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Design, Modeling and Finite Element Analysis of Brake Pad Materials for Use on Rough and Circular Roads of Ethiopia

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Abstract: Brake pads are a component of disc brakes used in automotive and other applications. Brake pads are plates with friction material bound to the surface that faces the disc brake rotor. This project presents design and modeling of brake Pad using appropriate material locally available materials. While it is recognized that thermal effects are unavoidable during braking they are outside the scope of this project. The dynamic modeling and analysis were developed for a brake pad by using Finite Element method. The finite element analysis is simplified by utilizing the inherent symmetry of a disc brake and applying symmetric boundary conditions. A 3D solid model is created using appropriate SOLID WORK 2016 and imported to ANSYS work bench for structural analysis. Two different locally available brake pad materials were analyzed to predict braking performance and mathematical models have done on; then, observing the results, comparison is done for materials to validate better lining material for brake pad using ANSYS 16. At the end of these a robust brake pad material were designed for use in countries with rough roads like Ethiopia.
Keywords: Finite element analysis, brake pad materials, total deformation.

I. INTRODUCTION

A. Background

Brake pads are a component of disc brakes used in automotive and other applications. Vehicles in Ethiopia; especially those with mid-duty passengers are mostly with problems of braking system. Ethiopia is a country with small number of vehicles but large degree of car accidents comparing with other developed countries [3]. Sustainability of brake pad and other vehicle equipments coming from foreign (i.e carbon, energy, air, water, and transportations) do not considered while sending for African countries. Most of the brake pads manufactured for developed countries in Europe, America, Asia, and Australia, are with a minimum terms of use of a year. But, for developing countries the terms of use of brake pad is to the maximum a single week. These are mostly the cause of braking system that happens due to environmental conditions and driving condition. The roads here in Ethiopia are mostly a rough and with lots of ups and downs beside their infinity of curves. The drivers are changing the brake pad after every 500km journey and expenses a lot for buying the pad every couple of days. Therefore, it is becoming increasingly important for automobile brake pad manufacturers to make brake pads with good friction and wear performance. Control systems and in particular brake discs and their components, are facing very difficult and diverse challenges in Ethiopia nowadays compared to the decades before. These challenges are triggered mainly by international legislation, which is tightening the regulations on trafficking and component part consumptions all around the globe. According to [3], in Ethiopia the accident emissions have been increased consecutively by 10% from 2009 to 2016. We can see, in the figure1 below; the trends in average accidents happening due to mid-duty passengers vehicles over the past decade.

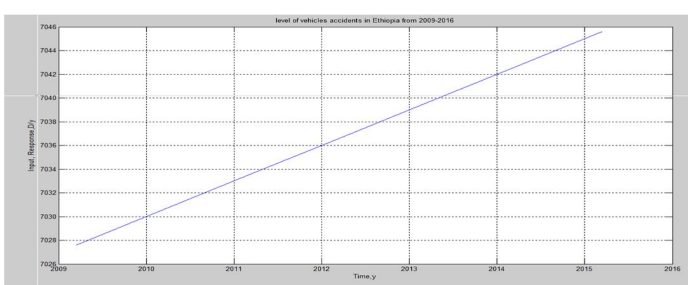


Figure 1: average emissions of car accidents for period 2005-2016 (Source; Ethiopia North Shoa transport office, report on June 2016)

A moving vehicle possesses an amount of kinetic energy depending on the weight and speed of the vehicle. The driving condition and environment limits the types of materials to be used for braking system. This energy must be dissipated in order for the vehicle to slow down or stop. Brakes serve to reduce the velocity of a vehicle in this scenario. The focus of this project is on the mechanisms of braking, primarily the physical interaction between the friction components in a disc brake system [1]. Braking torque and contact forces of different brake pad materials under a constant brake pressures are studied in order to analyze this interaction. The goal of this project is to allow for the prediction of pad performance based on intrinsic material properties. While such an approach does not completely study the external influences or sophisticated details of wear and heat dissipation, it will still provide a firm basis and potential starting point for the study of brake pad materials.

B. Function of brake bad

Brake pads convert the kinetic energy of the car to thermal energy by friction. In disc brake applications, there are usually two brake pads per disc rotor as shown in structure in figure 2, held in place and actuated by a caliper affixed to a wheel hub or suspension upright. Although almost all road-going vehicles have only two brake pads per caliper, racing calipers utilize up to six pads, with varying frictional properties in a staggered pattern for optimum performance. Depending on the properties of the material, disc wear rates may vary.

