STUDY OF TRIBOLOGICAL PROPERTIES OF TRAIN BRAKE BLOCK PRODUCED FROM CLAY BLENDED WITH STEEL SLAG

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Abstract
Rail transportation is one of the most important and economical transportation systems. Thus, this paper investigates the tribological properties of composites produced from clay blended with steel slag for the train brake block application. The problem with conventional brake blocks currently in use by the Nigerian Railway Corporation (NRC) is that the friction between the brake blocks and the train wheel leads to wear of the brake surface. This wear puts the safety of the passengers and freight being transported in jeopardy. Wearing of the brake surface renders the brake block unsafe for use. Furthermore, the brake blocks currently in use are imported, this frequent importation increases the cost incurred in maintaining and operating trains. Also, the importation of the brake blocks hinders the development of our local industries. In this study, brake block samples were produced using clay and steel slag. Clay served as the matrix, while induction furnace steel slag served as the reinforcement. Phenolic resin was used as the binder and quartz was added to improve friction properties. The Vickers micro hardness (HV), coefficient of sliding friction and wear rate of the produced brake block composite was evaluated. It was observed that the sample with composition: clay- 39%, steel slag-27%, phenolic resin-20% and quartz- 14% gave improved properties of: wear rate – 6g/min, hardness- 6.65HV and coefficient of friction-0.5774. From the results obtained, this study has established that clay and steel slag can be used to produce brake block composites with the required service properties which can serve as a viable alternative to imported brake blocks.

Keywords*:* Brake blocks, friction-wear, reinforcement, wear rate.

1.0 INTRODUCTION

Railways are very important in terms of freight transportation**,** as with other means of transportation safety is very important in railway transport**.** Central to the safety of operations of trains are the braking operations. Braking in trains is a very complex process which varies from the braking systems used in other transportation vehicles and is key to the safety of passengers and freight being transported.

Block braking is a commonly used braking system in railway vehicles. It is either used as the only braking system for a vehicle, e.g. for freight wagons, or in combination with other braking systems, such as disc brakes and electrodynamic brakes, e.g. for metro trains and intercity trains. An important aspect of block braking is that malfunctioning may result in unintended brake action for longer times in high brake power which may cause damage to the railway wheels. The wheels are safety components, the failure of which may even cause the train to derail. (Vernerson et. al., 2012).

Different kinds of phenomena occur during braking action; thermal, mechanical and pneumatic phenomena. These Phenomenon can be described using Equations 1-5.
Consider a train of mass (M) at a running speed (V) subjected to a constant deceleration (d), the breaking space (S) and the Stopping time (t) are related by known mechanical relationships in Equation 1 – 3.

$$S = \frac{V^2}{2d} \tag{1}$$

$V = dt$ (2)

Substituting Equation 1 into Equation 2 gives

$S = \frac{1}{2}dt^2$ (Crucean, 2012). (3)

The total breaking Force (F_b) of the train is proportional to the total Normal applying Forces $(\sum P_N)$ acting at the brake shoes on wheel tread or brake pads against the discs (Equation 4-5).

$F_b \propto \sum P_N$ (4)

Introducing the proportionality constant (μ) gives;

$F_b = \mu \sum P_N$ (5)

Where μ = Coefficient of Friction between the brake shoes and wheels.

Friction materials such as brake blocks are to decelerate a vehicle by converting kinetic energy to heat via friction. Therefore, any vehicle which uses the action of a brake pad rubbing on a brake rotor to convert the vehicle's kinetic energy into heat has the potential to develop brake fade (Shubham, et al.; 2017).
Clay, which is normally used as a refractory material, due to its high melting point or high refractoriness, which is closely related to thermochemical stability can be a suitable material to function properly under such conditions.

The braking elements must be constructed in a way that the thermal regime developed during braking does not impact negatively on the braking capacity. Train brake blocks are supposed to be light, corrosion resistant and have a stable coefficient of friction. Most important characteristics in train brake blocks is that they are wear resistant, long service life, less noisy and are cost effective (Akinlabi *et al*., 2016). Unfortunately, the coefficient of friction for brake blocks depends heavily on load, sliding speed and sliding distance.

