# Material Construction of Replacement Brake Discs: A Regulation Compliance Study

Lamin F., Omar A., Osman M. R., Wong S. V.

***Abstract*—** Brake disc is a component of friction materials in a typical automotive braking system. Similar to other wear and tear automotive parts, which requires replacement, this definitely involves the after-market industry. Even though standard has been set, the actual compliance of the commercialised discs is still ambiguous. Products with a higher quality and performance are frequently referred to those with a higher price. However, the currently available studies provide no evidence of price effect on product quality. In this study, an experimental investigation was conducted to assess the commercial brake discs elemental composition compliance to the United Nation regulation of brake disc replacement, UN Regulation 90. As a case study, it focuses on replacement disc for a model of M1 vehicle category. By scrutinizing samples that were randomly selected from the after-market, elemental composition analysis were carried out through Energy Dispersive X-ray spectroscopy and assessment of variability of brake disc elemental composition were accordingly performed. The result reveal that there were significant deviation of the aftermarket replacement brake discs to the standard requirement. On top of that, no correlation observed between price and the standard compliance. The results presented here may facilitate improvements in the standard implementation, enforcement, market surveillance as well as after-market price controlling mechanism. Indeed, this is crucial in ensuring the current safety standard and subsequently enhancing it to an adequate and satisfactory level.

***Keywords*—** After-market, brake, compliance, metallography, standard

## I. Introduction

Brakes discs are exposed to large thermal stresses during braking. High-g deceleration are known to generate extreme temperature, up to 900oC, and thermal cracking was commonly observed following this braking events [1, 2]. An analytical model for the determination of the contact temperature distribution on a brake working surface has been demonstrated by Gao and Lin [3]. Ideally, the heat generated due to friction between the brake friction materials, the disc and pad, should be dissipated to avoid decreasing the coefficient of friction and to eliminate possibility of the temperature rise in several brake components and brake fluid vaporization due to excessive heating [4].

According to Voldrˇich [5], formation of hot-spots as well as non-uniform distribution of contact pressure may result in disc material damage, frictional vibration, wear, etc. These phenomena require adequate thermal storage capacity in order to prevent distortion or cracking as result of thermal stress until the heat can be dissipated. Mackin et al. [6] showed that a relatively small number of high-g braking cycles in the absence of thermal shock could generate macroscopic cracks running through the disc thickness and along the radius of the disc brake.

The knowledge of the manufacturing quality in automotive is important for an understanding of component reliability, especially for the safety-critical components. In view of brake, numerous studies have attempted to explain the mechanics of braking, in which the factor of material design has been the major concerned. Among the studied properties is coefficient of friction, which could vary depending on the type of material used for the brake disc. Due to the two main functions of the brake disc i.e. transmission of mechanical force and the dissipation of heat [7], the materials construction should be able to bear thermal fatigue and should absorb and dissipate, as soon as possible, the heat generated during braking [2]. Stefan and Gheorghe [8] highlight the influence of the construction characteristics and material properties, of the brake discs, over the thermal stress.

Thermal response of disc brake systems to different materials and design of disc–pad integration has been studied by various researches for more than a decade [9–12]. For example, Dufre´noy [13] proposed a macro structural model of the thermo-mechanical behaviour of the disc brake, by considering the three-dimensional geometry of the disc–pad couple. Faramarz and Salman [4] presented a mathematical model of disc brake system thermal behaviour. Meanwhile, Maleque et al. [14] has discussed on the possible disc materials and developed the material selection method for the application of brake disc system. Various studies could be found to be primarily concentrated on performance of the brake pad [15-19] and disc [20-21]. The knowledge in the

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disc-pad couple as well as other braking components are significantly crucial since it work as a system.

Malaysia has acceded to the 1958 Agreement (UN Vehicle Regulations) as a Contracting Party since 2006. With regards to the UN Vehicle Regulations, material and metallurgical requirements of a replacement brake disc is clearly underlined in the UN Regulation 90 (UN R90) [22]. According to the regulation, in order to be considered as equivalent, the replacement brake disc shall be from the same material sub-group as the original brake disc. There are four original part material sub-groups defined i.e. (i) sub-group 1: base cast iron, (ii) sub-group 2: base high carbon, (iii) sub-group 3: alloyed high carbon and (iv) sub-group 4: unalloyed high carbon. Material elements content of these sub-groups as well as other required properties (hardness and tensile strength), outlined in the regulation are listed in Table 1.

