# Production and Characterization of Brake Pad Developed from Natural - Based Reinforcement Material Using Multi - Response Optimization Technique

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**Abstract:** ***Over the years, asbestos has been used as a reinforcement material in the production of friction lining but due to its hazardous nature, it has lost favour. As a result, there is need to find a possible replacement for asbestos. Many authors have carried a lot of work on the replacement of asbestos using different material with the aim of finding a possible replacement for asbestos. In this work, coconut shell was used as reinforcement material together with other materials (epoxy resin, graphite and barium sulphate) with the aim of finding possible replacement for asbestos. Experimental design was carried out in accordance with Taguchi L933 design technique using Minitab. Samples production was done using constant weight percent of 50% reinforcement, 30% binder, 12% abrasive and 8% friction modifier. The mechanical, tribological and physical properties of the composite were also studied. The results showed that sample 7 produced with moulding pressure, moulding temperature and curing time of 12 MPa, 110 ˚C and 11 minutes respectively gave better results in terms of its mechanical, tribological and physical properties. Also, Analysis of Variance (ANOVA) and regression analysis (confirmatory test) results revealed that the percentage errors obtained for individual responses were below 10% which showed that the experimental procedures were conducted under minima noise effects and the developed regression equations can be adopted for prediction of the friction lining performance. In addition, the thermogravimetric analysis (TGA) conducted on the sample 7 showed that the thermal properties of the best samples compared well with commercial sample and can be applied in automobile whose temperature at brake do not surpass 322.3oC.***

**Keywords:** Friction lining, coconut shell, Taguchi, mechanical, tribological, physical properties

## 1. Introduction

Materials for friction lining are used in automobile e. g. Cars, Motorcycles systems. Their properties keep on changing in order to attain the growing technology and requirements of the present days. Friction linings are subdivided into metallic, semi - metallic, organic and carbon - based. Most mechanics are exposed to dust of asbestors in many ways. In brake repair works dusts are wiped off with brush before replacement. This process can cause asbestos particle to become airborne. Old linings are hard mostly, mechanics use grinder to standardize the surface. These method often Cause particles of asbestos release. Working on asbestos materials often inhaled asbestos dust while handling it put them at risk of diseases contacting e. g peritoneal, pericardial or mesothelioma (Anon, 2012; Norton, 2010). Mesothelioma is a diseases which has a wide latency range period up to thirty or forty years depending on the initial asbestos exposure. Mesothelioma cure has not been developed till date. Efforts therefore have been put in towards research for replacement of asbestos in friction linings materials. Nakagawa et al. (2009). For the past 90 years, asbestos which has been called "God rewarding is used in making of friction lining material. As result of its excellent physical and chemical properties display over a long period of time at high temperature (Abutu 2018). Therefore, due to the danger reported with the handling of asbestos, it has lost its favour alternative composite are being source for replacement.

The problem identified by this research is health risk associated with the use of asbestos as a friction material and the incompatibility of the numerous materials currently used in the development of an asbestos free brake pads. Some of these health risks include; Asbestosis, Lung cancer, Mesothelioma (a cancer of the linings around the lungs), non - cancerous diseases that affect the linings around the lungs (commonly called 'benign pleural diseaseas identified by Dagwa and Ibhadode, (2005). Although several alternative materials such as; mineral fibers, cellulose, chopped glass, steel and copper fibers have been used to developed asbestos free brake pads, however, the incompatibility the numerous used in the replacement of asbestos brakes is also a challenge. Blau (2001) suggest that Coconut shell is seen as possible replacement. This is because the material is environmentally friendly, readily available and it has capacity to display same properties as asbestos. Therefore, this study will focus on using coconut shell agriculture waste as reinforce material for the production of the friction lining.

### 1.1 The Objective of the Research Include

1) To develop friction linings using coconut shell reinforcement material.
2) To study the effects of process parameters on the physical, tribological and mechanical properties of the developed friction lining using Taguchi experimental design and also to study the optimal process parameters and its significance on the properties of the friction lining using Analysis of variance (ANOVA) respectively.
3) To study Thermal stability of the optimised samples using Thermo gravimetric analysis (TGA).