Traditionally in Europe, the brake blocks have been made from cast iron. A main drawback of the cast iron brake blocks is the increased noise levels during rolling of the wheels on the track, which is a result of the wheel and block interaction during braking (Shahab *et al*., 2010).

A common phenomenon observed in the friction brakes is 'Brake Fade'. Brake fade is a reduction in stopping power that can occur after repeated application of the brakes. Brake fade is caused by a buildup of heat on the braking surfaces and the subsequent changes and reactions in the brake components. Loss of stopping power, known as fade, can be caused by mechanical fade, friction fade, or fluid fade. Brake fade can be significantly reduced by appropriate equipment, materials design and selection. This wear of the brake blocks due to friction limits safe reusability of and as such necessitates frequent replacement which is an added expense.

The brake blocks, for the most part, comprise of asbestos filaments inserted in the polymeric framework with some other elements, but it is no longer acceptable due to the health implication of the use of asbestos; in this way, new non-asbestos friction materials are being created (Aigbodion *et al*, 2010).

Many studies have been carried out in order to improve the wear resistance of train brake blocks. In this paper, some recent studies on brake blocks are discussed briefly with a view to understand the current trend of the discipline:

Dineshkumar *et al.* (2017) studied the properties of brake blocks made with Precast Pre-Fired Blocks. The blocks consisted of fused and non-fused ceramic materials. The blocks were developed as an alternative to asbestos brake pads which are carcinogenic in nature and as a result cause so many health problems. The new material is made by fused ceramic materials from industrial wastage. The blocks were tested for coefficient of kinetic friction and were found to produce stable friction performance comparable to the blocks made from asbestos.

Incesu *et al.* (2013) developed a composite brake block consisting of steel fibers, graphite, alumina (Al_2O_3), barite ($BaSO_4$), friction dust, novalac resin, glass fibers and cellulose. The brake block was made by mixing the constituents in a mixer and then heated in a hot press. The performance was evaluated using a burnout test. The material was declared commercially unviable due to its higher friction coefficient of 0.15.

Dungan *et al.* (2010) evaluated the effect of weight on the friction torque of steel brake blocks and determined that the weight of the brake blocks played little role in determining the performance of the brake block. They suggested further research into other lightweight materials as possible additives for brake blocks.

Szliching *et al.* (2016) investigated the effect of tribo-chemical properties of the surface of the brake blocks. The brake blocks were made of ceramic and were made by hot pressing. It was heated and then cooled for 7 hours to improve the surface finish. The brake blocks were then tested for hardness, shear strength and friction-wear. It was discovered that the formation of a thin film on the brake block surfaces helps in the increase of wear resistance.

Abbassi *et al.* (2013) determined the effect of high wear resistance on the wear rate of a cast iron brake block. They observed that at high performance temperatures, the wear rate in the cast iron brake blocks was reduced due to the formation of thin sheets on the surface of the brake blocks.

In an experiment carried out by Shivamurthy, et al. (2014), reinforced epoxy composites were prepared by open mould resin casting method. The mechanical and dry sliding wear properties epoxy was experimentally investigated as per the ASTM standards. Dry sliding wear test was conducted for these composites at a constant sliding distance of 500 m with different sliding velocities and applied loads by a pin-on-disc wear test machine. The results revealed a minimal specific wear rate and coefficient of friction with higher mechanical properties compared to other resins.

Byeong-Choon *et al.* (2017) investigated the suitability of Carbon fibre reinforced SiC composites for the manufacture of brake blocks. The brake block was made by hot forming and friction wear test was carried out on it. They discovered that as temperature increased, the wear rate of the produced brake block increased. This discovery as well as the high cost of obtaining carbon fibre made the composite unsuited for commercial production.

Fall *et al*. (2017) carried out a research on the characterization of train brake blocks. Their metallurgical characterization consisted of a study of the hardness and microstructural analysis of the different samples prepared using cast iron. The results show that the hardness of some soles is greater than that of the wheel, mainly associated with a cementite microstructure. This can lead to a premature wear of the wheels at the expense of brake blocks.