Besides UN R90, Malaysia has gazetted mandatory standard of brake disc through a specific Malaysian Standard, namely MS1164:2005 [23]. Aftermarket products certified with any of these regulations are acceptable and authorised to be sold in the market. However due to some constraints, including testing laboratory and industry readiness, implementation is not yet in place. Since regulation compliance among aftermarket brake discs is still ambiguous, this study was conducted to evaluate and benchmark the commercialised brake discs compliance to the UN R90, as of pre-regulation implementation. It is hoped that this study could be utilised as a reference to expedite the process of ensuring the current safety standard and subsequently enhancing it to an adequate and satisfactory level.

## II. Methodology

In this study, market survey was conducted at the Klang Valley South-East region and seven samples were acquired from the after-market. It were classified according to its price i.e. low (three samples), high (three samples). Another one sample was classified as control as it was approved by a recognised international Technical Service Provider. It is interesting to note that all these seven samples were sold using different brands. Table 2 summarised labelling details of the acquired samples according to its price classification, from the cheapest to the most expensive.

Table 2 Labelling details of the samples

| No | Brand | Classification |
|---|---|---|
| 1 | Brand A | Low Price |
| 2 | Brand B | Low Price |
| 3 | Brand C | Low Price |
| 4 | Brand D | High Price |
| 5 | Brand E | High Price |
| 6 | Brand F | High Price |
| 7 | Brand G | Reference |

Sample specimens were prepared in approximately 2 cm x 1 cm size for material analysis. The specimen sectioning was illustrated in Figure 1. Utilising the seven samples that have been randomly retrieved from the after-market, elemental analysis was carried out through Energy-dispersive X-ray spectroscopy (EDX). Observation was performed on the disc braking surface and 15 different spectrums were accordingly analysed for each specimen. As results, elemental content of each sample was obtained and comparison was then made between the attained result and the standard requirement, as underlined in the UN R90.

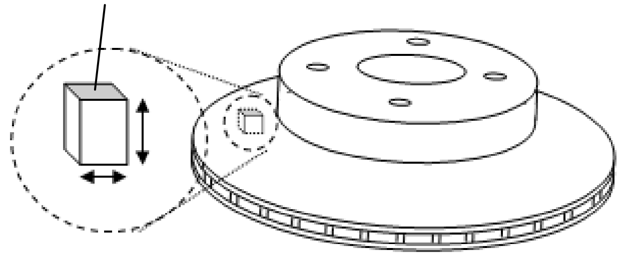


Fig. 1 Specimen sectioning and the studied surface.

Table 1 Material and metallurgical requirements of a replacement brake disc [22].

| Element/ properties | Sub-group 1: base cast iron | Sub-group 2: base high carbon | Sub-group 3: alloyed high carbon | Sub-group 4: unalloyed high carbon |
|---|---|---|---|---|
| Carbon content (%) | 3.2 – 3.6 | 3.6 – 3.9 | 3.55 – 3.9 | 3.6 – 3.9 |
| Silicon content (%) | 1.7 – 2.3 | 1.6 – 2.2 | 1.6 – 2.2 | 1.6 – 2.2 |
| Manganese content (%) | Min 0.4 | Min 0.4 | Min 0.4 | Min 0.4 |
| Chromium content (%) | Max. 0.35 | Max. 0.35 | 0.3 – 0.6 | Max. 0.25 |
| Copper content (%) | - | 0.3 – 0.7 | 0.3 – 0.7 | Max. 0.4 |
| Hardness HBW | 190-248 | 160-210 | 180-230 | 160-200 |
| Tensile strength ($N/mm^2$) | Min 220 | Min 160 | Min 170 | Min 150 |

## III. Results and Discussions

### A. Material Type and Sub-group Classification

Scanning electron micrographs of the specimens that was obtained showed the existence of graphite flakes, which reflects a gray cast iron microstructure. It can be observed that the graphite flakes were uniformly distributed throughout the specimen, as depicted in Fig. 2. This type of flakes distribution pattern indicates gray cast iron of type A, the desirable graphite structure distribution [24, 25].