## 2. Materials and Methods

**Table 1:** Production materials

| S/N | Material | Function | Source |
|---|---|---|---|
| 1 | Coconut shell | Reinforcement | Coconut trader in Kawo market |
| 2 | Graphite | Friction modifier | Used 1.5 volts batteries |
| 3 | Barium sulphate | Abrasive | Commercial chemical shop in Kaduna |
| 4 | Epoxy resin | Binder | Commercial chemical shop in Onitshazz |

Crushed coconut shell and 1.5 volt Batteries

### 2.1 Method

Production of friction linings include preparation of locally sourced coconut shell and graphite powder, experimental design using Minitab, compression moulding, testing of samples and analysis of results.

### 2.2 Materials preparation

Coconut shells obtained from Kawo market was prepared by washing using soap and detergent, removing the fibres on the surface of the shells, drying in the sun for 24 hours, crushing using mortar and pestle, grinding using a grinding machine situated in Samaru Zaria - Nigeria and sieving using a mesh size of 150 µm while the graphite powder obtained from used 1.5 volts batteries was prepared by removing the graphite rod from the used batteries, washing of the graphite rods using soap and detergent, drying in the sun for 24 hours, crushing of the dried rod using mortar and pestles, grinding using a grinder and sieving using a mesh size of 150 µm.

### 2.3 Design of Experiment using Taguchi Technique

Design of experiment was conducted using the experimental design technique (Taguchi L933) adopted by Ibhadode and Dagwa, (2008). This technique involves the use of Minitab 17 statistical software by specifying the factor level of experimental design (Table 2) which produced the orthogonal array and layout as shown in Table 3. As presented in Table 2, the factor levels selected include moulding pressure MP (8 - 12 MPa), moulding temperature MT (110 - 130˚C) and curing time CT (9 - 11 min). The selection of this range of factors was prompted by the earlier reports of Abutu et al. (2019b) and Matthew (2012) who reported that moisture desorption of coconut shells takes place between 25 and 150 °C while at 150 °C, the degradation of sclerenchyma cells, which are responsible for holding water in coconut shell occurs.

**Table 2:** Factor Level of Experimental Design

| Factor | Moulding pressure (MPa) | Moulding temperature ($^{o}$C) | Curing time (minute) |
|---|---|---|---|
| Level 1 | 8 | 110 | 9 |
| Level 2 | 10 | 120 | 10 |
| Level 3 | 12 | 130 | 11 |

**Table 3:** Taguchi Experimental Design Matrix

| Run | Moulding pressure (MPa) | Moulding temperature ($^{o}$C) | Curing time (minute) |
|---|---|---|---|
| 1 | 8 | 110 | 9 |
| 2 | 8 | 120 | 10 |
| 3 | 8 | 130 | 11 |
| 4 | 10 | 110 | 10 |
| 5 | 10 | 120 | 11 |
| 6 | 10 | 130 | 9 |
| 7 | 12 | 110 | 11 |
| 8 | 12 | 120 | 9 |
| 9 | 12 | 130 | 10 |

**Testing of Samples**

Produced samples were tested in order to evaluate the tensile strength, compressive strength, impact strength, friction coefficient, wear rate, hardness, and water and oil absorption. These tests were carried out using standard testing procedure outlined in literatures. Wear rate was conducted using Martindale Abrasion Testing Equipments (SATRA TECHNOLOGY, S/N: 11884, STM: 105, Supply - 230 - 1 - 50) and performed in accordance with ASTMD4966 - 98 standard which specified a specimen size 38mm diameter. Also, coefficient of friction (was conducted in accordance with the test procedure outlined by Standard Organization of Nigeria (S. O. N) using an Inclined plane (Model No.14678; NORWOOD Instrument Ltd.) while tensile strength test was conducted in accordance with ASTM D638 using Tensometer (MONSANTO; Serial No -