Most of the previous researchers used expensive synthetic materials as the additives whereas this study aims to use a readily available by-product of the manufacturing industry i.e. steel slag as well as a naturally occurring minerals (quartz and clay) as the additive material. This will help to provide sustainable alternative to the imported brake block.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials that were used in the course of this study include; Clay, Steel Slag, Sample brake block (Rubber matrix composite brake block), Phenolic Resins and Quartz. Apparatus includes; Wooden Mould, Weighing Balance and Silicon Carbide (Emery paper). The Equipment are: Grain Grinding Machine, X-Ray Fluorescence Analyzer, Hydraulic Press, Hardness Testing Machine, Sliding friction apparatus and Ball mill.

2.2 Methods

Clay obtained from the Osiele clay deposit, Ogun state was ground to fine powder (250 microns) using a grain grinding machine. The clay powder was sun dried. The clay serves as the matrix. The steel slag obtained as a by-product of an electric arc furnace was ground using ball mill. The steel slag serves as the reinforcement that improves the wear properties of the composite. The phenolic resins are synthesized by the reaction of Phenol and Formaldehyde. The phenolic resins serve as the binder. The chemical reaction is given as;

$$HOC_6H_5 \quad + \quad CH_2O \quad \rightarrow \quad HOC_6H_4CH_2OH$$

The quartz sample obtained at Ago-Iwoye, Ogun State was ground to micro particulate size and serves as the abrasive. The clay and quartz were sourced from Ogun State due to the nearness of the raw materials to the research location. Also, their Chemical composition revealed that they contain the required percentage of compounds needed for the work.

The raw materials were weighed to various proportions using a digital electronic weighing machine. The weighed raw materials were mixed in various proportion ranging from 5 – 45 wt%. The sample formulations are shown in Table 1. The mixture was poured into the prepared metal mould and the mould was fixed onto a hydraulic press which pressed the samples to the required shape and dimensions at an average pressure of 40 tonnes. Thereafter, the brake blocks samples produced were sintered (heated) to improve their mechanical properties. This was carried in an electric furnace at temperatures between 900 - 1000^{o}C and held for 4 hours before being left to cool in the furnace. Finally, various tests such as hardness, wear and friction tests were carried out. The control sample is the conventional imported brake blocks currently in use.

Table 1: Sample formulations for the produced train brake blocks

Sample Designation	Phenolic resin (wt. %)	Steel slag (wt %)	Quartz (wt. %)	Clay (wt.%)
A	5	30	23	42
B	10	29	20	41
C	15	28	17	40
D	20	27	14	39
E	25	26	11	38
F	0	0	0	100
G	33	0	33	34

3.0 RESULTS AND DISCUSSION

3.1. Hardness

The hardness result shown in Figure 1 indicates that hardness ranges between 5.65 – 6.8 (HV). The conventionally used brake block shows the highest hardness value of 9.45 HV, which is higher than that of the prepared composites. This high hardness of the conventional imported brake block can reduce its ductility; this may be responsible for its failure within a short period of time during service.

