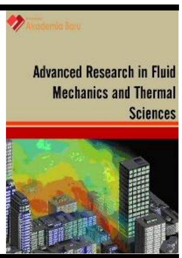
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Feasibility Studies of the Conversion of Agricultural and Metal Wastes into Use as A Brake Pad, A Numerical Approach

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ARTICLE INFO

Article history:
Received 10 January 2020
Received in revised form 20 February 2020
Accepted 20 February 2020
Available online 3 September 2020

Keywords:
Brake fade; Brake pad; Sweet sorghum bagasse; Metal wastes

ABSTRACT

The world's quest to be green in meeting human needs is a task that must be pursued. Plants cultivation results in the generation of waste, which if not properly channeled contributes in no small wall to the production of greenhouse gases, and one with a high tendency of contribution is sweet sorghum bagasse. Also, metallic wastes contribute to environmental pollution, and putting these into meaningful use is a win-win situation. This study seeks to numerically investigate the suitability of these waste in the production of brake pads with the ability to resist brake fade based on the temperature distribution. This was done with the aid of COMSOL Multiphysics 5.0 software and with the use of the rules of mixture for the determination of the mixture properties. A vehicle average mass of 1800 kg at a speed of 136 km/h which is the maximum allowable speed limit on motorways around the globe, which is expected to be brought to rest at the rate of 10 m/s^2 seconds was modelled. At a volume fraction of 0.5 and above, metal-sweet sorghum bagasse brake pads will have the ability to resist brake fade. The use of mild steel as an addition to sweet sorghum bagasse as a brake pad at a volume fraction of 0.5 will not only serve to prevent brake fade but will also be the most cost-effective of the investigated common metal wastes. Wastes can therefore be put into economical use in the production of brake pads.

1. Introduction

Every nation's government has aggressively continued to push for food sustainability with the use of advanced technologies. Not all the cultivated plants' part can be consumed, and studies have shown that about 80% of the yield of cereal crops are the stalk, and even after the extraction of juice from the stalk, the residue is still about 60% of the original weight [1-2]. Portions of the cultivated plants are left as agricultural residues, which are now being increasingly used as biofuels [3-4].

One agricultural waste of particular interest is the sweet sorghum bagasse, a leftover of the stalk after the extraction of its juice. The abundance of bagasse leaves most cultivators at no choice but to

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https://doi.org/10.37934/arfmts.75.1.5867

burn it off to prepare their lands for another planting season and thereby contributing to the much talked about climate change which has remained a daunting task waiting to be solved [5]. Bagasse is now increasingly used in green energy applications [6-7]. Brake fade occurs as a result of overheating in the brake system and can result in a temporary reduction in power or even total loss of function, and it is the work of engineers to prevent this by using materials with good heat dissipating properties [8-9]. The heat transfer characteristics of sweet sorghum bagasse have been investigated, and despite having a low value of thermal conductivity [6] which renders it impossible to use it as a whole because of brake fade, its high fibre content [4] makes it a good potential to be used in combination in parts with good conductors.

Brake pads are consumable materials in automobiles and do the critical task of slowing down and putting the wheels to a halt by friction [9], and their production from waste will make a better judgement economically.

The commonly available metallic wastes are food and beverage cans, bottle crown caps materials which include aluminium and copper; mild steel, iron and aluminium scraps among others from construction sites [11]; steel, aluminium, magnesium, and copper from automobile body wreckages [12].

Traditionally, brake pads are made from friction materials bounded on steel plates, and the high-grade class used in exotic cars because of its high cost are the ceramic composites pads [13]. Brake pads perform their functions by friction with the brake disc which is commonly manufactured from grey cast iron [14-15], because of its resistance to repeated thermal stress [8,16-17]. The potentials of using this commonly available metal wastes and agricultural wastes as brake pad materials can be determined numerically being a suitable alternative to experimental methods [18].

This study seeks to numerically investigate the possibilities of using canned food containers and discarded metallic objects which are found as wastes around us in part with sweet sorghum for the production of affordable brake pads having the ability to resist brake fade.

2. Materials and Methods

Material properties required for the investigation of a no-fade quality brake system include thermal conductivity, specific heat capacity, and density. The different metallic waste that was considered in the course of this investigation is aluminium, copper, mild steel, wrought iron and were used separately in parts with sweet sorghum bagasse having a moisture content of 8.52% to simulate the performance of a brake pad with the capacity to resist fade using COMSOL Multiphysics 5.0 software.