05232). In addition, hardness test was carried out using a Brinell hardness tester (Model SE B3000J) using ASTM E10 standard while impact test was conducted in accordance with ASTM E23 using a Charpy impact tester (Norwood instrument, model No: 412 - 07 - 0715269C). Similarly, ccompressive strength test was performed in accordance with ASTM D695 testing procedure using Universal testing machine (ENERPAC P391: Cat. Nr.261, Norwood Instruments Ltd) while water and oil absorption test were conducted in accordance with accordance to ASTM D570 standard using distilled water and brake/clutch fluid (BENDIX; B 03202)

**Table 4:** Experimental Result

| Run No | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.772 | 0.003 | 21.8 | 3.3 | 5.4 | 32 | 0.14 | 0.15 |
| 2 | 0.661 | 0.0006 | 31.2 | 5.0 | 8.1 | 25 | 0.15 | 0, 30 |
| 3 | 0.697 | 0.00065 | 2.5 | 3.9 | 9.4 | 14 | 0.05 | 0.30 |
| 4 | 0.675 | 0.00130 | 31.2 | 5.4 | 10.8 | 21 | 0.06 | 0.15 |
| 5 | 0.580 | 0.00131 | 37.5 | 5.1 | 5.4 | 41 | 0.25 | 0.26 |
| 6 | 0.492 | 0.00066 | 18.7 | 3.7 | 13.5 | 32 | 0.11 | 0.30 |
| 7 | 0.626 | 0.00131 | 37.5 | 6.4 | 6.7 | 44 | 0.11 | 0.11 |
| 8 | 0.561 | 0.00262 | 18.7 | 6.4 | 6.7 | 30 | 0.11 | 0.36 |
| 9 | 0.657 | 0.000655 | 31.2 | 3.7 | 8.1 | 168 | 0.21 | 0.26 |
| 10 | 0.697 | 0.00065 | 31.2 | 5.0 | 8.1 | 25 | 0.15 | 0, 30 |

Table 1: Experimental Results

From the experimental results presented in Table 7, it can be observed that the ultimate tensile strength (UTS), compressive strength, impact energy and hardness varies from 2.50 - 37.50 N/mm2, 3.310 - 6.483 N/mm2, 5.43 - 13.56J and 14.83 - 168 BHN respectively. The friction coefficient and wear rate varies from 0.492– 0.772 and 0.000655 - 0.002619 mg/m respectively while the oil and water absorption varies from 0.0573 - 0.2593 and 0.1148 - 0.3609 respectively. In addition, the highest UTS (37.5N/mm2), compressive strength (6.483 N/mm2), impact energy (13.56J) and the lowest water absorption (13.56) value were obtained using MP (12MPa), MT (110˚C) and CT (11minutes) while the highest friction coefficient (0.697) and lowest wear rate (0.000655mg/m) as well as oil absorption (0.0573) using MP (8MPa), MT (130˚C) and CT (11minutes). These results are in good agreement with the earlier work of Abutu et al. (2019a) who reported an optimal friction coefficient, wear rate and compressive strength of 0.0.788, 0.0066mg/m and 5.309 MPa respectively using coconut shell as reinforcement matgerial. Therefore, the performance of the developed friction lining possess good mechanical, physical and tribological properties are in close agreement with results reported in literature.

## 3. Analysis of Experimental Results

**Analysis of Variance (ANOVA**

ANOVA was conducted on the experimental response inorder to study the percentage contribution of individual parameter. This analysis was carried out using confidence level of 95 % and significance level of 5 %. ANOVA table shown in Table 6 - 13 consist of degree of freedom (DOF), sum of square (SS), mean square (MS), f - value and percentage contribution (P %).