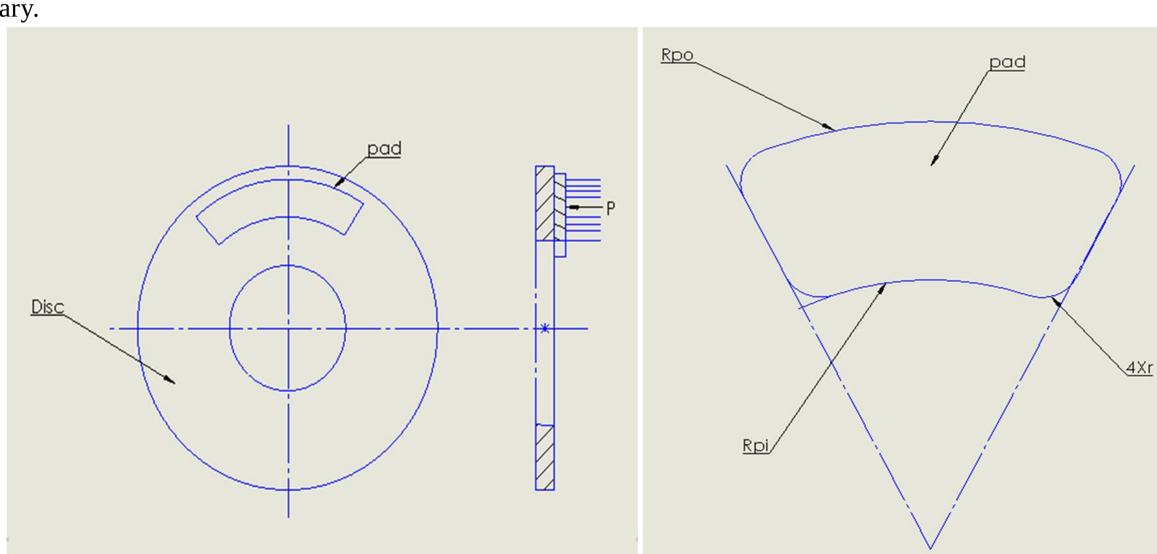


Figure 2: Geometry of disc and pad plates

The brake pads must usually be replaced regularly (depending on pad material), and most are equipped with a method of alerting the driver when this needs to take place. Some are manufactured with a small central groove whose eventual disappearance through wear indicates that the pad is nearing the end of its service life. Others are made with a thin strip of soft metal in a similar position that when exposed through wear causes the brakes to squeal audibly. Still others have a soft metal tab embedded in the pad material that closes an electric circuit and lights a dashboard warning light when the brake pad gets thin. These all happens and causes unexpected accidents regularly in Ethiopia due to driving conditions and environment. These in turn makes the drivers to force the brake regularly. Eventhough there is no well driving conditions in Ethiopia due to rough features on the land escape, manufacturers should identify and develop a better lining materials those with higher coefficient of friction and higher wear rate for brake pads [2].

C. Types Of Brake Pads

There are numerous types of brake pads, depending on the intended use of the vehicle, from very soft and aggressive (such as racing applications) and harder, more durable and less aggressive compounds. Most vehicle manufacturers recommend a specific kind of brake pad for their vehicle, but compounds can be changed (by either buying a different make of pad or upgrading to a performance pad in a manufacturer's range) according to personal tastes and driving styles. Care must always be taken when fitting non-standard brake pads, as operating temperature ranges may vary, such as performance pads not breaking efficiently when cold or standard pads fading under hard driving. In cars that suffer from excessive brake fade, the problem can be minimized by installing better quality and more aggressive brake pads.

D. Selection of Materials

There are environmental factors that govern the selection of brake pad materials. For example, aluminum materials are not allowed to be used for brake pad materials in Ethiopia because of bad surface texture, and rough roads. The import item which is that of copper brake pads nowadays in our country is not satisfying the drivers and customers. So, for its substitution, different material combinations those satisfying the customers and working for a long time with the environmental driving conditions should be developed.

The five most important characteristics that are considered when selecting a brake pad material are as follows:

1) The material's ability to resist brake fade at increased temperatures
2) The effects of water on brake fade (all brakes are designed to withstand at least temporary exposure to water)
3) The ability to recover quickly from either increased temperature or moisture
4) Service life as traded off vs. wear to the rotor
5) The ability of the material to provide smooth, even contact with the rotor or drum (rather than a material that breaks off in chunks or causes pits or dents). (source)

Some of the materials proposed for modeling brake pad of Ethiopia roads are;

E. Fiber re enforced Epoxy Material

Has been mass-produced these Years for use as a course. Grains of Epoxy Materials can be bonded together by sintering to form very hard resisting materials that are widely used in applications requiring high staying power, such as car brakes, car clutches, grinding wheels, in bulletproof vests. When surrounded in composite matrix a composite Fiber re enforced Epoxy Material certainly improves the overall strength of the composite also it improves deterioration and wear resistance.

F. Gray Cast Iron As Friction Material

Gray iron, or grey cast iron, is a type of cast iron that has a graphitic microstructure. It is named after the gray color of the fracture it forms as shown on figure 3 below, which is due to the presence of graphite. It is the most common cast iron and the most widely used cast material based on weight. The brake pad disc is generally made from grey cast iron, and/or Asbestos free materials [4,7].This is because grey cast iron has a good wear resistance with high thermal conductivity and the production cost is low compare to other brake disc materials such as A1-MMC (aluminum-metal matrix composite), carbon composites and ceramic based composites [6]. High thermal conductivity of diffusivity of the material is considered advantageous because heat is then allowed to dissipate at higher rate [5]. In this project, BS200 or ASTM G2500 grade grey cast iron is selected as the material for the commercial brake pad.

