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***Journal of Scientific and Engineering Research*, 2024, 11(7):221-228**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Investigation of Thermal Properties and Ash Content of Sawdust-Reinforced Composite Brake Pads

Ajibola, K.A[1], Olaiya, K.A.[2], Alabi, I.O.[3]

[1]Department of Mechanical Engineering, The Polytechnic Ibadan, Oyo State, Nigeria
[2]Department of Mechatronics Engineering, The Polytechnic Ibadan, Oyo State, Nigeria
[3]Department of Mechanical Engineering, Elizade University Ibara-Mokin, Ondo State, Nigeria
Corresponding author e-mail address: abolanlekafayat@gmail.com

Abstract In various automobile and automotive applications, brake pads are used to prevent motion following each application, resulting in a progressive or immediate vehicle standstill. However, each moment the brake is applied, a significant quantity of heat energy is produced owing to friction, which wears down the pads. The choice of suitable material during pad fabrication determines the ability to lessen the detrimental effects of friction on the pads. However, before making a recommendation, it is necessary to investigate the heat behavior of any brake pad or lining. This paper thus investigated thermal properties and ash contents of three different laboratory developed sawdust reinforced composite brake pads. Samples of sawdust from two distinct sawmills were obtained, including *Tectona grandis* (Teak), *Gmelina arborea* (Gmelina), and *Terminalia superba* (Afara). Local sources were also consulted for the hardener and other reinforcement components. The wood composite brake pads were produced using powder metallurgy, which was modified from methods documented in literature. Differential Thermal Analysis (DTA) revealed that the *T. grandis* composite underwent an endothermic glass transition process, yielding the maximum specific heat capacity of 8.010, followed by *T. superba* at 6.496 and *G. arborea* at 5.196. The sawdust composite brake pads were found to have thermal conductivity values that were 61.6% and 44.05% lower, respectively, than the commercial brake pad and the brake pad made from natural fibers. The heat conductivity of composite pads derived from *T. grandis* was generally higher than that of *G. arborea* and *T. superba*, respectively. The sawdust composites exhibit an increase in thermal diffusivity and thermal effusivity from 0.0155 to 0.0245 m^2/s and 0.8562 to 1.3422 $W/m^2.Ks^{1/2}$, respectively. In comparison to commercial and agro-allied brake pads, the sawdust composite brake pads' ash content values were determined to be 69% and 12–40% lower, respectively. In conclusion, considering their achieved ash concentrations and thermal qualities, sawdust reinforced composite pads may be a viable substitute for commercial and natural fiber pads.

Keywords Sawdust-reinforced composite, Brake pads, Thermal conductivity, Ash content

1. Introduction

Brakes are safety devices in automobiles which generally consist of friction lining or brake pad as the essential component (Chand *et al.*, 2004). They have applications in automotive, aerospace and industrial brake systems, thus, serving as the most important part of automobile due to the safety requirements (Arnab and Raji, 2007). They comprise of either pads or lining depending on the design and the required application. The pads or lining are either very soft aggressive materials such as racing application or sometimes, a harder more durable less aggressive compound. Brake pad materials range from asbestos to organic or semi-metallic formulation. Each of these materials has proven to have advantages and disadvantages regarding environmental friendliness, wear, noise and stopping capability. For instance, semi-metallic pads provide strength and conduct heat away from rotor but they generate noise and may be so abrasive to increase rotors wear. Asbestos fibre is no longer popular as a material for brake pad production due to its carcinogenic nature, while some countries have banned the usage of asbestos as constituent of brake pads; others are still working hard on its replacement (Lawal *et al*., 2017). Therefore, it is imperative to seek for an alternative readily available, affordable material that could effectively replace asbestos in performance. However, sawdust is a potential brake pad reinforcement material produced in large quantities in most countries around the globe. It is one of the constituents of wood wastes or residues: leftovers and industrial by-products from sawmilling activities. It has served as substantial raw materials in the manufacturing of particleboard, fiberboard, briquettes (Olorunnisola and Lucas, 2005).