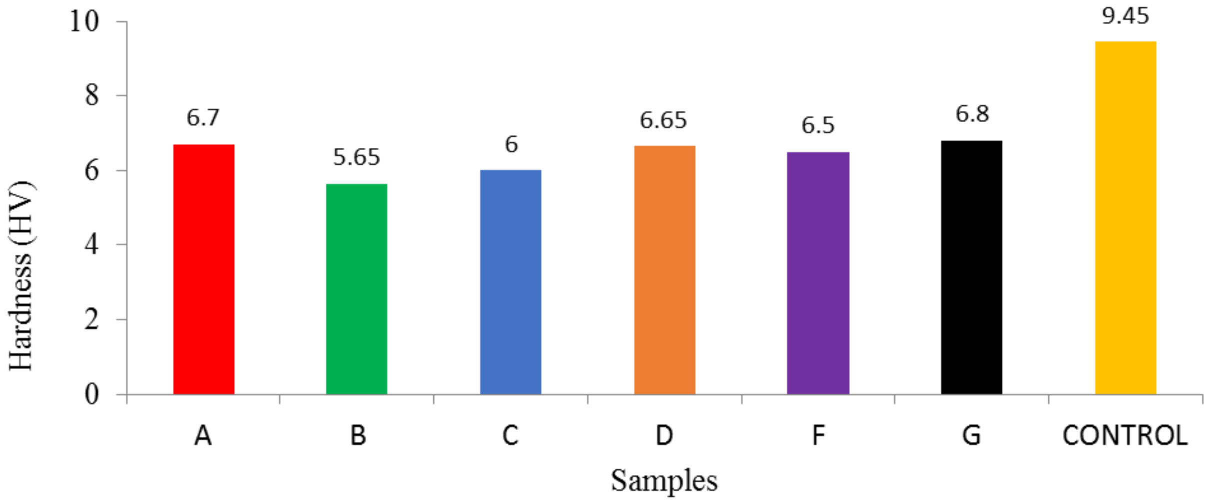

Figure 1: Variation of hardness with the composition of different samples

3.2 Coefficient of Sliding Friction

It is observed that the coefficient of sliding friction increases with increase in binder content as shown in Figure 2. The value of the coefficient of static friction of sample F without slag reinforcement, is higher than that of any of the prepared composites. This is due to the higher amount of clay present in sample 'F' which improves surface grip leading to better friction properties. The coefficient of sliding friction of the conventionally used brake block is 0.4432. Samples C (40 % clay) and Sample D (39 %) have coefficient of sliding friction of 0.4663 and 0.5774 respectively. This value is close to the value of conventional break block which indicate that the clay content between 39 – 40 % is sufficient to produce a good quality brake block.

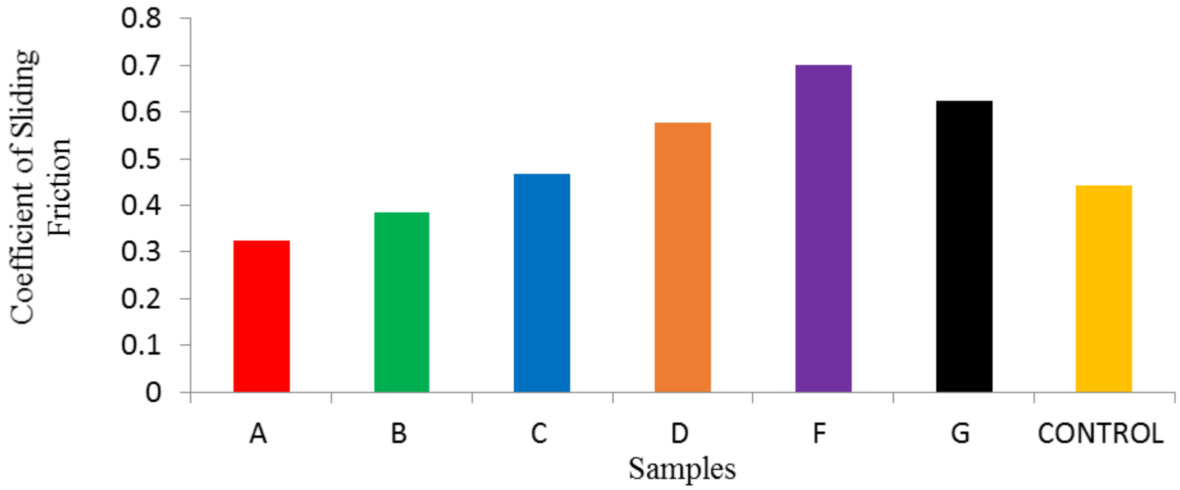

Figure 2: Variation of coefficient of sliding friction within the different samples

3.3 Wear Rate

It is observed from Figure 3 that Sample 'D' has the lowest wear rate of 6g/min when compared with other produced samples. This is due to the high binder content leading to better cohesion between the particles. The wear rate of the control sample (conventionally imported sample) is 5g/min, though this value is close to that of sample 'D', sample 'D' is better suited for use as a friction brake when compared to other locally produced samples.