**Table 5:** ANOVA for Friction Coefficient

| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 0.0283 | 0.0142 | 8.9145 | 52.04 |
| MT | 2 | 0.0161 | 0.0081 | 5.0823 | 29.67 |
| CT | 2 | 0.0068 | 0.0034 | 2.1305 | 12.43 |
| Error | 2 | 0.0032 | 0.0016 | | 5.83 |
| Total | 8 | 0.0544 | 0.0068 | | 100.00 |

**Table 6:** ANOVA for wear rate

| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 0.0001 | 0.0050 | 25.00 | 32.89 |
| MT | 2 | 0.0001 | 0.0050 | 25.00 | 32.89 |
| CT | 2 | 0.0001 | 0.0050 | 25.00 | 32.89 |
| Error | 2 | 0.0004 | 0.0002 | | 1.32 |
| Total | 8 | 0.0304 | 0.0038 | | 100.00 |

**Table 7:** ANOVA for UTS

| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 285.70 | 142.85 | 2.4054 | 28.00 |
| MT | 2 | 358.70 | 179.35 | 3.0200 | 35.15 |
| CT | 2 | 257.10 | 128.55 | 2.1646 | 25.19 |
| Error | 2 | 118.77 | 59.38 | | 11.64 |
| Total | 8 | 1020.3 | 127.53 | | 100.00 |

**Table 8:** for Comprehensive Strength

| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 0.9900 | 0.4950 | 1.0439 | 9.9304 |
| MT | 2 | 2.5890 | 1.2945 | 2.7299 | 25.969 |
| CT | 2 | 5.4420 | 2.7210 | 5.7381 | 54.587 |
| Error | 2 | 0.9484 | 0.4742 | | 9.5131 |
| Total | 8 | 9.9694 | 1.2462 | | 100.00 |

**Table 9:** for Impact Strength

| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 5.3070 | 2.6535 | 3.2721 | 8.9686 |
| MT | 2 | 7.7640 | 3.8820 | 4.7870 | 13.120 |
| CT | 2 | 44.480 | 22.240 | 27.424 | 75.169 |
| Error | 2 | 1.6219 | 0.8109 | | 2.7409 |
| Total | 8 | 59.172 | 7.3966 | | 100.00 |

**Table 10:** for Hardness

| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 7158.0 | 3579.0 | 4.54 | 40.25 |
| MT | 2 | 4530.0 | 2265.0 | 2.87 | 25.47 |
| CT | 2 | 4519.0 | 2259.5 | 2.87 | 25.41 |
| Error | 2 | 1577.0 | 788.50 | | 8.87 |
| Total | 8 | 17784 | 2223.0 | | 100.00 |

**Table 11:** For Oil Absorption

| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 0.0047 | 0.0023 | 1.3512 | 11.44 |
| MT | 2 | 0.0130 | 0.0065 | 3.7100 | 31.43 |
| CT | 2 | 0.0201 | 0.0100 | 5.7403 | 48.64 |
| Error | 2 | 0.0035 | 0.0017 | | 8.47 |
| Total | 8 | 0.0414 | 0.0051 | | 100.00 |

**Table 12:** for Water Absorption

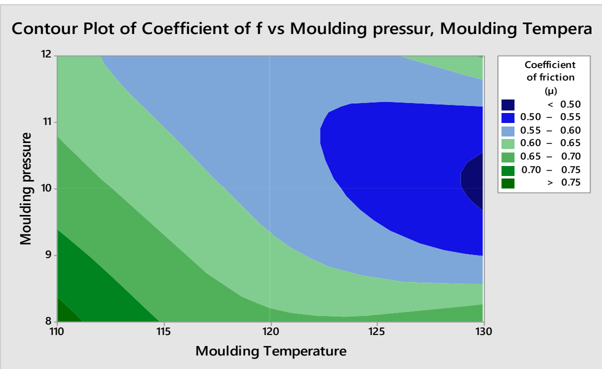
| Factors | DOF | SS | MS | F | P% |
|---|---|---|---|---|---|
| MP | 2 | 0.0003 | 0.0001 | 0.1058 | 0.656 |
| MT | 2 | 0.0499 | 0.0249 | 13.994 | 86.732 |
| CT | 2 | 0.0036 | 0.0018 | 1.0347 | 6.4132 |
| Error | 2 | 0.0035 | 0.0017 | | 6.1977 |
| Total | 8 | 0.0576 | 0.0072 | | 100 |