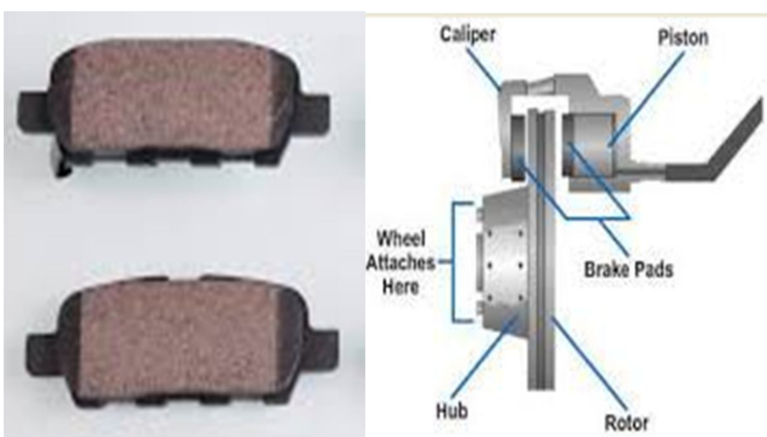


Figure 3:3D view of brake pad

1) Brake Pad specifications: The brake pad model is based on the pad used in most mid duty vehicles.

Torque (T) = 28 N-m @ 5000 rpm

Number of friction surfaces (n) = 9

thickness of pad and area as 10mm and 10,600mm^2 respectively,

and inner diameter of 204mm. and outer diameter of 350mm

2) Theoretical design calculations

GRAY CAST IRON {where maximum permissible stress for Gray Cast Iron [P_{max}=0.69]}

Pressure (p)= (P_{max}* r_i)/r_o (1)

$F_n = \int_{ri}^{ro} pdA$ (2)

$= \int_{ri}^{ro} ((P_{max} * r_i)/r_o * 2\pi\, r\, dr$

$= 2\pi\, P_{max} * r_i\, dr$

$= [2\pi\,(0.69 \times 102) * r_i\,(r_o - r_i)]/r_o$

$= [2\pi\,(0.69 \times 102) * 102\,(175-102)]/175$

= 18806 N

F_n= <u>18.9KN</u>

Area = 10,600 mm^2

Stress=F/A (3)

=18806/10,600

=<u>1.8</u> N/mm^2

Similarly for SILCON CARBIDE {where maximum permissible stress for SiC is [P_{max}= 0.58]}

Fn= <u>15.81KN</u>

Stress =<u>1.5</u> N/mm^2

Table 1: Material properties of selected materials

S.No.	material	Density (Kg/m^3)	Young's Modulus (Mpa)	Poisson's ratio	Tensile strength (Mpa)	Coefficient of friction
1	Fiber re enforced Epoxy	3210	476000	0.19	310	0.4
2	Gray cast iron	7200	120000	0.29	220	0.28

II. ANALYTICAL CALCULATIONS FOR FIBER RE ENFORCED EPOXY MATERIAL

A. Friction Material with Finite Element Method

Rectangular cross-section of the friction material is divided into two CST elements which are in plane stress conditions [9]

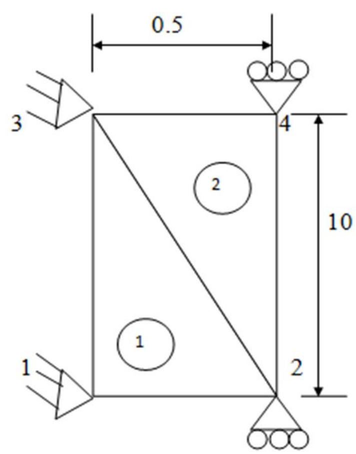


Figure 4: rectangular cross-section of friction material

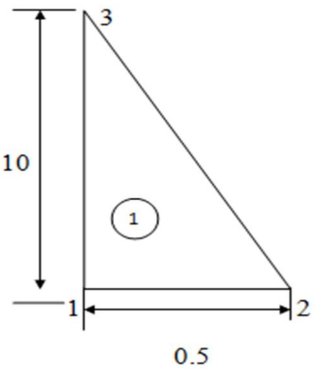
Elements	Nodes		
1	1	2	3
2	2	4	3

E = 476000 MPa

ρ = 3890 Kg/m^3

μ = 4.0
V = 0.19
W = 28Nm/4*36.5 = <u>0.2</u>N

1) Element 1



a) Area Of Triangle

A= $\frac{1}{2}\begin{matrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{matrix}$ Type equation here.

$$A = \frac{1}{2}\begin{matrix} 1 & 0 & 0 \\ 1 & 0.5 & 10 \\ 1 & 0 & 10 \end{matrix}$$

A = 2.5 mm^2

b) Cofactors

C_{12} =-10
C_{22} =10
C_{32} =-10
C_{13} =-0.5
C_{23} =0
C_{33} =-0.5

c) Stress Strain relationship Matrix [D]

$$[D] = \frac{E}{1-V^2}\begin{matrix} 1 & V & 0 \\ V & 1 & 0 \\ 0 & 0 & \frac{1-V}{2} \end{matrix} = 493827 * \begin{matrix} 1 & 0.19 & 0 \\ 0.19 & 1 & 0 \\ 0 & 0 & 0.405 \end{matrix}$$

d) Strain Displacement Relationship Matrix [B]:

$$[B] = \frac{1}{2A}\begin{matrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{matrix}$$

$$[B] = 0.2 * \begin{matrix} -10 & 0 & 10 & 0 & -10 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -10 & 0 & 10 & -10 & -0.5 \end{matrix}$$