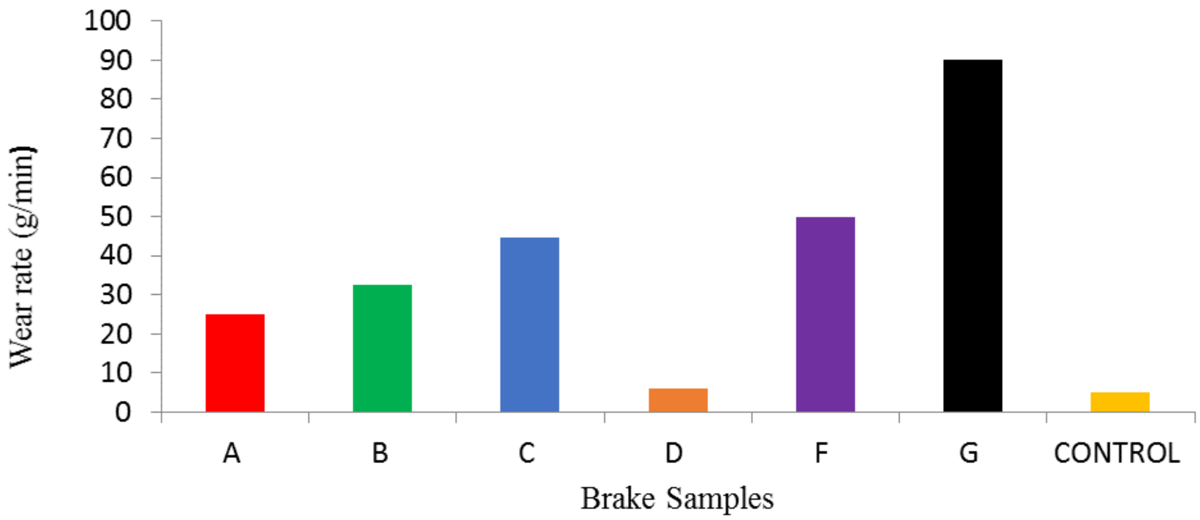

Figure 3: The Variation of wear rate within samples

3.4. Tensile Strength

The tensile result shown in Figure 4 indicates that sample A has the highest tensile strength of 7.406 MPa compare to others. This could be attributed to its highest content of steel slag when compare with other samples. Naturally steel has higher tensile strength than clay. Sample D has the tensile strength of 3.988 MPa very close to the control sample with tensile strength of 3.925. This shows that sample D has the required properties that can be used for brake block.