As shown in Table 6, it can be observed that MP (52.0483 %) has most effect on the coefficient of friction of the developed friction material while curing time gave the least significant effects with percentage error of 5.8386 %. Also, Table 7 showed that all the process parameters (32.89%) contributed similar effects on the wear rate of the developed friction material. The percentage error obtained was 1.32% while Table 8 indicates that MP (35.1572%) has most effect on the UTS of the developed friction material while CT (25.1991%) gave the least significant effects with percentage error of 11.6415 %. In addition, Table 9 revealed that curing time (54.5870 %) has more effect on the compressive strength of the developed friction material while MP (9.9304 %) gave the least significant effects with a percentage error obtained was 9.5131 % and Table 10 indicates that CT (75.1696%) has most effect on the impact strength of the developed friction material while MP (8.9686%) gave the least significant effects and produced a percentage error obtained was 2.7409%. In addition, from Table 11, it can be observed that MP (40.25%) has most effect on the hardness of the developed friction material while MT (25.47 %) gave the least significant effects and percentage error obtained was 8.87 % while Table 12 showed that CT (48.640%) has most effect on the oil absorption of the developed friction material and MP (11.45%) gave the least significant effects with a percentage error of 8.473387 %. Finally, Table 13 indicates that MT (86.733 %) has most effect on the water absorption of the developed friction material while MP (0.656081%) gave the least significant effects with a percentage error of 6.197711 %. The percentage errors obtained for all the responses were found to be below 10 %which indicates that the experiment produced less noise effects.

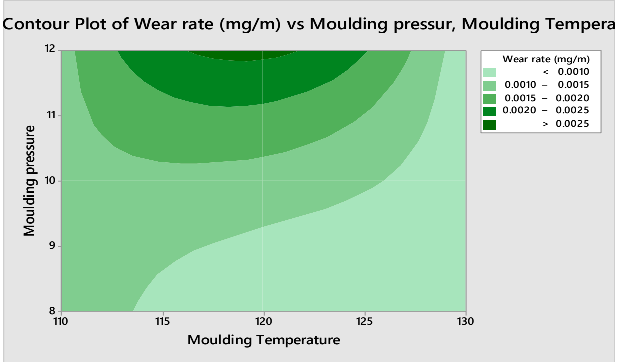
**Contour plots**

Contour plot was obtained using the experimental results with the aim of studying the effect of variation in two process parameters on a response when the other parameter is kept constant. The plots were obtained using Minitab 17 software. The contour plots for all the responses shown in

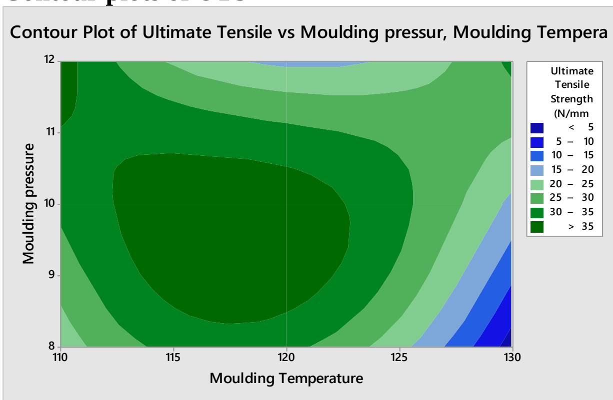
**Contour plots of coefficient of friction**