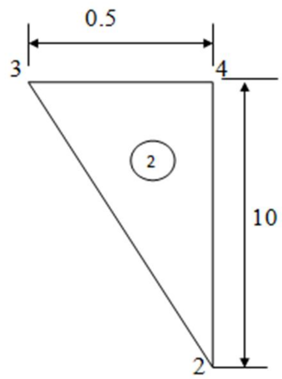
$$[B]^T = 0.2 * \begin{matrix} -10 & 0 & -0.5 \\ 0 & -0.5 & -10 \\ 10 & 0 & 0 \\ 0 & 0 & 10 \\ -10 & 0 & -10 \\ 0 & -0.5 & -0.5 \end{matrix}$$

e) Element Stiffness Matrix $[K]_1$

$[K]_1 = tA[B]^T[D][B] =$

$$[K]_1 = 493827 * \begin{matrix} 100.1125 & 3.2 & -100 & -2.25 & 102.25 & 1.0625 \\ 3.2 & 40.75 & -0.95 & -40.5 & 41.45 & 2.5 \\ -100 & -0.95 & 100 & 0 & -100 & -0.95 \\ -2.25 & -40.5 & 0 & 40.5 & -40.5 & -2.25 \\ 102.25 & 41 & -100 & -40.5 & 140.5 & 2.1 \\ 1.0625 & 2.5 & -0.95 & -2.25 & 2.975 & 0.3625 \end{matrix}$$

2) Element 2



a) Area Of Triangle

A=

$$\frac{1}{2}\begin{matrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{matrix}$$ Type equation here.

$$A = \frac{1}{2}\begin{matrix} 1 & 0.5 & 0 \\ 1 & 0.5 & 10 \\ 1 & 0 & 10 \end{matrix}$$

$A = 7.5mm^2$

b) Cofactors

$C_{12} = 0$

$C_{22} = 10$

$C_{32} = -10$

$C_{13} = -0.5$

$C_{23} = 0.5$

$C_{33} = 0$

c) Stress Strain relationship Matrix [D]

$$[D] = \frac{E}{1-V^2}\begin{matrix} 1 & V & 0 \\ V & 1 & 0 \\ 0 & 0 & \frac{1-V}{2} \end{matrix}$$

$$[D] = 493827 * \begin{matrix} 1 & 0.19 & 0 \\ 0.19 & 1 & 0 \\ 0 & 0 & 0.405 \end{matrix}$$

d) Strain Displacement Relationship Matrix [B]:

$$[B] = \frac{1}{2A}\begin{matrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{matrix}$$

$$[B] = 0.1 * \begin{matrix} 0 & 0 & 10 & 0 & -10 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & 10 & -10 & 0 \end{matrix}$$

$$[B]^T = 0.1 * \begin{matrix} 0 & 0 & -0.5 \\ 0 & -0.5 & 0 \\ 10 & 0 & 0.5 \\ 0 & 0.5 & 10 \\ -10 & 0 & -10 \\ 0 & 0 & 0 \end{matrix}$$

e) Element Stiffness Matrix $[K]_2$

$[K]_2 = tA[B]^T[D][B] =$

$$[K]_{2} = 370370 * \begin{matrix} 100.1125 & 3.2 & -100 & -2.25 & 102.25 & 1.0625 \\ 3.2 & 40.75 & -0.95 & -40.5 & 41.45 & 2.5 \\ -100 & -0.95 & 100 & 0 & -100 & -0.95 \\ -2.25 & -40.5 & 0 & 40.5 & -40.5 & -2.25 \\ 102.25 & 41 & -100 & -40.5 & 140.5 & 2.1 \\ 1.0625 & 2.5 & -0.95 & -2.25 & 2.975 & 0.3625 \end{matrix}$$

f) Global Stiffness Matrix [K]

$$[K] = 864197 * \begin{matrix} 100.11 & 3.2 & -100 & -2.25 & 102.25 & 1.06 & 0 & 0 \\ 3.2 & 40.75 & -1.45 & -35.5 & 36.95 & 2.025 & 0 & 0 \\ -100 & -0.95 & 200.11 & 0 & -100.09 & -3.25 & -2.25 & 0 \\ -2.25 & -40.5 & 0 & 35.75 & -36.95 & -2.05 & 1.45 & 0 \\ 102.25 & 41 & -100.09 & -36.95 & 235.59 & 6.5 & -101.8 & 0 \\ 1.06 & 2.5 & -3.25 & -2.05 & 6.5 & 36.09 & -36.95 & 0 \\ 0 & 0 & -2.25 & 1.45 & 101.8 & -36.95 & 135.5 & 0 \\ 0 & 0 & 0 & -1.45 & 100 & 1.45 & -100 & 0 \end{matrix}$$

g) Displacement Matrix [U]

$$[U] = \begin{matrix} U1x \\ U1y \\ U2x \\ U2y \\ U3x \\ U3y \\ U4x \\ U4y \end{matrix} = \begin{matrix} 0 \\ 0 \\ U2x \\ 0 \\ 0 \\ 0 \\ U4x \\ 0 \end{matrix}$$

h) Force Matrix [F]

$$[F] = \begin{matrix} F1x \\ F1y \\ F2x \\ F2y \\ F3x \\ F3y \\ F4x \\ F4y \end{matrix} = \begin{matrix} 0 \\ 0 \\ 0.2 \\ 0 \\ 0 \\ 0 \\ 0.2 \\ 0 \end{matrix}$$

i) Global equation

[K][U] = [F]

j) Applying Boundary Conditions:

$U_{1x}=U_{1y}=U_{2y}=U_{3x}=U_{3y}=U_{4y}=0$

$F_{1x}=F_{1y}=F_{2y}=F_{3x}=F_{3y}=F_{4y}=0$

$$864197* \begin{matrix} 200.11 & -2.25 \\ -2.25 & 135.5 \end{matrix} \begin{matrix} U2x \\ U4x \end{matrix} = \begin{matrix} 0.2 \\ 0.2 \end{matrix}$$

Then;

$U = \underline{2.1 * 10^{-9}}$ mm

k) Elemental strain $\{ \varepsilon \}_1$

$\{\varepsilon\}_1 = [B]_1[U]$

$$\{\varepsilon\}_1 = (0.2)\begin{bmatrix} -10 & 0 & 10 & 0 & -10 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -10 & 0 & 10 & -10 & -0.5 \end{bmatrix} \begin{Bmatrix} 0 \\ 0 \\ 2.1 * 10-9 \\ 0 \\ 0 \\ 0 \end{Bmatrix}$$

$$\{\varepsilon\}_1 = \begin{Bmatrix} 4.22 * 10^{-9} \\ 0 \\ 0 \end{Bmatrix} \text{mm/mm}$$

l) Elemental strain $\{\varepsilon\}_2$

$\{\varepsilon\}_2 = [B]_2[U]$

$$\{\varepsilon\}_2 = 0.1 * \begin{matrix} 0 & 0 & 10 & 0 & -10 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & -10 & -10 & 0 \end{matrix} \quad \begin{matrix} 0 \\ 0 \\ 2.1 * 10-9 \\ 0 \\ 0 \\ 0 \end{matrix}$$

$$\{\varepsilon\}_2 = \begin{matrix} 2.1 * 10^{-9} \\ 0 \\ 0 \end{matrix} \text{ mm/mm}$$

Then $\{\varepsilon\} = 8.7 * 10^{-9}$ mm/mm

m) Elemental stress $[\sigma]_1$

$[\sigma] = [D]\{\varepsilon\}$

$$[\sigma] = 493827 * \begin{matrix} 1 & 0.19 & 0 \\ 0.19 & 1 & 0 \\ 0 & 0 & 0.405 \end{matrix} \quad \begin{matrix} 8.7 * 10^{-9} \\ 0 \\ 0 \end{matrix}$$

$$[\sigma] = 493827 * \begin{matrix} 8.7 \\ 1.6 \\ 0 \end{matrix} * 10^{-9} = \begin{matrix} 43 \\ 8.3 \\ 0 \end{matrix} * 10^{-9} = \underline{0.044} \text{N/mm}^2$$

III. ANALYTICAL CALCULATIONS FOR GRAY CAST IRON

A. Friction Material with Finite Element Method

Rectangular cross-section of the friction material is divided into two CST elements which are in plane stress conditions [9]

Elements	Nodes		
1	1	2	3
2	2	4	3

E = 120000 MPa

ρ = 7200 Kg/m^3

μ = 0.28

V = 0.29

W = 28Nm/0.28*36.5

= $\underline{2.74}$N

1) Element 1

a) Area of triangle

$$A = \frac{1}{2}\begin{vmatrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{vmatrix} \text{Type equation here.}$$

$$A = \frac{1}{2}\begin{vmatrix} 1 & 0 & 0 \\ 1 & 0.5 & 10 \\ 1 & 0 & 10 \end{vmatrix}$$

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$A = 2.5\ mm^2$

b) Cofactors

C_{12} =-10

C_{22} =10

C_{32} =-10

C_{13} =-0.5

C_{23} =0

C_{33} =-0.5

c) Stress Strain relationship Matrix [D]

$$[D] = \frac{E}{1-V^2}\begin{matrix} 1 & V & 0 \\ V & 1 & 0 \\ 0 & 0 & \frac{1-V}{2} \end{matrix}$$

$$[D] = 131018 * \begin{matrix} 1 & 0.19 & 0 \\ 0.29 & 1 & 0 \\ 0 & 0 & 0.355 \end{matrix}$$

d) Strain Displacement Relationship Matrix [B]

$$[B] = \frac{1}{2A}\begin{matrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{matrix}$$

$$[B] = 0.2 * \begin{matrix} -10 & 0 & 10 & 0 & -10 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -10 & 0 & 10 & -10 & -0.5 \end{matrix}$$

$$[B]^T = 0.2 * \begin{matrix} -10 & 0 & -0.5 \\ 0 & -0.5 & -10 \\ 10 & 0 & 0 \\ 0 & 0 & 10 \\ -10 & 0 & -10 \\ 0 & -0.5 & -0.5 \end{matrix}$$