The brake disc material for this study was grey iron because of its high cyclic thermal load resistance, conductivity and affordable cost [15]. Table 1 gives the properties of the investigated materials and the brake disc.

Table 1
Brake system material properties

Material	Thermal conductivity (W/ (m K)	Specific heat capacity (J/ (kg K)	Density (kg/m^3)
Sweet sorghum bagasse	0.0921	3300	227.26
Aluminum	225	921	2,700
Copper	401	376.8	8,700
Mild steel	46	510.8	7,860
Wrought iron	60.4	502.4	7700
Brake disc	82	449	7,870
Air	0.026	1,100	1.17

*Data sourced from [6,19-20]

The following assumptions were made in the simulation of the brake system performance

I. There was no skidding, and all the kinetic energy of the moving vehicle was converted into heat in the brake system
II. Uniform pressure distribution was generated by the brake pad on the disc
III. Drag and other losses were neglected.

The retardation power exerted by the brake is equivalent to the brake's total frictional heat source and can be expressed as

$$P_r = P_{friction} = -m_v V \frac{dV}{dt} \quad (1)$$

The frictional heat source on an individual brake pad for an all-disc brake system fitted standard car is

$$P_p = \frac{P_{friction}}{8} = -\frac{1}{8} m_v V \frac{dV}{dt} \quad (2)$$

The disc rotation is modelled as convection, and the pad and disc relation contact pressure concerning the frictional thermal source per unit area is

$$p = \frac{P_p}{\mu V} \quad (3)$$

The brake disc dimensions used in the simulation studies are stated as in Table 2.

Table 2
The dimension of the brake disc

	Radius (m) x10^{-3}	Thickness (m) x10^{-3}
Wheel bearing	80	10
Rotor	140	13

The impregnation of the sweet sorghum bagasse with the metallic materials will result in changes in their properties, and these were determined using the rules of mixture.

The mixture specific heat capacity [21] was determined using the relation

$$c_{p_{mix}} = \sum_1^z \frac{c_{pj} M_j}{M_j} \quad (4)$$

where $c_{p_{mix}}$ is the mixture specific heat capacity,
c_{pj} is the specific heat capacity of the individual constituents, and
M_j is the mass of the individual constituents.

The density of the mixture was determined with the relation

$$\rho_{mix} = \sum_1^z \rho_j V_{cj} \quad (5)$$

where ρ_{mix} is the mixture density,
ρ_j is the density of the constituents, and
V_{cj} is the volume fraction of the constituents.

The Lewis-Nielsen formula [22] was used to determine the thermal conductivity of the mixtures.

$$k_{mix} = \frac{1+QR\emptyset}{1-R\varphi\emptyset} \quad (6)$$

where $R = \frac{\left(\frac{k_a}{k_b}-1\right)}{\left(\frac{k_a}{k_b}+Q\right)}$,

$$\varphi = 1 + \left(\frac{1-\emptyset_m}{\emptyset^2 m}\right)\emptyset$$

k_{mix} is the mixture thermal conductivity,
k_a is the thermal conductivity of the metal,
k_b is the sweet sorghum bagasse thermal conductivity,
$\emptyset$ is the metal volume fraction, and
$\emptyset_m$ is the maximum filler volume fraction, $\emptyset_m$= 0.52 was chosen for this study based on data from text [23].
Q is the metal particle shape coefficient, for a particle aspect ratio of ten, Q = 4.73 [23].

The obtained properties for different percentage by volume of metal in sweet sorghum bagasse using the rules of a mixture are stated in Table 3.

These properties were used to simulate the temperature distribution in the disc brake system of an automobile of average mass 1800 kg moving at a peak speed of 136 km/h which is the maximum allowable speed limit on motorways around the globe and is expected to be brought to rest at the rate of 10 m/s^2 seconds.