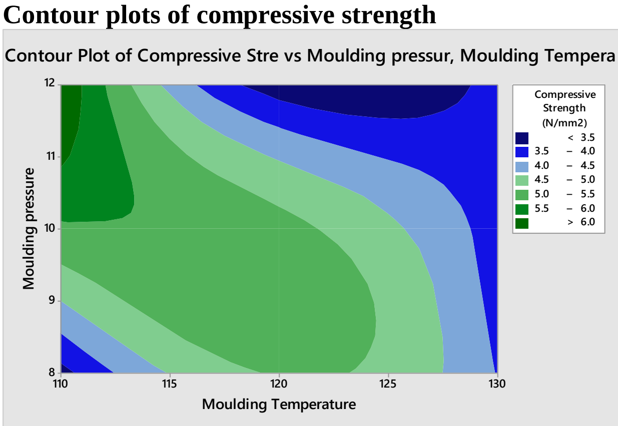

**Contour plots of wear rate**




**Contour plots of UTS**

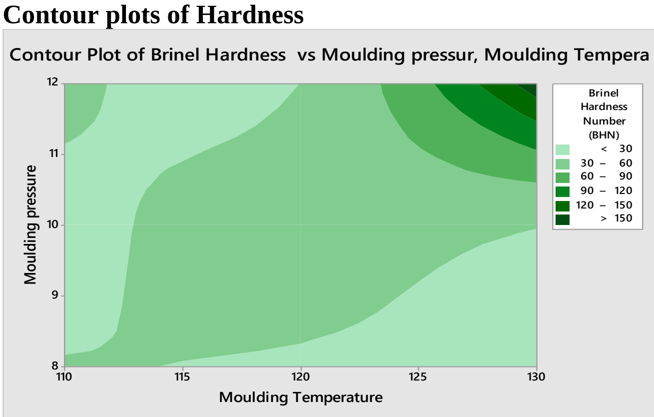



**Contour plots of compressive strength**

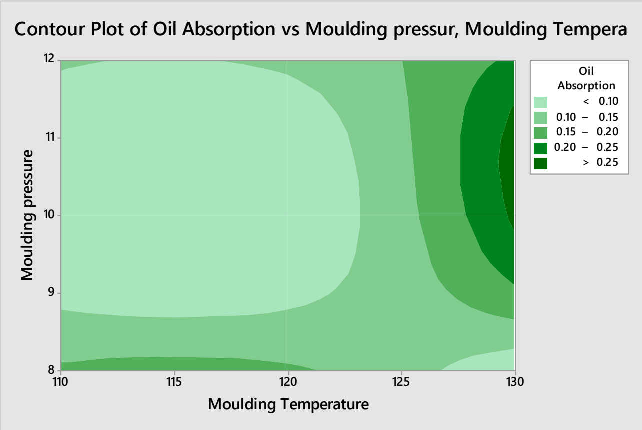



**Contour plots of impact strength**

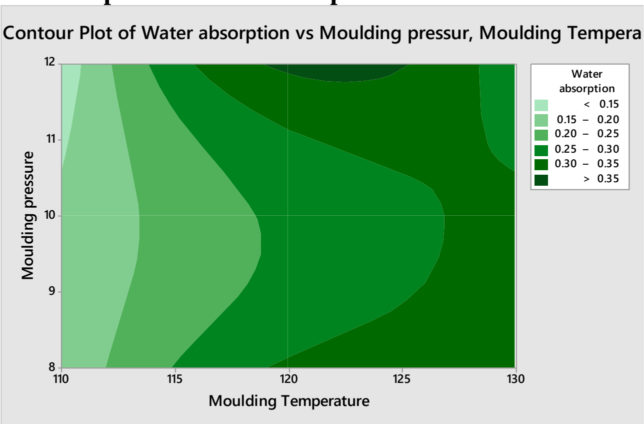
**Contour plots of Hardness**



**Contour plots of oil absorption**



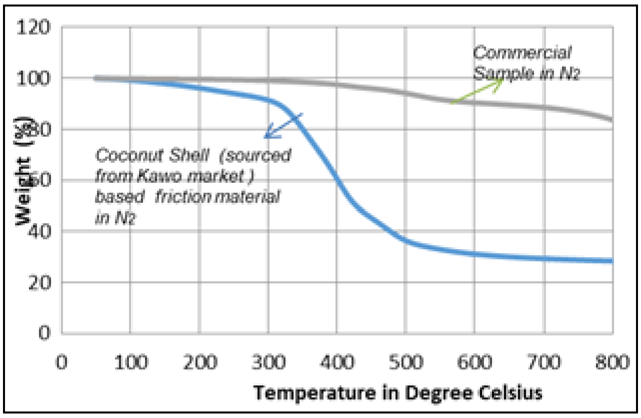

**Contour plots of water absorption**




As shown in Fig.4, it can be observed that while keeping the CT constant, Fig.4 (a) revealed that a coefficient of friction of greater 0.75 can be obtained using MP of 8 MPa and MT of 110 ˚C while Fig.4 (b) indicates that a wear rate of less than 0.001 can be obtained using MP of 11 MPa and MT of 127 ˚C and Fig.4 (c) showed that UTS of greater than 25 N/mm2 can be obtained using MP of 10 MPa and MT of 115 ˚C. Also, Fig.4 (d) showed that a compressive strength of greater than 6 N/mm2 can be obtained using MP of 11.5 MPa and MT of 110.2 ˚C while Fig.4 (e) revealed that a impact strength of greater than 18.5 Joules can be obtained using MP of 11.5 MPa and MT of 110.5˚C and Fig.4 (f) indicates that a hardness of greater than 150 HBN can be obtained using MP of 12 MPa and MT of 130 ˚C. In addition, Fig.4 (g) showed that a oil absorption of less than 0.1 can be obtained using moulding pressure of 11 MPa and moulding temperature of 115 ˚C whileFig.4 (h) revealed that a water absorption of less than 0.15can be obtained using moulding pressure of 12 MPa and moulding temperature of 110 ˚C.

**Thermal Analysis of friction materials**

Based on observation of the experimental data obtained from the examination, it was found that compared to the other samples, sample 7 produced with moulding pressure, moulding temperature and curing time of 12 MPa, 110 ˚C and 11 minutes respectively gave a better results in terms of its mechanical, tribological and physical properties. Therefore, the thermal resistance of the optimal sample (sample 7) was studied along with commercial based sample (Toyota car) using thermogravimetric analyser (Pyris TGA 1, Perkin Elmer) operating at a maximum temperature of 800oC under Nitrogen environment and situated at the Centre for Genetic Engineering and Bio - Technology (STEP B) in Federal University of Technology, Minna. The Thermogravimetric Analysis (TGA) and Derivative Thermogravimetric (DTG) results are shown in Fig.5 and Fig.6 respectively.