e) Element Stiffness Matrix $[K]_1$

$[K]_1 = tA[B]^T[D][B] =$

$$[K]_{1=} 131018 * \begin{matrix} 100.09 & 3.25 & -100 & -1.8 & 1001.8 & 1.54 \\ 3.225 & 35.75 & -1.45 & -35.5 & 36.95 & -2.025 \\ -100 & -1.45 & 100 & 0 & -100 & -1.45 \\ -1.8 & -35.5 & 0 & 35.5 & -35.5 & -1.8 \\ 101.8 & 36.95 & -100 & -35.5 & 135.5 & 3.25 \\ 1.54 & 2.05 & -1.45 & -1.8 & 3.25 & 0.34 \end{matrix}$$

2) Element 2

a) Area of triangle

$$A = \frac{1}{2}\begin{matrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{matrix}$$ Type equation here.

$$A = \frac{1}{2}\begin{matrix} 1 & 0.5 & 0 \\ 1 & 0.5 & 10 \\ 1 & 0 & 10 \end{matrix}$$

$A = 7.5mm^2$

b) Cofactors

C_{12} =0

C_{22} =10

C_{32} =-10

C_{13} =-0.5

C_{23} =0.5

C_{33} =0

c) Stress Strain relationship Matrix [D]

$$[D] = \frac{E}{1-V^2}\begin{bmatrix} 1 & V & 0 \\ V & 1 & 0 \\ 0 & 0 & \frac{1-V}{2} \end{bmatrix}$$

$$[D] = 131018 * \begin{bmatrix} 1 & 0.29 & 0 \\ 0.29 & 1 & 0 \\ 0 & 0 & 0.355 \end{bmatrix}$$

d) Strain Displacement Relationship Matrix [B]

$$[B] = \frac{1}{2A}\begin{bmatrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{bmatrix}$$

$$[B] = 0.1 * \begin{bmatrix} 0 & 0 & 10 & 0 & -10 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & 10 & -10 & 0 \end{bmatrix}$$

$$[B]^T = 0.1 * \begin{bmatrix} 0 & 0 & -0.5 \\ 0 & -0.5 & 0 \\ 10 & 0 & 0.5 \\ 0 & 0.5 & 10 \\ -10 & 0 & -10 \\ 0 & 0 & 0 \end{bmatrix}$$

e) Element Stiffness Matrix $[K]_2$

$$[K]_2 = tA[B]^T[D][B] =$$

$$[K]_2 = 98263.5 * \begin{bmatrix} 0.09 & 0 & -0.09 & -1.8 & 1.8 & 0 \\ 0 & 0.25 & -1.45 & -0.25 & 1.45 & 0 \\ -0.09 & -1.45 & 100.09 & 3.25 & -101.8 & 0 \\ -1.8 & -0.25 & -3.25 & 35.75 & -36.95 & 0 \\ 1.8 & 1.45 & -101.8 & -36.95 & 135.5 & 0 \\ 0 & -1.45 & 100 & 1.45 & -100 & 0 \end{bmatrix}$$

f) Global Stiffness Matrix [K]

$$[K] = 229281.5 * \begin{bmatrix} 100.09 & 3.25 & -100 & -1.8 & 101.8 & 1.54 & 0 & 0 \\ 3.225 & 35.75 & -1.45 & -35.5 & 36.95 & 2.025 & 0 & 0 \\ -100 & -1.45 & 100.09 & 0 & -100.09 & -3.25 & 1.8 & 0 \\ -1.8 & -35.5 & 0 & 35.75 & -36.95 & -2.05 & 1.45 & 0 \\ 101.8 & 36.95 & -100.09 & -36.95 & 235.59 & 6.5 & -101.8 & 0 \\ 1.54 & 2.05 & -3.25 & -2.05 & 6.5 & 36.09 & -36.95 & 0 \\ 0 & 0 & 1.8 & 1.45 & 101.8 & -36.95 & 135.5 & 0 \\ 0 & 0 & 0 & -1.45 & 100 & 1.45 & -100 & 0 \end{bmatrix}$$

g) Displacement Matrix [U]

$$[U] = \begin{bmatrix} U1x \\ U1y \\ U2x \\ U2y \\ U3x \\ U3y \\ U4x \\ U4y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ U2x \\ 0 \\ 0 \\ 0 \\ U4x \\ 0 \end{bmatrix}$$

h) Force Matrix [F]

$$[F] = \begin{bmatrix} F1x \\ F1y \\ F2x \\ F2y \\ F3x \\ F3y \\ F4x \\ F4y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 2.74 \\ 0 \\ 0 \\ 0 \\ 2.74 \\ 0 \end{bmatrix}$$

i) Global equation

[K][U] = [F]

j) Applying Boundary Conditions

$U_{1x}=U_{1y}=U_{2y}=U_{3x}=U_{3y}=U_{4y}=0$

$F_{1x}=F_{1y}=F_{2y}=F_{3x}=F_{3y}=F_{4y}=0$

$$\begin{matrix} 100.09 & 1.8 \\ 1.8 & 135.5 \end{matrix} \begin{matrix} U2x \\ U4x \end{matrix} = \begin{matrix} 1.2 * 10^{-5} \\ 1.2 * 10^{-5} \end{matrix}$$

