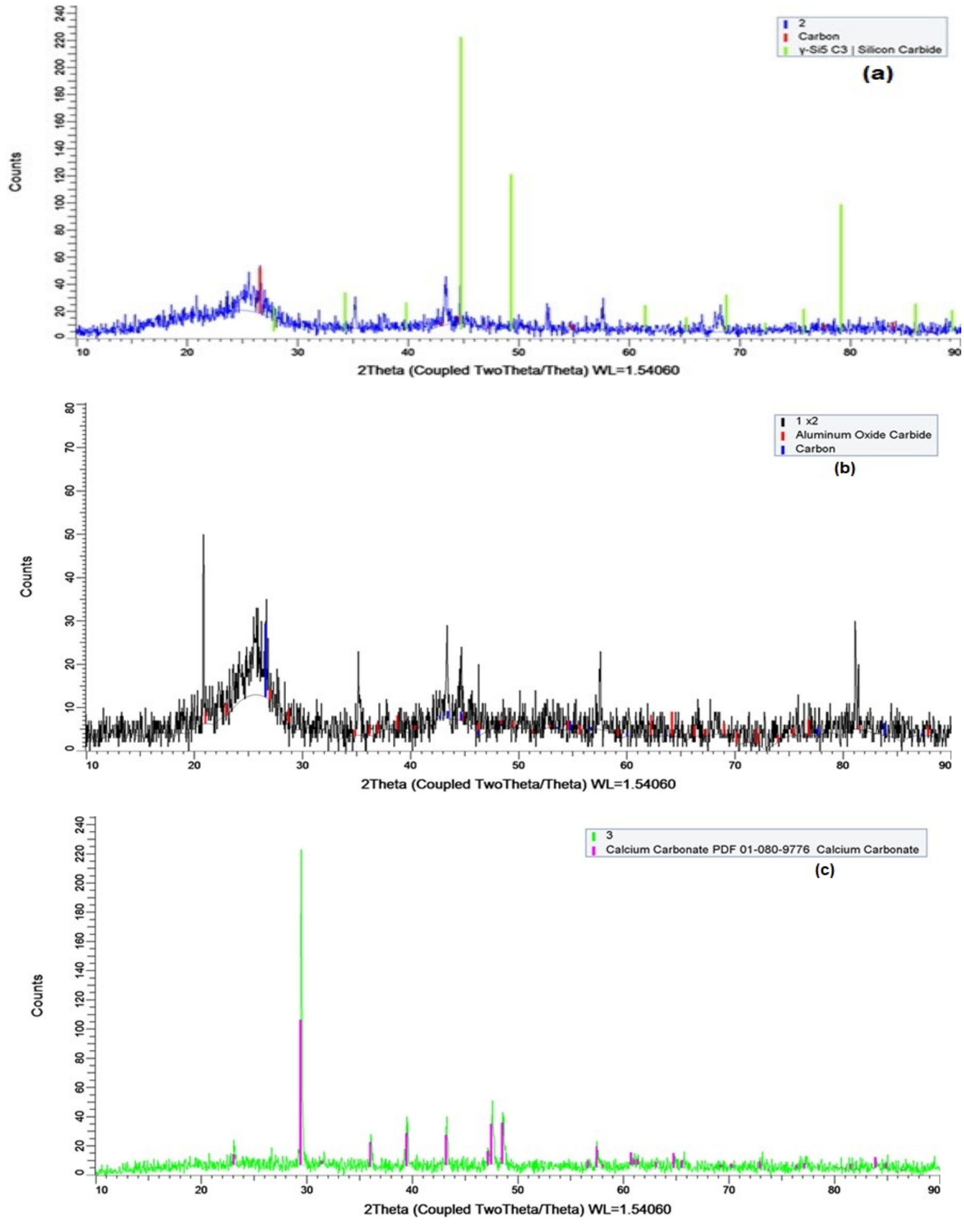


Figure 7. The results of XRD test for the (a) Sideria(K), (b) Sideria(M) and (c) Class91 samples

The main materials for these three samples are all carbon-based. However, the presence of aluminium oxide carbon in the Sideria(M) sample resulted in the bindings between the particles becoming stronger compared to the other two samples. As a result of the presence of these additional elements, the melting strength had increased due to the presence of high independent dislocation densities [14]. This makes the Sideria(M) sample had the highest strength.

3.5 Scanning Electron Microscope (SEM) Test

The result of the SEM test is important for obtaining detailed information regarding the materials contained in the sample (composition) as well as detailed images of the sample (topography, morphology and crystallography information) [15-16]. The list of materials contained will be listed in detail, along with their mass and atomic percentages. However, the detailed image and list of sample materials depend on the area selected to be examined and the magnification rate used. As a result, each amount of material contained in the detailed image varies by location. Based on the results obtained from the three brake pad samples tested as shown in Figures 8(a), (b) and (c), the carbon element was made as to the main material for all three samples.