As shown in Fig.5 and 6, it can be observed that the thermal stability of the optimal coconut shell based sample compared favourably with commercial based friction material. Though, the commercial sample showed better thermal properties compared to the formulated sample which may be due to the presence of the "giant compound" known as asbestos which has been proven by several researchers to be carcinogenic and required to be replaced with another materials like coconut shell (Blau, 2001). Also, the DTG plot presented in Fig.6 revealed that the onset thermal degradation of the coconut shell based composite begin at a temperature of 322.3$^{o}$C while that of commercial sample begin at 514.8 $^{o}$C. This indicates that the coconut shell based friction material possesses good thermal properties and can be applied in automobile whose braking temperature does not exceed 322.3 $^{o}$C

## 4. Conclusions

From the results obtained, the following conclusion can be drawn;

1) Changes in experimental factors affects the properties of the developed friction linings as all the samples produced with varying parameters gave different performance characteristics.
2) From the experimental results obtained, it can be concluded that sample 7 produced with moulding pressure, moulding temperature and curing time of 12 MPa, 110 ˚C and 11 minutes respectively gave the optimal performance since it gave better mechanical, tribological and physical properties compared to the other samples.
3) Also, Analysis of Variance (ANOVA) and regression analysis (confirmatory test) results revealed that the percentage errors obtained for individual responses were below 10% which indicates that the experimental procedures were conducted under minima noise effects and the developed regression equations can be adopted for prediction of the properties of the friction linings.

4) The thermogravimetric analysis (TGA) conducted on the optimal samples (sample 7) indicates that the thermal stability of the developed optimal sample compared favourably with the commercial sample and can be applied in a automobile whose braking temperature do not exceed 322.3 oC.

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