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Investigations into the Mechanical Properties and Microstructural Behavior of Foreign and Locally Fabricated Brake Disc

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The present work reports investigations on mechanical and microstructural properties of foreign and locally fabricated brake disc. From safety point of view, brake disc is a crucial component of the braking system. Foreign brake disc (FBD) are known for their long life span and better mechanical properties under service condition. However, locally fabricated brake disc (LFBD) may possess similar or better mechanical properties than the foreign one. Therefore, the need to investigate their mechanical properties in order to determine which brake disc has better mechanical properties under the same service condition. It was observed that a high machinability index occurs in the locally fabricated brake disc as compared with the foreign brake disc, noticeable in the softness and weak graphite flakes formation in the matrix. Higher resistance to indentation was noticeable in the foreign brake disc as compared to the locally fabricated disc. The locally fabricated brake disc however, witnesses about 22% reduction in toughness compared to the foreign brake disc. An offshoot from this research will enhance the choice of material selection in the manufacturing of brake disc and assurance of locally made spare parts at affordable prices, and the provision of employment opportunities by establishing spare-parts production and allied industries.

Keywords: *brake disc, toughness, microstructure, strength, ferrite*

1. Introduction

Disc brake system generates braking force by clamping brake pads unto a disc brake that is mounted on the hub. It has a metal disc, with a leaf shaped rigid connector to each of the back wheels of a vehicle and its borders pressed by a pair of claws to brake (Clark, 1995; Harper, 1998). As reported by Halderman and Mitchell (2000), in terms of geometry, the disc brake system has higher wear resistance and easier maintenance when compared to the drum brake system. The high mechanical advantage of hydraulic and mechanical disc brakes allows a small lever input force at the handle bar to be converted into a large clamp force at the wheel. To attain the desired properties, there are more than 2000 types of different materials used in commercial brake components (Weintraub, 1998). The surfaces of brake comprises mainly gray cast iron. The metallurgical properties of the gray cast iron determines to a great extent its mechanical properties and its application. Cast iron dominate most of the available brake disc in the world market, however, ceramic-matrix composite and carbon-carbon composites are reportedly suitable candidates. (Harper, 1998; Halderman and Mitchell, 2000; Weintraub, 1998 and Aravind et al., 2010). Attention has been however given to improving brake discs performance. This led to materials development such as, non-ferrous copper alloys, aluminium matrix composites and carbon–composites (Wycliffe, 1993; Rhee, 1970). As investigated Fiche (1993), observed that the composite structure of brake disc type results in an extreme complexity in terms of chemical-physical properties; as a result of the organic elements subject to series of transformation. Brake dics finds its application in automobile industry in production such as engine blocks, piston rings, cylinder liners, machine frame and crankshaft (Farag, 2008). This large clamp force pinches the rotor with friction material pads and generates brake power. The higher the co-efficient of friction for the pad, the more brake power will be generated. Co-efficient of friction can vary depending on the type of material used for the brake disc. The pad wear may be checked by direct inspection, stripping of the assembly not been necessary. Farag, (2008) suggested that Pad should be replaced when worn down to about 3mm thickness. Disc may be found to be badly scored, or to suffer from surface cracking. Faulty disc brake should be replaced by new units. The choice of a brake disc is hinged on the mechanical properties of the brake disc (Jared, 2013). The speed of a vehicle can be control by the application of brake system, through an energy balance mechanism. Maleque et al., (2010), reported a functional properties of the brake discs as candidate for the initial screening. The foreign brake disc (FBD) had been known for their long life span and better mechanical properties under service condition. The locally fabricated brake disc (LFBD) may possess similar or better mechanical properties than the foreign brake disc type. This research work is aimed at investigating the mechanical properties of two different disc brake (FBD and LFBD) and determining the disc brake with better mechanical properties. So as to compete favourably with the highly graded foreign disc brake; encourage self-reliance through industrialization, conservation of foreign exchange, assurance of locally made spare parts at affordable prices, and the provision of employment opportunities by establishing spare-parts production and allied industries.

2. Materials and Method

2.1. Materials

The materials for this research is locally fabricated disc brake (LFDB) sourced from the Ground foundries and Engineering works Nigerian Limited, while the foreign disc brake (FDB) was obtained as scraps. The representative composition analysis are presented in table 1 and 2 respectively.