Then;

$U2x = 1.18 * 10^{-7}$ & $U4x = 8.72 * 10^{-8}$

$U = U_x^2 + U_y^2 + U_z^2 =$ $\underline{\mathbf{1.47 * 10^{-7}}}$ mm

k) Elemental strain { ε }₁

$\{ \boldsymbol{\varepsilon} \}_1 = [B]_1[U]$

$$\{ \boldsymbol{\varepsilon} \}_1 = (0.2) \left[\begin{matrix} -10 & 0 & 10 & 0 & -10 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -10 & 0 & 10 & -10 & -0.5 \end{matrix} \right] \left\{ \begin{matrix} 0 \\ 0 \\ 1.47 * 10-7 \\ 0 \\ 0 \\ 0 \end{matrix} \right\}$$

$$\{ \boldsymbol{\varepsilon} \}_1 = \left\{ \begin{matrix} 2.94 * 10^{-7} \\ 0 \\ 0 \end{matrix} \right\} \text{mm/mm}$$

l) Elemental strain { ε }₂

$\{ \boldsymbol{\varepsilon} \}_2 = [B]_2[U]$

$$\{ \boldsymbol{\varepsilon} \}_2 = 0.1 * \begin{matrix} 0 & 0 & 20 & 0 & -20 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & -20 & -20 & 0 \end{matrix} \quad \begin{matrix} 0 \\ 0 \\ 1.47 * 10-7 \\ 0 \\ 0 \\ 0 \end{matrix}$$

$$\{ \boldsymbol{\varepsilon} \}_2 = \begin{matrix} 1.47 * 10^{-7} \\ 0 \\ 0 \end{matrix} \text{ mm/mm}$$

Then $\{ \boldsymbol{\varepsilon} \}= 3.28 * 10^{-7}$mm/mm

m) Elemental stress [σ]₁

$[\sigma] = [D] \{ \boldsymbol{\varepsilon} \}$

$$[\sigma] = 131018 * \begin{matrix} 1 & 0.33 & 0 \\ 0.33 & 1 & 0 \\ 0 & 0 & 0.335 \end{matrix} \quad \begin{matrix} 23.28 * 10^{-7} \\ 0 \\ 0 \end{matrix}$$

$$[\sigma] = 131018* \begin{matrix} 3.28 \\ 0.95 \\ 0 \end{matrix} *10^{-7} = \underline{0.045}\text{N/mm}^2$$

B. Material used is GRAY CAST IRON with μ = 0.28, power (P) = 85Kw, and torque capacity of 180.5 Nm at a speed of 4500rpm

R1 and R2 outer and inner radius of friction faces

r1 =35 mm and r2 = 50 mm

n = no of pairs of contact surfaces

n = n1 + n2 – 1

Wheren1 andn2 are no of disc on driving and driven shaft n1 = 1 and n2 = 1; n = 1

by considering uniform wear theory which states that, wear depends upon intensity of pressure P and velocity of rubbing which further depend on R, thus for uniform rate of wear PR = constant.

For uniform wear R = (R1+R2)/2 (1)

Where R = mean radius of friction material

R = (50+35)/2 = 0.0425mm

Torque (T) = μ W R n (2)

Where, μ = coefficient of friction and W = clamping force in N

180.5 = 0.28 *W * 0.0425 * 1

W = 15168 N

Now, from uniform wear theory,

W = 2π x (Pmax * r1) x (r2 – r1) (3)

Where, Pmax= maximum pressure between the contacting surfaces

15168 = 2π x (Pmax * 0.035) x (0.05 – 0.035)

Pmax= = 4.6MN/m^2

C. Similarly, for Fiber re enforced Epoxy Material (μ=0.4), power of 85KW, and 180.5 Nm at 4500rpm.

W = 10618 N

Pmax= 322050 N/m^2 = 3.2MN/m^2

The maximum pressure obtained by calculations from results of equations 2&3 are applied on friction plate model of each materials and results are obtained in ANSYS 16 and stress and deformation values are compared for two different materials.