Furthermore, elemental analysis reveals that all samples does not contain copper. This result can be used to confirm that the samples are in the sub-group 1, which is base cast iron. Referring to properties highlighted in Table 1, it is interesting to note that this sub-group is the hardest and strongest in tension among the other sub-groups as it has the highest value of hardness (190-248) and tensile strength (min 220 N/mm2). In addition, all samples also does not contain Chromium. It is considered to be acceptable as the regulation only set the maximum Chromium value of 0.35 for the subgroup 1. In addition, high percentage of carbon can be observed in all specimens. It was reported that brake discs with high carbon grade cast iron were able to withstand cracking against both hard and soft pad materials [26], which reflects that the observed samples have a good properties for pad integration.

### B. Silicon Composition

Comparison was then made to other element contents, which are Silicon and Manganese in order to further confirm the samples compliance to the standard material and metallurgical requirement. Fig. 3 shows the Silicon content for the two price classification i.e. low and high. The first 15 spectrums is referring to the Brand A and D specimen for the low and high price classification respectively. While the next 15 spectrums are referring to the following brand, as listed in the Table 2. With reference to the UN R90 requirement, it sets a minimum and maximum value of 1.7 and 2.3 respectively for Silicon content. However, a large group of data can be seen under the requirement for both price ranges.

When looking into specific brand, it can be seen that none of the tested samples was found to be 100% compliance. The worse is recorded by Brand A (the lowest price), in which all spectrums of Brand A are located below the minimum requirement. In contrast, Brand F (the highest price) showed a better compliance, in which all spectrums of Brand F are above the minimum requirement, with some spectrums located slightly higher than the maximum requirement.