Table 3
Properties of Test Brake Pad Materials

	Percentage by volume in bagasse	Thermal conductivity (W/ (m K)	Specific heat capacity (J/ (kg K)	Density (kg/m^3)

Aluminium	5	1.307	2384.71	350.90
	10	1.668	1946.41	474.53
	20	2.664	1520.22	721.81
	30	4.463	1311.53	969.08
	40	9.092	1187.67	1216.36
	50	57.503	1105.70	1463.63
Copper	5	1.307	1346.39	650.90
	10	1.669	933.22	1074.53
	20	2.666	653.34	1921.81
	30	4.469	544.74	2769.08
	40	9.119	487.02	3616.36
	50	58.515	451.22	4463.63
Mild Steel	5	1.304	1499.76	608.90
	10	1.661	1086.74	990.53
	20	2.644	799.94	1753.81
	30	4.405	687.08	2517.08
	40	8.866	626.74	3280.36
	50	45.965	589.18	4043.63
Wrought Iron	5	1.305	1507.55	600.90
	10	1.663	1088.44	975.53
	20	2.650	797.80	1721.81
	30	4.422	682.65	2469.08
	40	8.933	621.00	3216.36
	50	51.933	582.60	3963.63

3. Results

The addition of the waste metal to sweet sorghum bagasse led to changes in its properties especially the thermal conductivity which is a criterion that governs the ability of the pad to conduct heat away from the contact surface where heat is generated. The temperature distribution plots of the braking system using brake pads from sweet sorghum bagasse and the studied metals; Aluminium, Copper, Mild Steel, and Wrought Iron are depicted in Figure 1-6. Figure 1-6 depicted the maximum temperature attained in the brake system during braking for 5%, 10%, 20%, 30%, 40%, and 50% by volume of the metal part in the brake pad material respectively.

Brake fade sets in at about 600 K, an indication that based on fade, metal-sorghum bagasse brake pads with volume ratio of 0.2 will possibly fade as is depicted in Figure 1-3 respectively, while percentage by volume of 30% and above of the metals can be utilized as depicted in Figure 4-6 respectively for the car conditions investigated. However, another limiting factor is the ignition temperature of bagasse which stands at about 554 K. Hence, to avoid a possible failure in services, the peak braking temperature must be less than 554 K, making the use of percentage volume of metal in the brake pad material mixture of 40% and lesser values unsuitable.

The impregnation of sweet sorghum bagasse with Aluminium resulted in a more pronounced impact on the peak braking temperature for a volume fraction of 0.4 and below, followed by Copper while Mild Steel had the least impact, however, at 50% volume ratio of metal in the mixture, Copper and Wrought Iron showed the greatest impact.