In general, high friction composites are three-member compositions made of friction, anti-wear and reinforcing elements in a matrix of polymeric blends. The phenolic resins or modified phenolic resins with good thermal stability rank among the most popular polymeric systems or thermosets (Natarajan *et al.*, 2012). They frequently mix easily with other materials of composites, allowing for relatively high content usage. When burned, they produce high carbon content and provide heat resistance up to about 250 °C. Phenolic resin will decompose at a temperature of about 450 ºC, while epoxy resin decomposes at 269 ºC (Onyeneke *et al*., 2014). However, phenolic resins have some limitations including inherent brittleness and when heated above 300 ºC, will emit volatile organic compounds (VOCs) (Umamaheswara and Babji, 2015). In addition, due to loss of weight with usage of phenolic resin at high temperature (curing temperature which mostly starts at 150 ºC) phenolic resin is not suitable for friction material (Ruzaidi *et al*., 2011; Umamaheswara and Babji, 2015). Thus, they have been strengthened using tougheners like epoxy resin. Irrespective of the binder used, the standard property requirement must be met. Therefore, it is important to note that any brake pad which is to be put into operation must have the required thermal properties and low ash content in order to reduce or inhibit its degeneration or loss of initial quality but to maintain the life span and ensure safety. Such thermal properties should include; thermal conductivity, specific heat capacity, thermal diffusivity, thermal effusivity and the ash content generated after the facial combustion of the brake pads.

Thermal Diffusivity is used to characterize unstable heat conduction. It is the area of a material covered by thermal energy per unit time. It measures the ability of a material to conduct thermal energy relatively to its ability to store such (withhold). It should be noted that; temperature is an important factor which affects the rate of chemical reaction, and flash temperature from friction induced devices also contributes greatly to the rate of tribo-chemical reaction of a friction material. However, Dante (2016) noted that a high value of thermal diffusivity does not imply that heat is better dissipated from the material since it is the ratio of thermal conductivity to volumetric heat capacity at constant pressure (the product of density and specific heat capacity at constant pressure). In essence, the most efficient friction material is always one that can absorb (dissipate) more heat without increasing temperature since friction generates a lot of heat at the interface that needs to be dissipated. Therefore, the importance of thermal effusivity over diffusivity appears to be greater in the study of thermal properties of friction materials (Dante, 2016). In addition, good brake pads must be capable to removed heat which is generated during braking operation, in order to retain the structural integrity and maintain the coefficient friction.

2. Materials and Methods

2.1 Materials

i. *Tectona grandis* (Teak) sawdust was collected from Bodija sawmill in Ibadan, while *Gmelina arborea* (Gmelina) and *Terminalia superba* (Afara) sawdust samples were collected from the Isopako-Sango sawmill, Sango Ibadan, Oyo.
ii. The carbon black, calcium carbonate, silicon oxide and graphite were procured from Ojota chemical market, Ojota Lagos State.
iii. Plain broken glasses were collected from an Aluminium-Glass frame workshop at Bembo Street, Polytechnic road, Sango, Ibadan, Oyo State. Iron filling was obtained from Agodi Gate spare parts market, Agodi Ibadan, Oyo State, while the resin and the hardener were procured from a chemical sales outlet in Ikeja, Lagos state, Nigeria.

2.2 Methods

Powder metallurgy was employed for the production of the wood composite brake pads as adapted from the procedures of Deepika *et al*., (2013) and Adeyemi *et al*., (2016). The is procedure as described in Ajibola *et al*., 2022.

3. Test and Analysis

3.1 Differential Thermal Analysis (DTA)

1g of each of the brake pads was used for Differential Thermal Analysis (DTA). The machine used was NETZSCH DTA 404 PC. The setup is as shown in Plate 3.1. The sample was ground in a mortar with a pestle to fine grains and placed into the furnace of the machine which was connected to a monitor and a computer that read and interpreted the reading. The heating was left until 400 ºC, the specified temperature for a composite material. The result was printed which gave a graphical representation.

3.2 Thermal Conductivity

The experiment setup shown in Plate 3.2 comprised a well-insulated heating chamber, heating mantle and heat monitoring unit. The experiment started with the preheating of the chamber to the desire temperature. Each of the three samples from the wood composite brake pads (cylindrical in shape with 10 mm thickness and 125 mm diameter) was placed into the heating chamber and allowed to stand for 10 minutes while the data logger already connected to a computer read and interpreted the readings in a graphical form. Equation 3.1 was used to compute the thermal conductivity which is given as;

$$dQ/_{dt} = KA[T_1 - T_2]/_{x} \quad 3.1$$

Plate 3.1: Differential Thermal Analysis (DTA) Setup for the Thermal Properties of the Brake Pads

Plate 3.2: Determination of Thermal Conductivity of the Brake Pad Sample

3.3 Specific Heat Capacity

The specific heat capacity of each of the samples was obtained from the DTA experiment.