Table 1: Elemental composition of FBD

Element	% wt
C	3.550
Si	2.000
Mn	0.468
S	0.194
Ni	0.110
Cu	0.185
Co	0.015
Mo	0.005
P	0.079
Cr	0.071
Fe	bal

2.2. Preparation of Specimen

Twelve samples each for FBD and LFBD were machined to standard specimen for tensile test, impact test, and hardness test respectively. After which a metallographic examination of the microstructure was investigated before subjecting them to various mechanical tests. The test was done for different number samples in other to ensure reproducibility.

2.3. Hardness Test Measurement

The Brinell hardness test was carried out on the prepared samples of both FBD and LFBD. Each of the prepared samples was taken in turn and tested in the Brinell hardness tester. A Hardened steel ball 10 mm diameter was used, an indentation on the specimen was done for 10 seconds. The diameter of impression produced was determined by foundrax microscope. The Brinell hardness number (BHN) was calculated from a foundrax Brinell conversion table.

2.4. Tensile Test Experiment

The test specimen of FBD and LFBD were mounted on the two jaw of the Tensometer and a tensile force was applied gradually. Initially the gauge length and diameter was measured before subjecting them to tension. As the force increases, a point was reached where the specimen fractured without showing any noticeable necking. The yield and maximum load was recorded directly from the resulted graph, the final gauge length and also the smallest diameter of the neck were measured and evaluated.

2.5. Impact Test Experiment

The prepared specimens of the two sample of brake disc were mounted on the Izod impact tester. A blow was released behind the v-notch through the pendulum hammer and the energy absorbed in fracturing the test piece was recorded.

2.6. Metallographic Examination

Samples were mounted in hot phenolic powder and was ground on a water lubricated hand grinding set-up of abrasive papers, progressing through from the coarsest to the finest grit sizes. The 240, 320, 400 and 600 grades were used in that order. Polishing was carried out in a rotating disc of a universal polisher. Rough polishing was done with a synthetic velvet polishing cloth impregnated with micron alumna paste. Final polishing was carried out with diamond paste. The specimens were etched with the standard 2 % nital so as to reveal the ferrite grain boundaries. An optical microscopic examinations was latter carried out on the samples to access the phases present in the structure.

3. Results and Discussion

The results obtained from the Brinell Hardness for FBD is presented in Table 3, it shows that the foreign brake disc has higher resistance to indentation and the average Brinell value observable was 210 BHN.

In Table 4 however, the representative value of the results obtained from the Brinell hardness for the samples LFBD are documented. From this, a lower resistance to indentation was noticeable with an average Brinell value of 173 BHN.

Table 3. Brinell Hardness for FBD Foundrax Brinell Conversion Table

Diameter of impression (mm)	d_1	d_2	d_3	d_4
Reading (mm)	5.10	5.15	5.20	5.25
Load (3000 g)	3000	3000	3000	3000
Hardness value (BHN)	217	210	207	209

Table 4. Brinell Hardness for LFBD Foundrax Brinell Conversion Table

Diameter of impression (mm)	d_1	d_2	d_3	d_4
Reading (mm)	4.10	4.40	4.00	4.15
Load (3000 g)	3000	3000	3000	3000
Hardness value (BHN)	143	187	180	182

Table 5. Notch Impact Test Result for FBD

Sample designation	A	B	C	D
Energy absorbed (Joules)	10.472	9.792	8.840	8.160

Table 5, shows the results of the impact energy of FBD, from the values above, with an average deformation of 9.32 Joules, the material exhibit a high toughness value.

Table 6. Notch Impact Test Result for LFBD

Sample designation	A	B	C	D
Energy absorbed (Joules)	7.752	8.432	6.800	6.120

3.2. Microstructural Examination

Representatives of the photomicrograph of FBD and LFBD are presented in the figures 1 and 2 respectively.

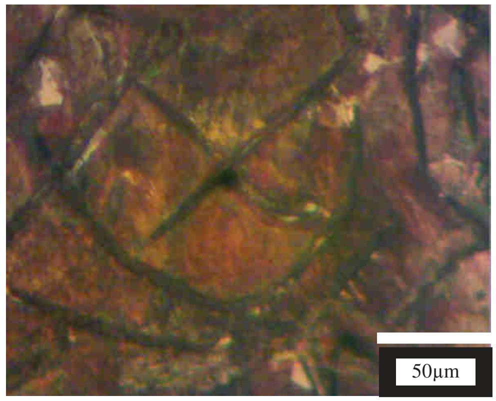

Figure 1. Photomicrograph of Specimen A, a representative of FBD etched in 2% Nital.