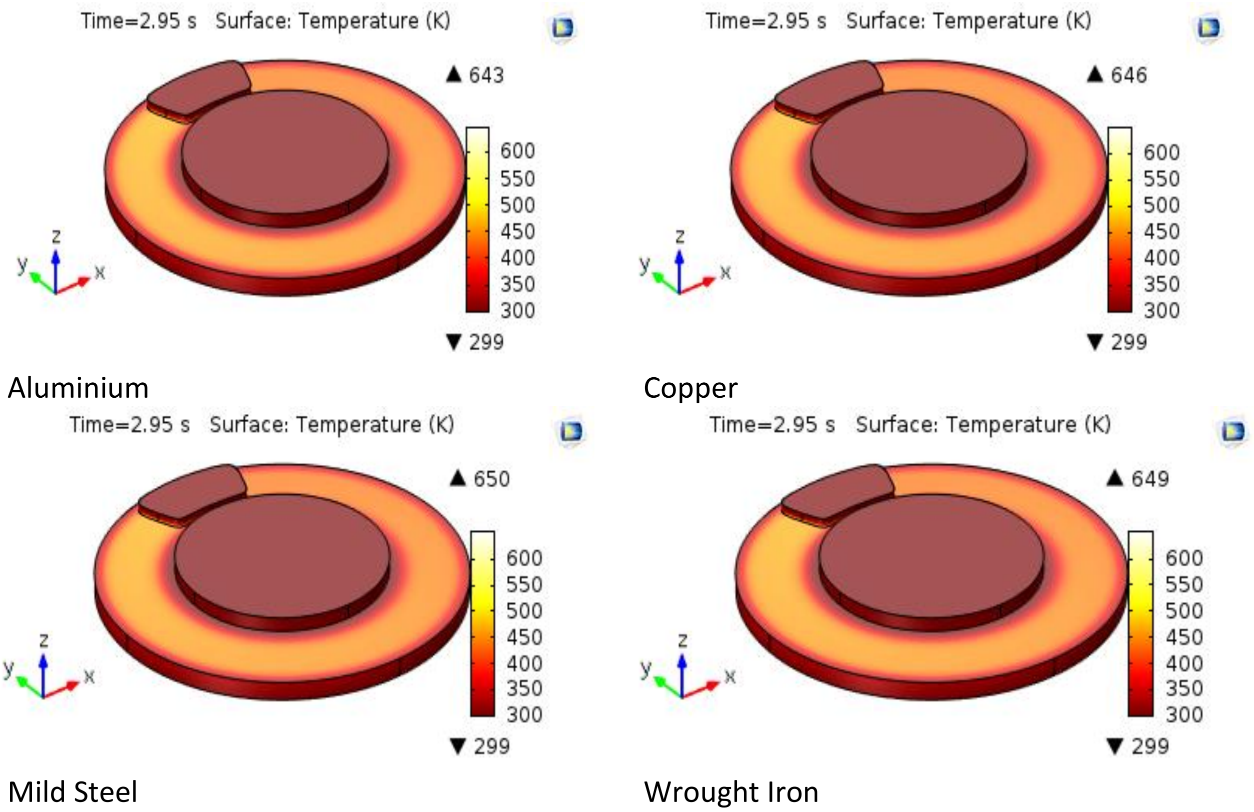

Fig. 1. Temperature distribution for a brake pad with 5% by volume of metal

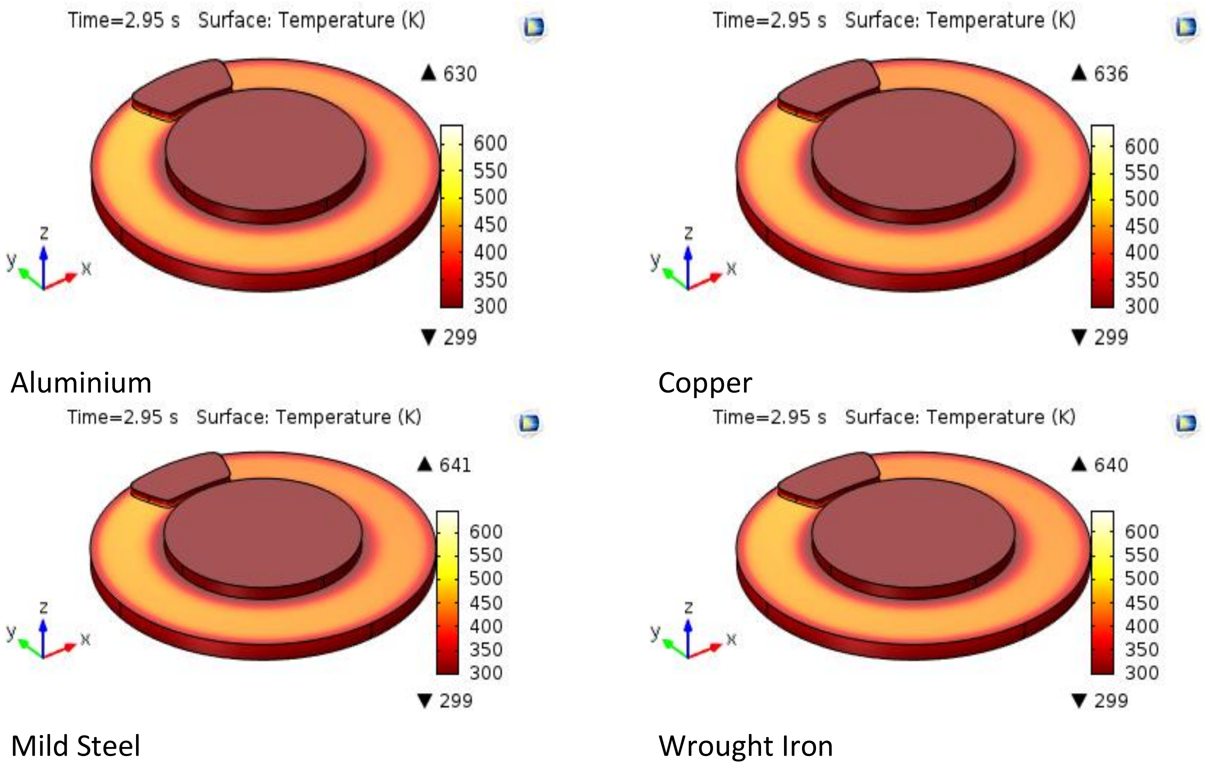

Fig. 2. Temperature distribution for a brake pad with 10% by volume of metal