3.4 Thermal Diffusivity

The Thermal Diffusivity of each of the samples wascalculated using the values obtained from the thermal conductivity, density and heat capacity in compliance with equation 3.2. This is given as;

$$D = {}^{K}/_{\rho c_p} \quad 3.2$$

Where D is Thermal Diffusivity, K is Thermal Conductivity, ρ is the Density and c_p is the Specific Heat Capacity.

3.5 Thermal Effusivity

The thermal effusivity of each of the samples was also calculated using the values obtained from the thermal conductivity, density and heat capacity in compliance with equation 3.3. This is given as;

$$e = \sqrt{K \rho c_p} \quad 3.3$$

Where e is Thermal Effusivity, K is Thermal Conductivity, ρ is the Density and c_p is the Specific Heat Capacity.

3.6 Ash Content

The ash content was determined by subjecting 2.0 g of each of the samples of the developed brake pads in different porcelain crucible to heating at a temperature of 550 ^{0}C in a Carnivore Muffle Furnace. The beginning of ash formation was noted and preceded for 2 hours 50 minutes when a completely greyish substance was obtained from each of the samples.

The experiment is as shown on Plates 3.3. The calculation is also shown on equation 3.4.

$$\%Ash = (S - X)/M \times 100 \quad 3.4$$

(a) **(b)**

Plate 3.3: Determination of Ash Contents of the Samples of the Brake Pads Before (a) and After (b) Heating

4. Results and Discussion

4.1 Differential Thermal Analysisof the Wood Composite Brake Pads

The Differential Thermal Analysis indicated that there was an endothermic process in which some quantities of heat were absorbed for the glass transition process. *T. grandis* composite has the highest specific heat capacity of 8.010, followed by *T. superba* with a value of 6.496 while *G. arborea*has the lowest value of 5.196. The enthalpy for the process is lowest with *T. grandis* composite with a value of - 1.662, *G. arborea* has the highest value of - 0.6946 and *T. superba* has an enthalpy of -0.7443. The summary of the result is show on Table 4.1 as indicated on the DTA results on Figure 4.1, 4.2 and 4.3.

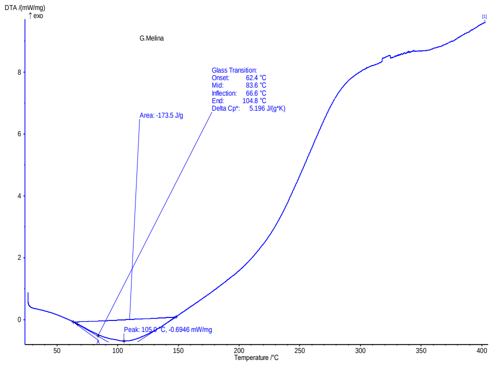

Figure 4.1: DTA of G. arborea Wood Composite Brake Pad.

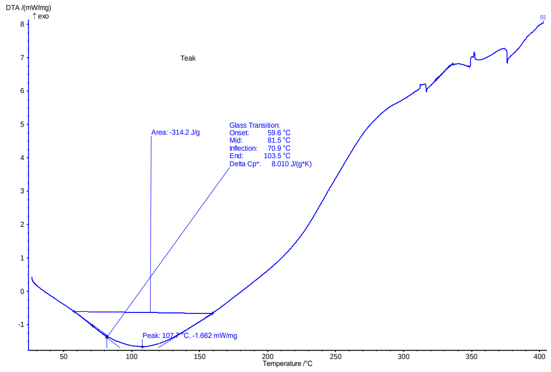

Figure 4.2: DTA Test of T. grandis Wood Composite Brake Pad.