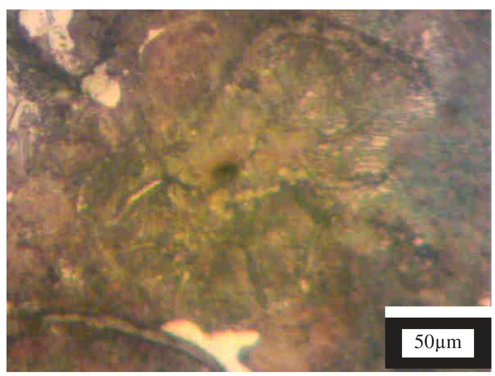

Figure 2. Photomicrograph of LFBD when polished and etched with 2% Nital

3.3. Tensile Test Results

Table 7. Computation of Yield Strength, Young Modulus and Percentage Elongation of the FBD

Sample	Yield Strength	Young Modulus (N/mm^2)	%elongation
1	119.476	2437.815	4.9
2	118.886	6346.568	1.9
3	100.218	2116.808	7.0

Table 8. Computation of Yield Strength, Young Modulus and Percentage Elongation of the LFBD

Sample	Yield Strength	Young Modulus (N/mm^2)	%elongation
1	94.16	10421.65	0.90
2	117.04	8780.16	1.33
3	115.45	4093.65	2.77

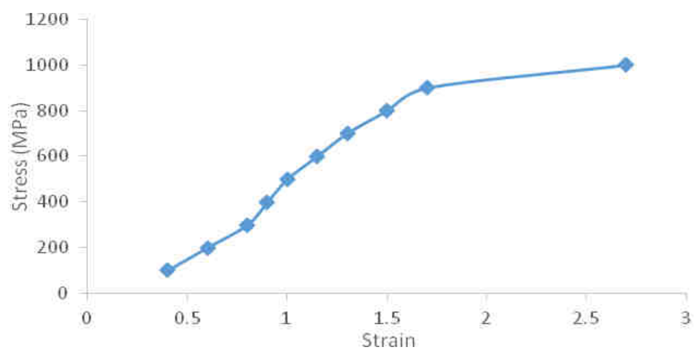

Figure 3. Stress/Strain response of FBD

Figure 3 above is a representative of the stress - strain graph obtained for samples of foreign brake disc (FBD). It was observed that the ultimate stress level before fracture of the material was 1000 MPa.

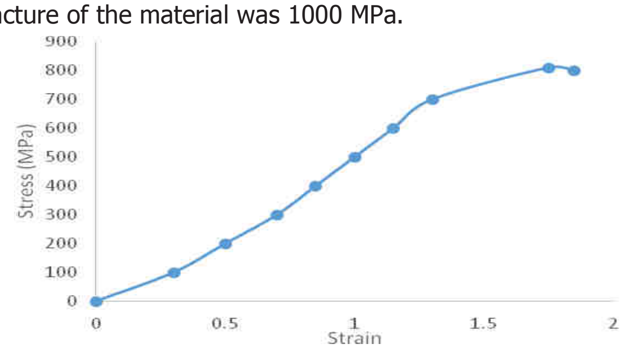

Figure 4. Stress/Strain response of LFBD

From figure 4 above, representative of the stress - strain graph obtained for samples of locally fabricated brake disc was plotted. It was observed that the material fractures shortly after necking which is a typical characteristics of cast iron.

Discussions

From table 1 and 2, the compositional nomenclature is an index of a grey cast iron (Odusote et al., 2014). The result obtained from the Brinell hardness test of the samples for FBD and LFBD shows that the FBD is slightly harder than the LFBD. Reasons might be due to process route and the proportion of alloying element in the matrix.

From table 4, showing that the average Brinell hardness value for the locally fabricated disc brake was in the range of BH for G9 (Mark Ihm, 2011). The value shows that the foreign brake disc has a higher resistance to wear, indentation and scratching than the locally fabricated one. From this result, it can be deduced that the life span of the foreign disc brake will be higher than the locally fabricated one. The result obtained from the impact test of the two samples of brake disc show that the foreign brake disc is tougher than locally fabricated one. Table 5 shows the average amount of energy absorbed in fracturing the test piece for foreign disc brake is 9.32 Joules. However, table 6 shows the average amount of energy absorbed in fracturing the test piece for the LFBD is 7.28 Joules.