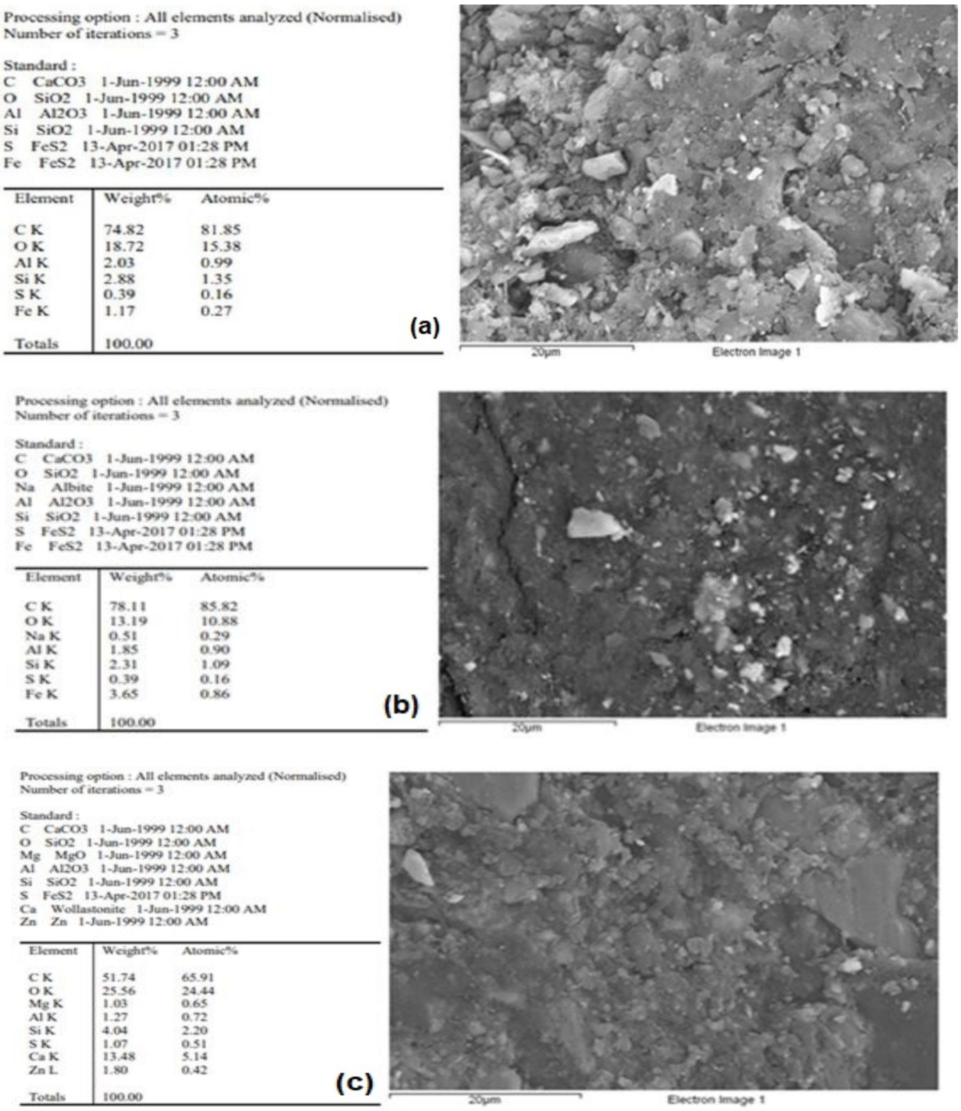


Figure 8. The result of the material and topography list for the (a) Sideria(K), (b) Sideria(M) and (c) Class91 samples

The percentage of carbon in each sample differed, with Sideria (K) accounting for 74%, Sideria (M) for 78% and Class91 for 51%. The percentage of carbon content greatly affects the strength of a product to be produced. Due to that, it can be seen from both the hardness test and the transverse acceleration strength test that the strength and durability of Sideria (M) samples are better than that of Sideria (K) and Class91 samples. This proves that the strength and durability of the material also depend on the ratio of carbon used in the creation of a product.

Conclusion

A conclusion can be made based on the overall test results, which found that the material content of the brake pads has a significant impact on their physical and mechanical properties. In addition, carbon (C) is the best material for producing railway brake pads. The percentage of carbon content can greatly affect the strength of a product to be created. In addition, the wear rate is strongly influenced by the hardness factor and the carbon composition in the brake pads. The low wear rate indicates that the sample has good resistance to friction and is very suitable to be used.

Meanwhile, the amount of porosity or cavities formed in the Sideria (M) sample was the least due to its highest carbon content. As such, it has the densest particle composition and arrangement. Next, the sample with the highest durability will likewise obtain the highest reading of transverse rupture strength. Most importantly, Sideria (M) is the best example of a brake pad material used in railway vehicle applications. For the next research, a locally made brake pad will be produced to enhance the ability of the brake pads to address the problems faced by the railway industry.

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