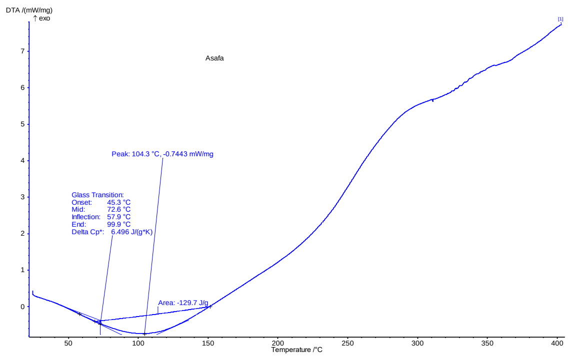

Figure 4.3: DTA of T. superba Wood Composite Brake Pad

Table 4.1: Summary of the Results of Differential Thermal Analysis of Wood Composite Brake Pads

S/No	Properties	*T. grandis*	*G. arborea*	*T. superba*
1	Peak Temp. (ºC)	107.7	105.8	104.3
2	Area (J/g)	- 314.2	- 173.5	129.7
3	Glass transition;			
	Onset (ºC)	59.6	62.4	45.3
4	Mid (ºC)	81.5	83.6	72.6
5	Inflection (ºC)	70.9	66.6	57.9
6	End (ºC)	103.5	104.8	99.9
7	Specific Heat Capacity C_p (J/gK)	8.010	5.196	6.496
8	Specific Enthalpy H (mW/mg) *Endothermic	- 1.662	- 0.6946	-0.7443

4.2 Thermal Conductivity

Thermal conductivity of the sawdust composite brake pads increased from 0.107 to 0.207 W/mK (Figure 4.4). These values are lower than thermal conductivity of commercial brake pad (0.539 W/mK) and 0.24 - 0.37 recorded for brake pads made from natural fibres (Abutu *et al*., 2018). Composites pads made from *T. grandis* generally had higher thermal conductivity than those of *G. arborea* and *T. superba*. Anova revealed no significant differences ($P > 0.05$) among the three sawdust-reenforced composite brake pads investigated (Table 4.2).

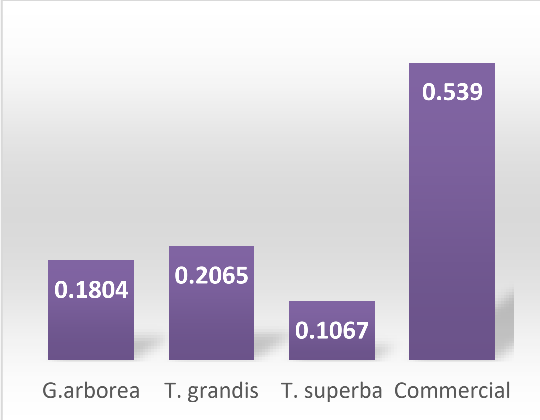

Figure 4.4: Comparison of Thermal conductivity of Sawdust-Reinforced Composite and Commercial Brake Pads.

Table 4.2: Analysis of Variance of Sawdust-Reinforced Composites Brake Pads

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.60534	2	0.80267	1.282146	0.343858	5.143253
Within Groups	3.756218	6	0.626036			
Total	5.361558	8				

4.3 Thermal Diffusivity

Thermal diffusivity of the sawdust composite brake pads increased from 0.0155 to 0.0245 m^2/s, as shown in Figure 4.5. These values could not be compared to other brake pads in literature because thermal diffusivity was not reported for any of the reviewed laboratory formulated and commercial brake pads.

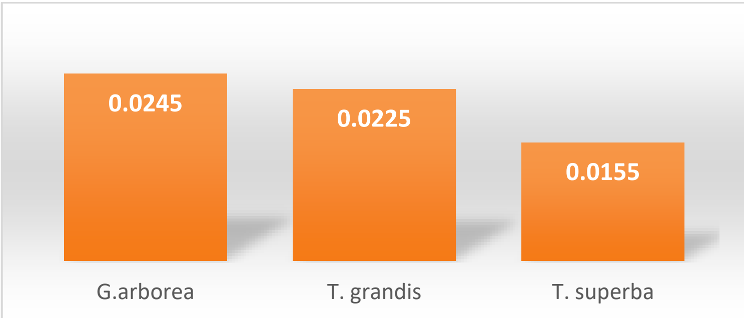

Figure 4.5: Comparison of Thermal Diffusivity of Wood Composite and Commercial Brake Pads

4.4 Thermal Effusivity

Thermal effusivity of the sawdust composite brake pads also increased from 0.8562 to 1.3422 W/ $m^2Ks^{1/2}$ as shown in Figure 4.6. These values could not be compared to other brake pads in literature because thermal effusivity was not reported for any of the reviewed laboratory formulated and commercial brake pads.