The chemical analysis results obtained in table 1 and 2 respectively for FBD and LFBD. From table 2, the amount of carbon and silicon are both higher in the locally produced disc brake than in the foreign one in table 1. This can be minimized by slow cooling of the locally fabricated disc brake which facilitates the formation of good graphite by the precipitation of carbon by silicon. From literature, carbon/silicon ratio greatly determine the strength of the flake graphite grey cast iron, this is better expressed in terms of the carbon equivalent. The carbon equivalent (CE) for the foreign brake disc in table 1, based on the use of the formula $CE = C\ \% + 1/3\ (Si\ \% + P\ \%)$ is 3.7. while the carbon equivalent for the locally fabricated brake disc in table 2 based on the same formulae is 4 %. When the carbon equivalent is 4 %, we have relatively weak and soft graphite but when the carbon equivalent is 3.7 %, we have relatively tough and strong graphite. Therefore, the locally produced disc brake is easy to machine than the foreign disc brake because of the soft and weak graphite flakes. One can deduced that, slow cooling rate favors the formation of good graphite in the local brake disc which account for the lower value of hardness and tensile strength while high cooling rate decreases the tendency to form graphite in the foreign disc brake thereby resulting to the formation of chilled casting which account for higher hardness and tensile strength of the foreign brake disc. Another factor which favors foreign disc brake is probably the grains refinement of the matrix in the casting while the locally produced disc brake is not subjected to grain refinement which eventually lowers its hardness and strength. The sulphur content is higher for local brake disc than for the foreign while the amount of phosphorus is higher for foreign disc brake than for locally fabricated one. The effects of high proportion of sulphur content in the locally fabricated disc brake is that, sulphur react with the iron to form iron sulphide (FeS) which is a low melting point compound with thin interdendritic layers. This compound increases the possibility of the brake disc cracking at elevated temperature; this effect is called ‘red shortness’. The excess sulphur content reverses the graphitization tendency of silicon and thus reduced the fluidity during casting and self-lubricating of the disc brake while in use. The excess phosphorus in the foreign disc brake combines with the iron to form iron phosphide Fe_3P, the Fe_3P form a ternary eutectic with cementite and austenite (pearlite at room temperature) the ternary eutectic is known as steadite. The brittle steadite area tends to form a continuous network out lining the primary austenite dendrite. This reduces the toughness of the foreign brake disc. The excess manganese in the locally fabricated disc brake reduces the harmful effect of excess sulphur present in its matrix. The graph of stress against strain obtained from the tensile test for both samples shows that cast iron fracture before the inset of necking. This is the nature of cast iron which exhibits the brittle fracture process of deformation. The higher tensile strength of the foreign brake disc shows that it can resist the highest stress imposed during severe braking than the local one. The results obtained from micro-structured examination of the two samples of brake disc are mere photomicrographs. From figure 1, uniform orientation of graphite flake was noticeable and that, the disc brake comprises of both graphite flakes and pearlitic phases. The dark grayish parts of the micrographs indicate graphite owing to the fact that graphite has low absorption tendency, while the whitish part of the photographs represents cementite as a result of its high absorption tendency. All the micrograph for both foreign and local disc brake have almost the same size of graphite flake (of about 2-4 inches). The difference in the micrograph of FBD and the LFBD is that the micrograph of the foreign brake disc have some large thick graphite flake while for locally made disc brake have long, thin graphite flakes because of higher proportion of inoculators like copper, ferrosilicon as observed in figure 2. Also, the locally produced brake disc has higher proportion of graphite flakes, because of its higher value of carbon equivalent while the foreign disc brake has lower proportion of flake graphite because of its lover value of carbon equivalent (CE). The dark spots on the micrographs of FBD indicates iron sulphide impurities while the dark spots on the micrographs of LFBD indicates iron phosphide impurities.

4. Conclusion

The mechanical and microstructural behavior of a foreign and locally fabricated disc brake has been investigated. It was observed that, at higher strength values, the foreign material witnesses a severer braking over the locally fabricated type. Grain refinement of the matrix during casting favors the FBD as compared to the LFBD.

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