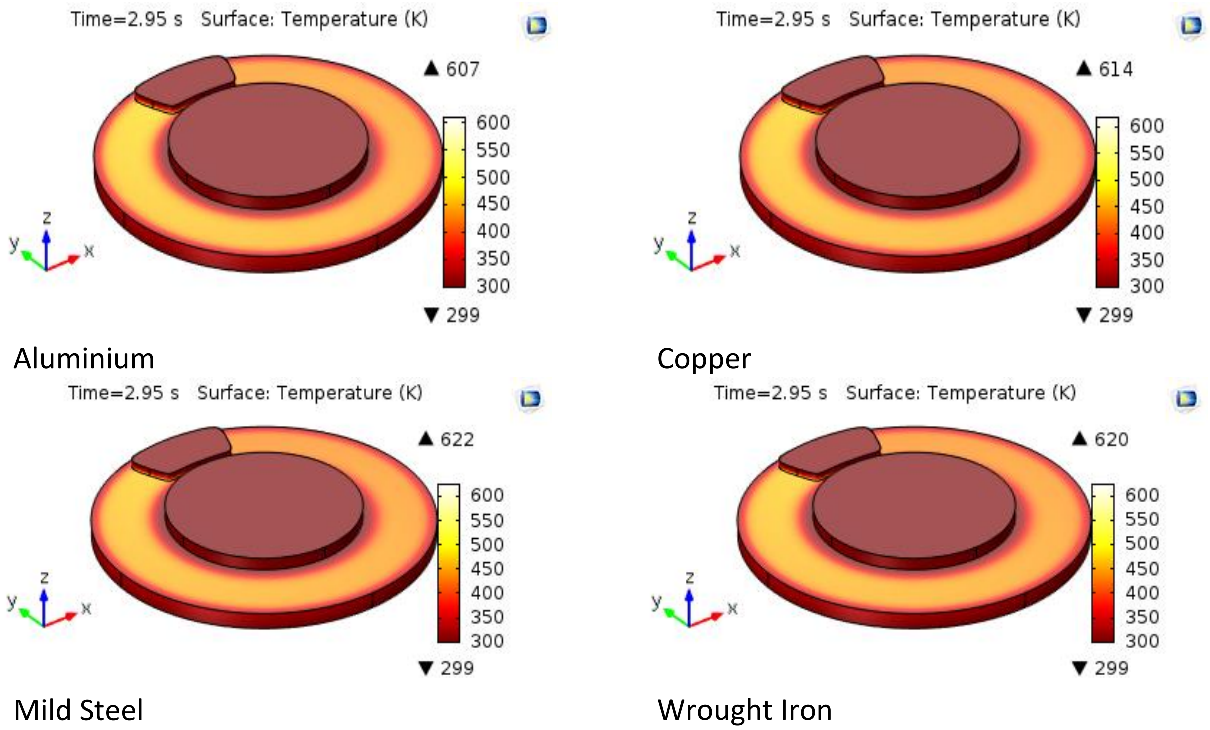

Fig. 3. Temperature distribution for a brake pad with 20% by volume of metal

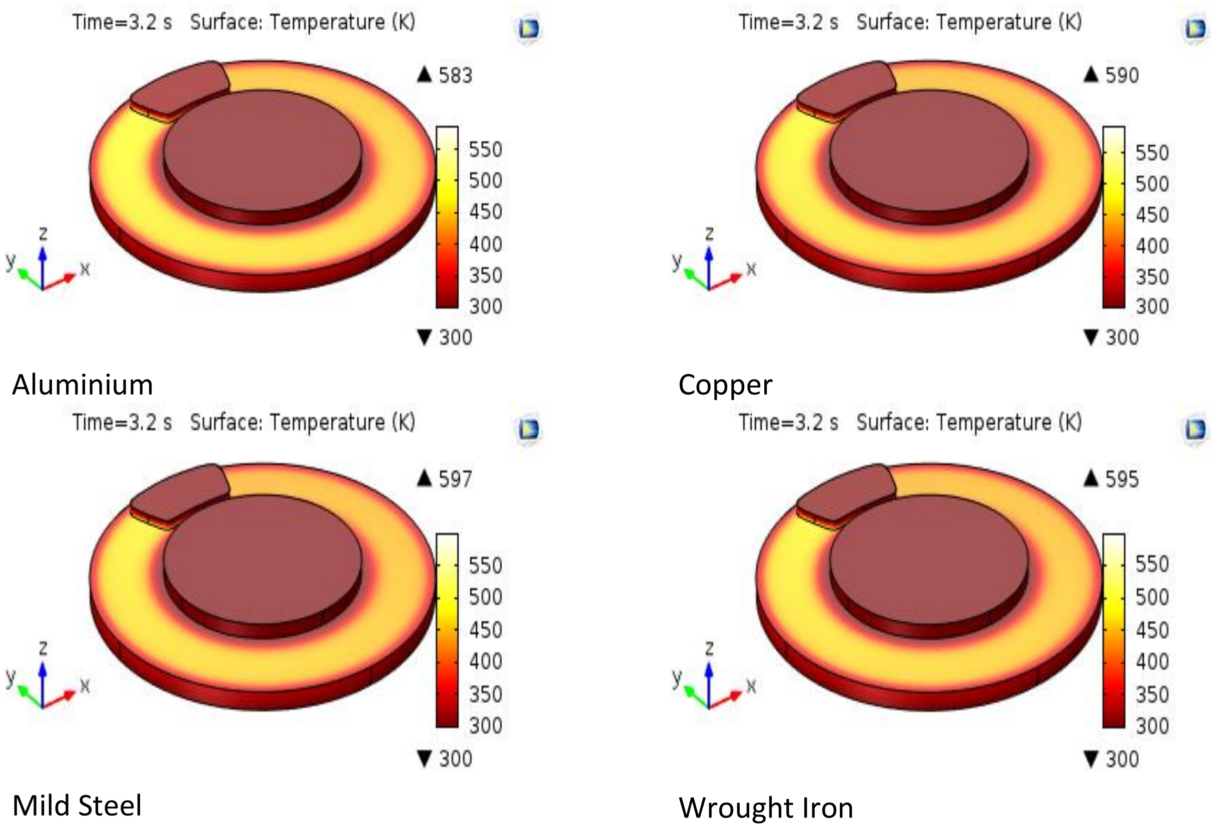

Fig. 4. Temperature distribution for a brake pad with 30% by volume of metal