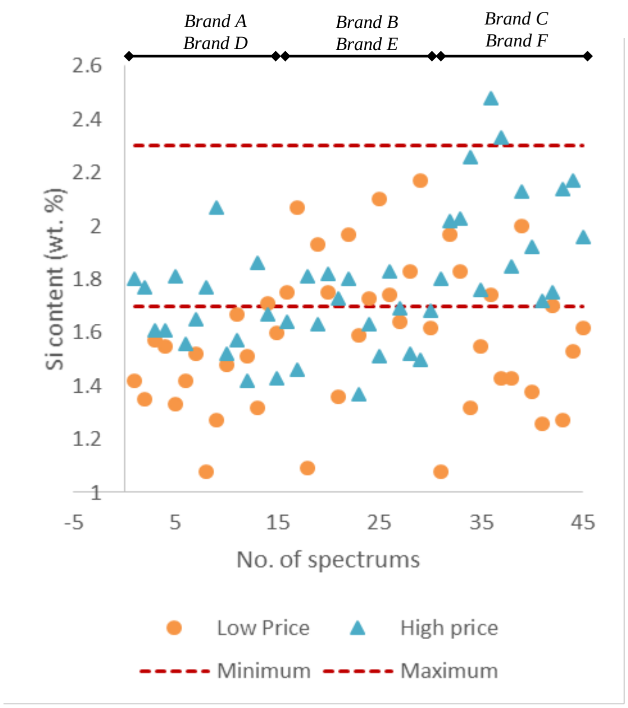


Fig. 3 Silicon content of the tested samples with regard to UN R90 requirement

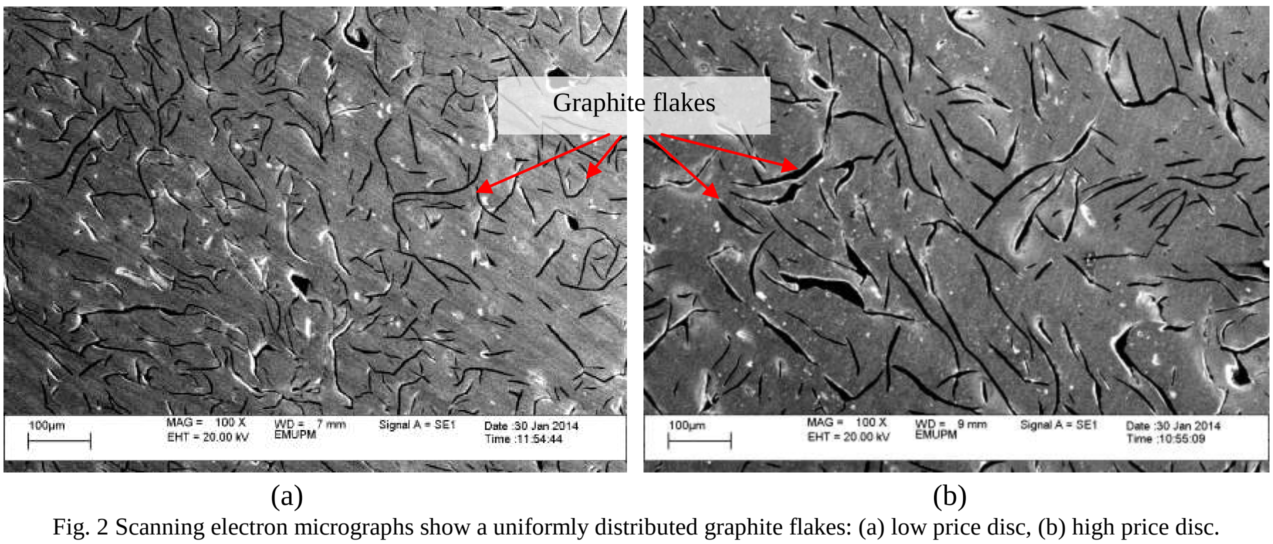


Fig. 2 Scanning electron micrographs show a uniformly distributed graphite flakes: (a) low price disc, (b) high price disc.


Fig. 4 Comparison of Silicon content percentage deviation between low and high price disc.

By analysing the spectrums that falls the under requirement, low price spectrum data are more away from the minimum value compared to the high price spectrums. As illustrated by the deviation percentage of the Silicon content from the minimum or maximum requirement (refer to Fig. 4), a significant difference can be observed. By comparing mean of the two price range, percentage deviation of the low price spectrums is double the high price.

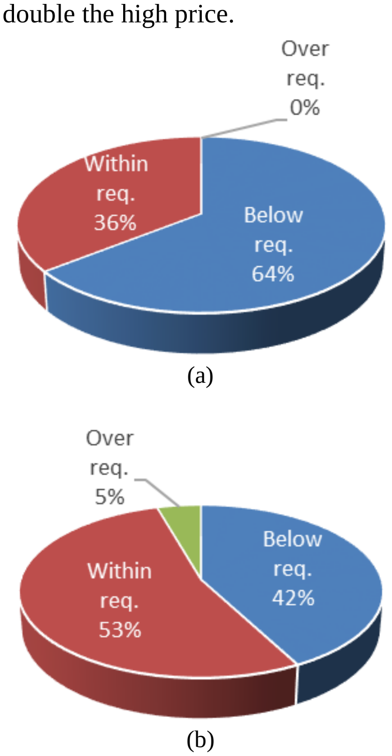


Fig. 5 Silicon content compliance: (a) low price, (b) high price.

In terms of percentage, only about one-third (36%) of the low price specimens tested spectrum comply with the UN R90 Silicon content requirement, as illustrated in Fig. 5. Meanwhile, more than half (53%) of the high price spectrums met the standard requirement. And yet, the remaining percentage of spectrums that contain Silicon outside the requirement range are still high for both price ranges.

### *C. Manganese Composition*

In view of Manganese content, a relatively high number of the high price spectrums were found below the minimum requirement. Fig. 6 depicts the Manganese content for both price classifications. Non-compliance are quite significant for the high price classifications, in which involving almost half (49%) of the spectrums (refer to Fig. 7). These results confirms that compliance of Manganese was more frequent in the low than the high price specimens.