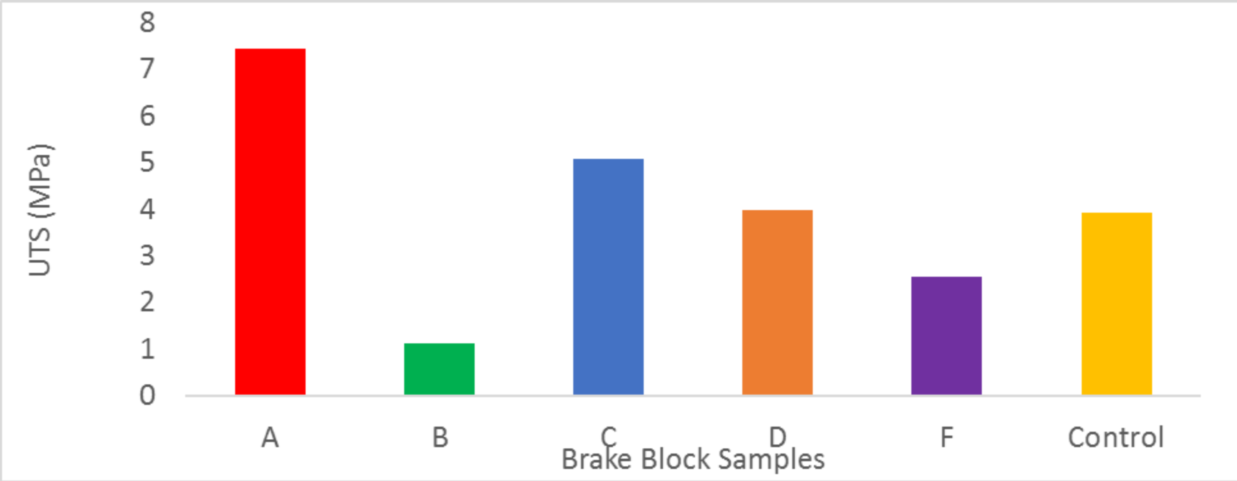

Figure 4: Effect of composition on tensile strength

3.5 Compressive Strength

The result of the compressive test shown in Figure 5 revealed that the control sample has the highest compressive strength. Nevertheless, the compressive strength of samples C, D and F are very close to that of the control samples. Therefore, the values of their compressive strength are still within the standard value.

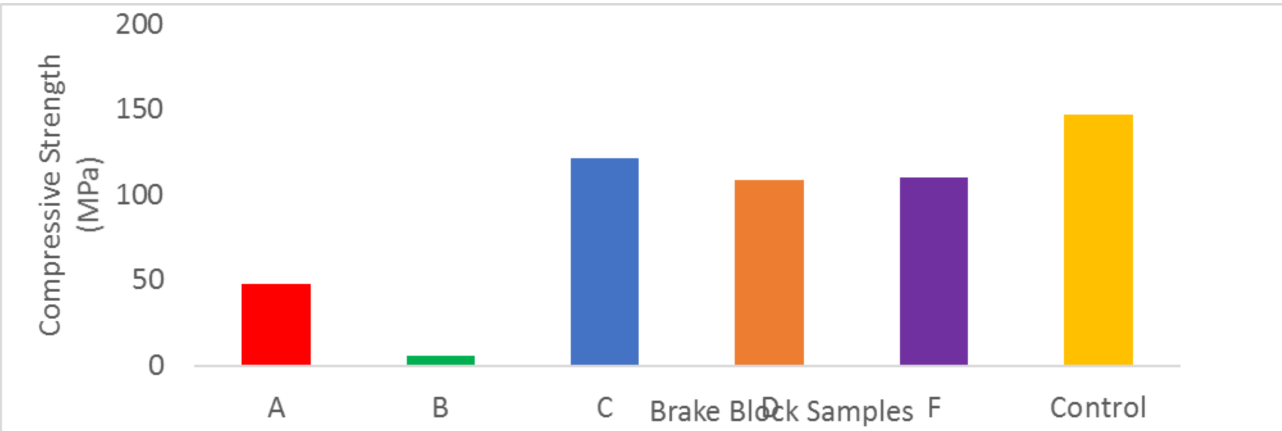

Figure 5: Compressive strength of various brake block samples

4.0 CONCLUSIONS

The experimental results show that it is possible to develop composite friction materials using steel slag as the reinforcing material. In this work, three mechanical tests (Wear, Sliding friction and Hardness) have been carried out.

Sample 'D' with composition Clay- 39% Steel Slag-27% Phenolic Resin-20% Quartz- 14% is seen to have mechanical properties that satisfy the requirements specified by the Rail Industry Safety and Standards Board (RISSB).

The Hardness value of Sample D (6.65 HV) is greater than the minimum value of 6.00 HV specified by the RISSB AS 7504:2017 standard. This makes it have sufficient hardness to be utilized as a brake block material.

Sample D has a coefficient of sliding friction 0.5774 which is greater than the minimum value of 0.35 set in RISSB standard. This means that Sample D would generate enough stopping power via friction required to cause a reduction in the trains' velocity. Sample D also has a higher coefficient of sliding friction than the commercially used brake block material (0.4432). This means that sample D would cause faster deceleration of the train than the commercially used brake blocks. This would mean that sample D would be safer for use than the commercially used brake blocks especially in the event of emergency braking.

The Wear rate of Sample D (6g/min) is very close to that of the commercially used brake blocks (5g/min). As such, Sample D is suitable for use in the production of train brake blocks.

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