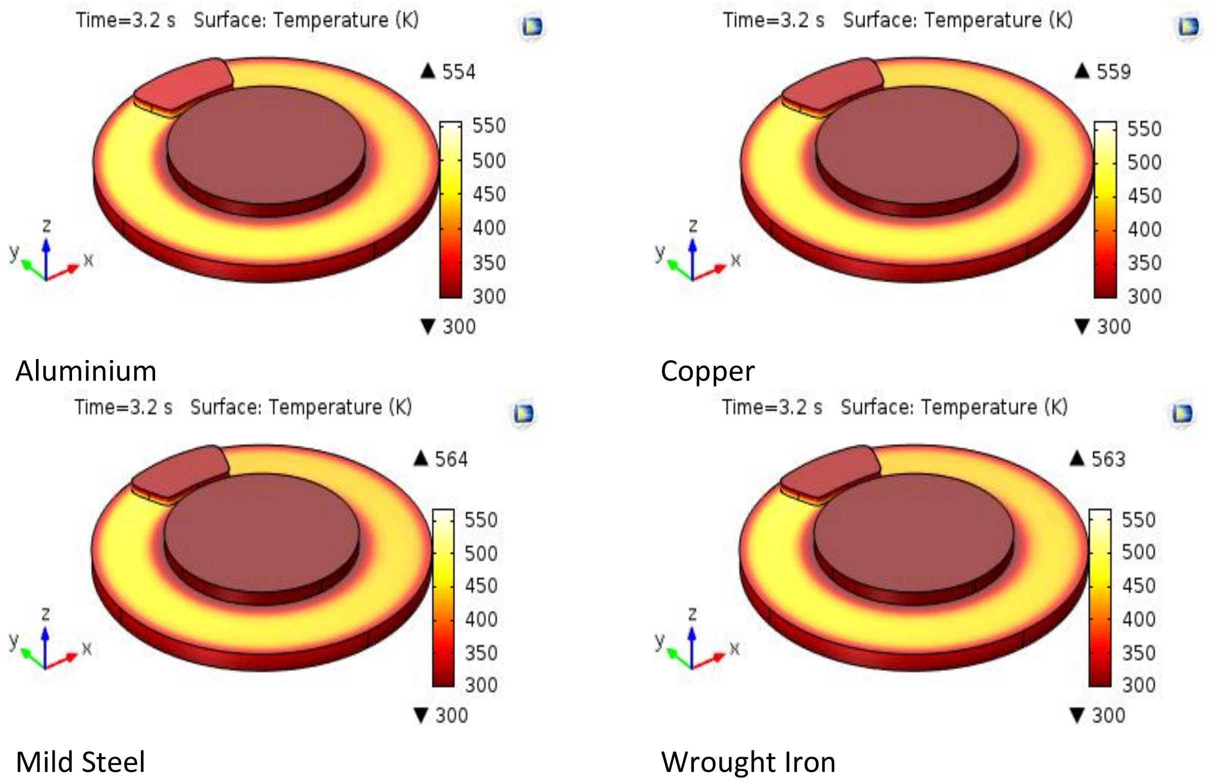

Fig. 5. Temperature distribution for a brake pad with 40% by volume of metal

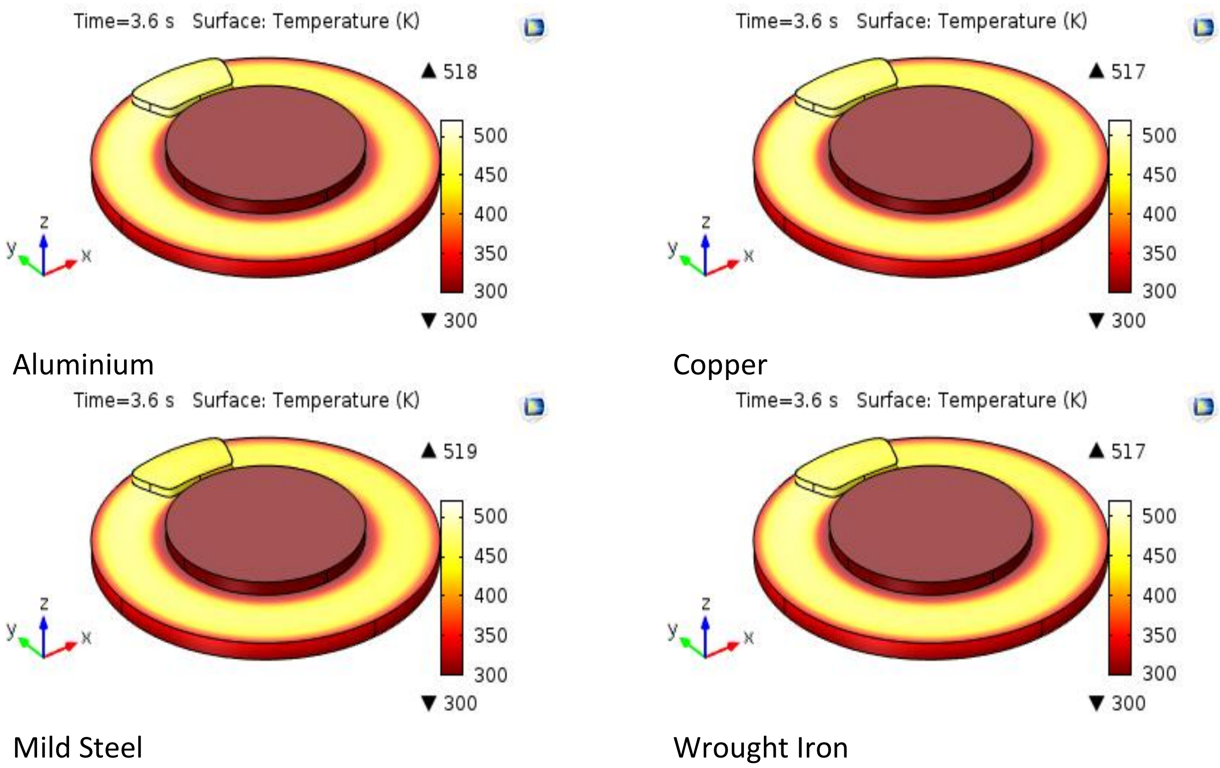

Fig. 6. Temperature distribution for a brake pad with 50% by volume of metal

The increase in the fraction of the waste metals in sweet sorghum bagasse resulted in a decrease in the peak braking temperature as shown in Figure 7, an indication of getting reduced peak temperature values.