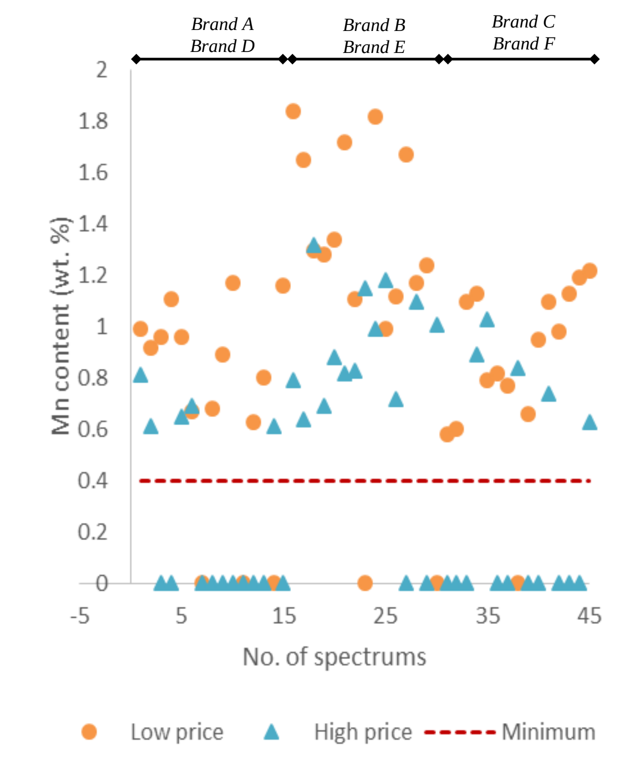


Fig. 6 Manganese content of the tested samples with regard to UN R90 requirement.

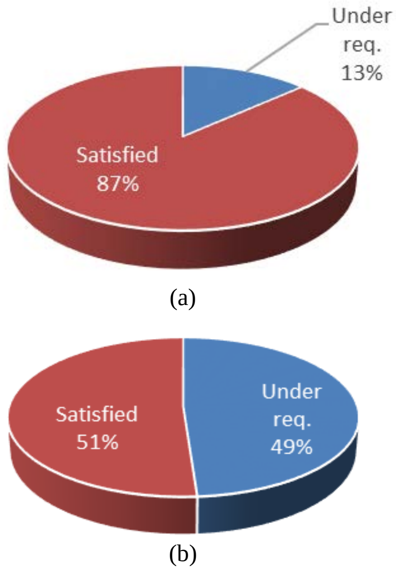


Fig. 7 Manganese compliance: (a) low price, (b) high price

Overall compliance of the tested samples was summarised by comparing both material composition requirement. As shown in Fig. 8, Brand B, exhibits the highest compliance compared to others. Even though the brand offers the second lowest in price, both Silicon and Manganese content for the sample are relatively high. This result confirms that there are no clear effects between the price and the material composition of the brake disc.

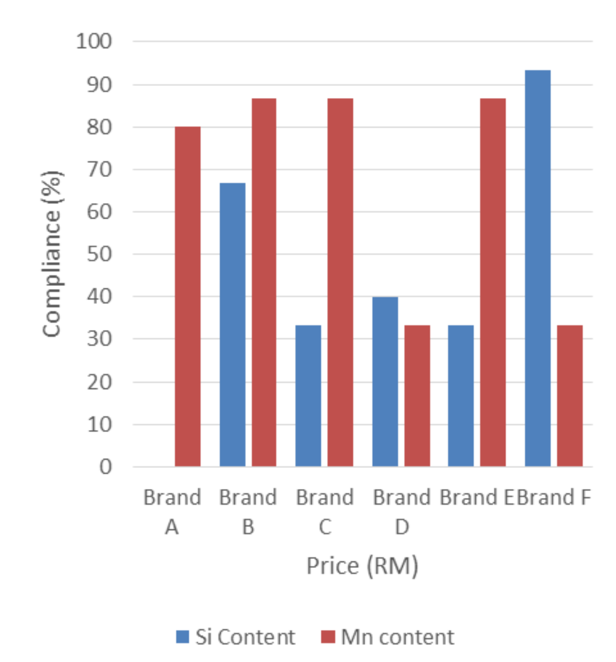


Fig. 8 Overall compliance of the tested samples

## IV. Conclusion

In this paper, evaluation of elemental composition has been carried out on the commercialised brake discs by utilising metallographic approach. The results exhibit an apparent non-compliance of the regulation requirement, particularly on Silicon and Manganese content. There are no distinct correlation between the sample after-market price and the material composition compliance. In respond to the UN R90 implementation, the demonstrated results could be utilised as a pre-regulation implementation benchmarking. This explains that the process of enhancing the current safety standard to an adequate and satisfactory level should be expedite. The extension to mechanical testing as well as performance testing will be considered in the future work. This may include testing on brake disc specimen for strength and hardness evaluation, and furthermore testing on the brake disc sample for static and on the road performance evaluation.

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