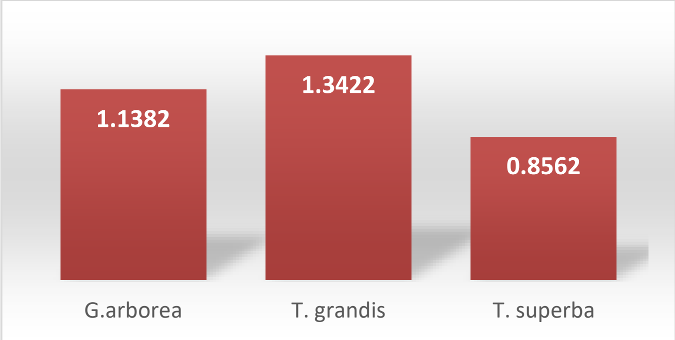

Figure 4.6: Comparison of Thermal Effusivity of Sawdust-Reinforced Composite and Commercial Brake Pads

4.5 Ash content

Ash content of the sawdust composite brake pads increased from 49.13 - 52.62% as shown on Figure 4.7. These values are lower than 69% obtained from commercial but higher than 12 - 40% obtained from other agro waste brake pads. This low ash content compared with the commercial brake pad is an added advantage in terms of reduction of sludge formation (an alkaline compound capable of causing brake fade) on the rotors of the vehicle during brake application. Composites from *T. grandis* had lower ash contents than those of *G. arborea* and *T. superba* but were not significantly ($P > 0.05$) difference among the three wood residues investigated (Table 4.5).

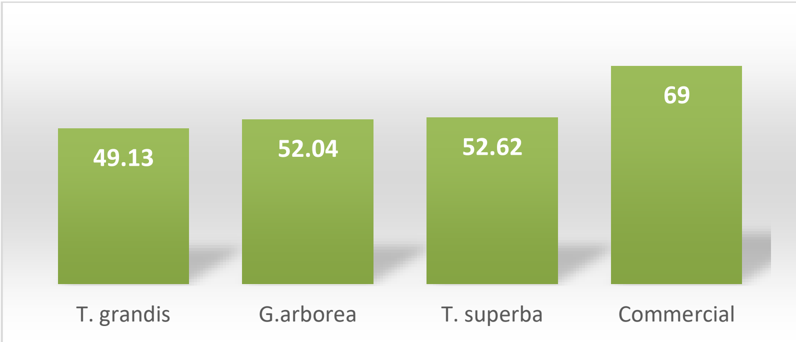

Figure 4.6: Comparison of Ash Content of Sawdust-Reinforced Composite and Commercial Brake Pads.

5. Conclusions

The importance of brake pads in many automobile and automotive applications cannot be underestimated. However, in braking operation substantial amount of heat energy is usually generated due to friction induced on the two mating parts, which later results into wear and tear of the pads. This however necessitates the need to study the heat behavior of any brake pad or lining before recommendation. This paper thus investigated the different thermal properties and ash contents of three different laboratory developed sawdust reinforced composite brake pads. The Differential Thermal Analysis (DTA) showed an endothermic glass transition process with *T. grandis* composite produced the highest specific heat capacity of 8.010, followed by *T. superba*, 6.496 and *G. arborea*, 5.196, respectively. Thermal conductivity values obtained in the sawdust composite brake pads were found to be 61.6% and 44.05% lower than those of the commercial brake pad and brake pads made from natural fibres, respectively. Composites pads made from *T. grandis* generally had higher thermal conductivity than those of *G. arborea* and *T. superba*, respectively. The thermal diffusivity and thermal effusivity of the sawdust composites increases from 0.0155 to 0.0245 m^2/s and 0.8562 to 1.3422 $W/ m^2Ks^{1/2}$, respectively. Anova revealed no significant differences ($P > 0.05$) among the three sawdust-reinforced composite brake pads investigated. Ash content of the sawdust composite brake pads increased from 49.13 - 52.62%. These values were found to be lowered by 69% and 12 - 40% to those obtained from commercial and agro-allied pads, respectively. Conclusively, pads made from sawdust reinforced composites can serve as a possible replacement to the pads made from natural fibres and commercial ones based of their thermal properties and ash contents obtained.

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