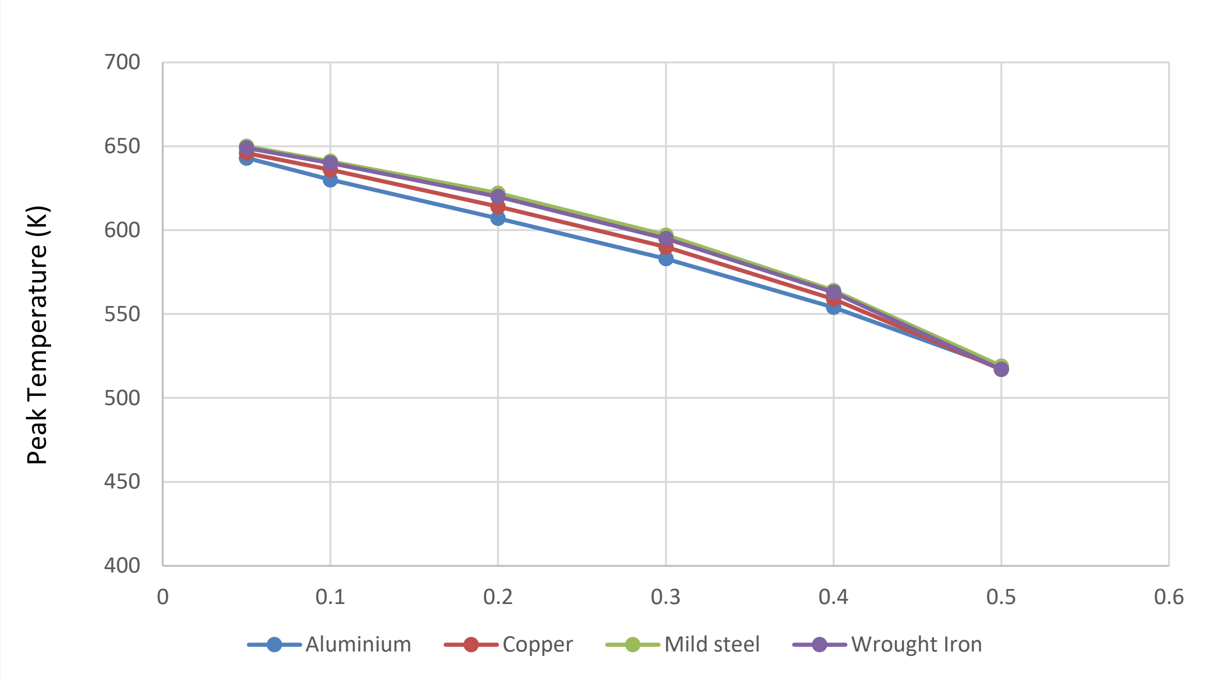

Fig. 7. Peak Temperature values for Metal-Sweet Sorghum bagasse brake pad

At a metal volume fraction of 0.5, the peak temperature values of the investigated waste metals were very close, an indication that any of them could be effectively used, however, the cost of these materials are different, Copper and Wrought iron are very expensive in comparison to the other metals with mild steel being the cheapest.

4. Conclusions

Agricultural and metal wastes can be put into economical use in the production of automobile brake pads with the ability to resist brake fade in service as revealed by this study. Sweet sorghum bagasse was the agricultural waste of choice, while the investigated metals were Aluminium, Copper, Mild Steel and Wrought Iron. The use of sweet sorghum bagasse with Aluminium resulted in a more pronounced impact on the peak braking temperature for a volume ratio of below 40%, followed by Copper while Mild Steel had the least impact, however, at 50% volume ratio of metal in the mixture, Copper and Wrought Iron showed the greatest impact.

For a vehicle of mass 1800 kg moving at a 136 km/h which is expected to be brought to rest at the rate of 10 m/s^2, the commonly found metal waste can be impregnated into sweet sorghum bagasse to produce brake pads that will function without fade for a metal volume fraction of over 0.5.

The use of mild steel as an addition to sweet sorghum bagasse as a brake pad will not only serve to prevent brake fade but will also be the most cost-effective of the investigated common metal wastes.

Acknowledgement
The authors wish to appreciate Covenant University Ota for the payment of the APC.

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