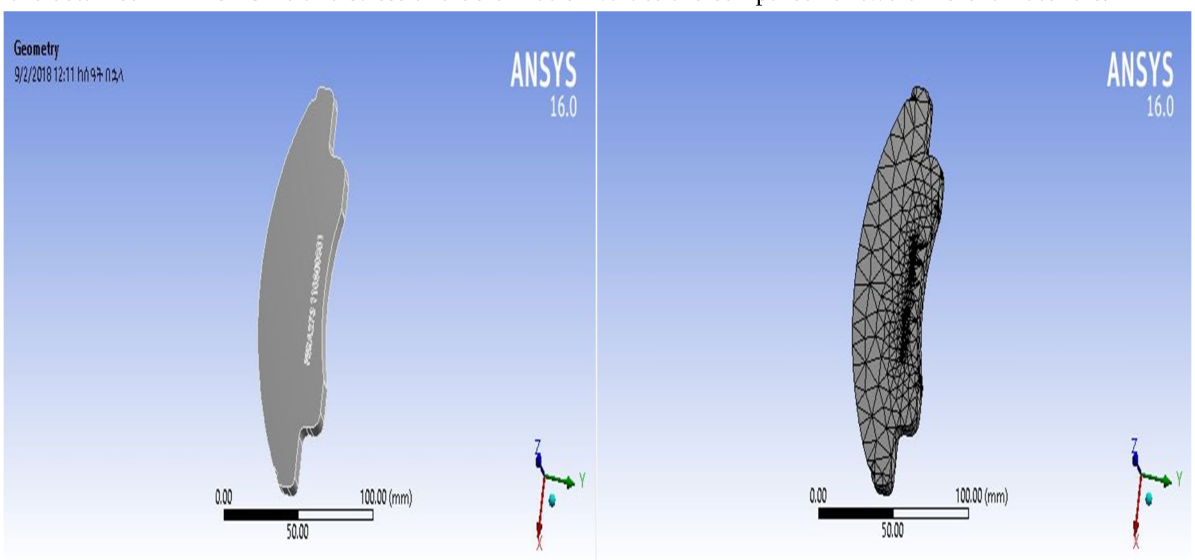

Figure 5: after transporting from solid work and meshing

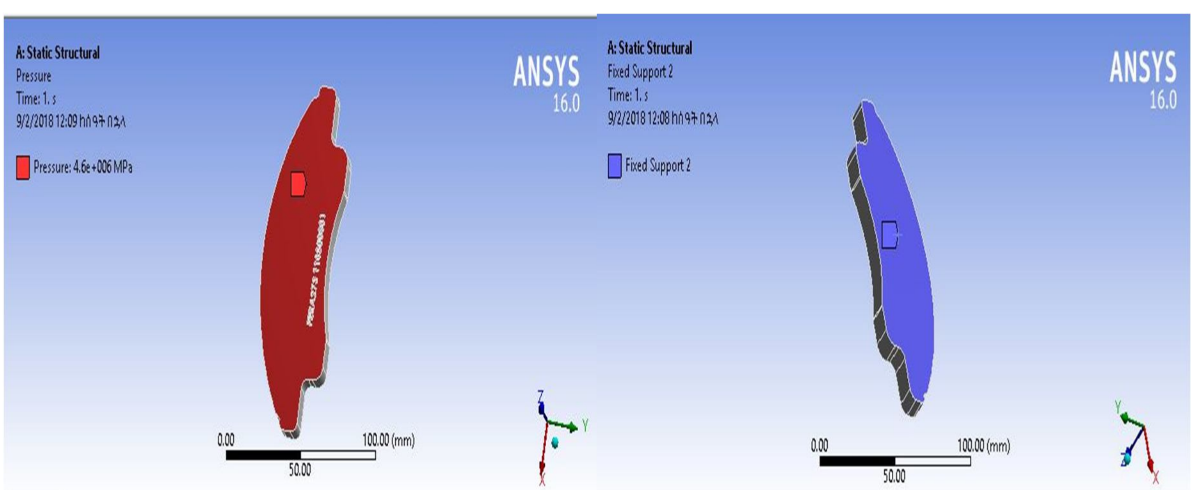

Figure 6: maximum pressure to Gray Cast Iron and a fixed support

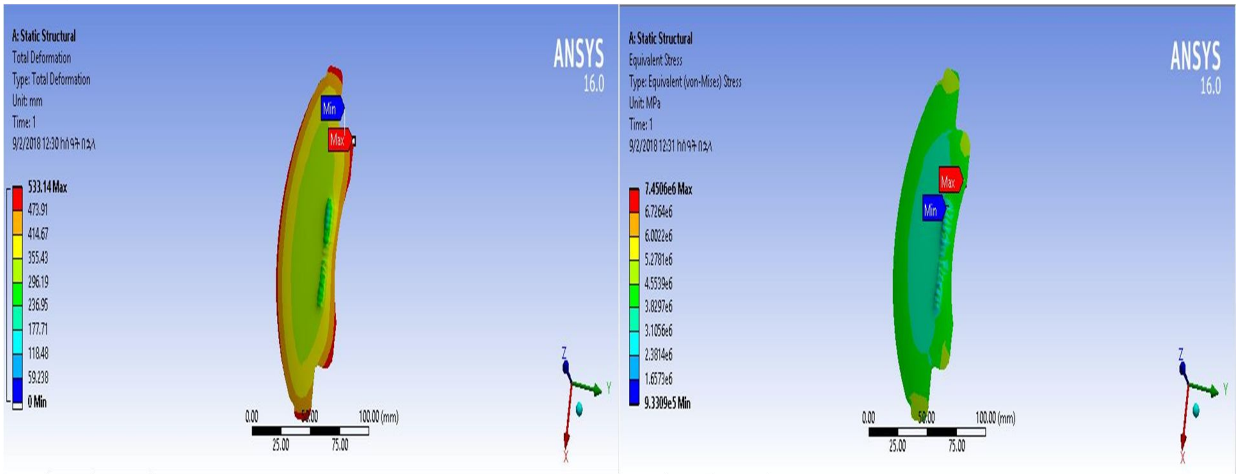

Figure 7: Total deformation and von-misses stress value for Gray Cast Iron

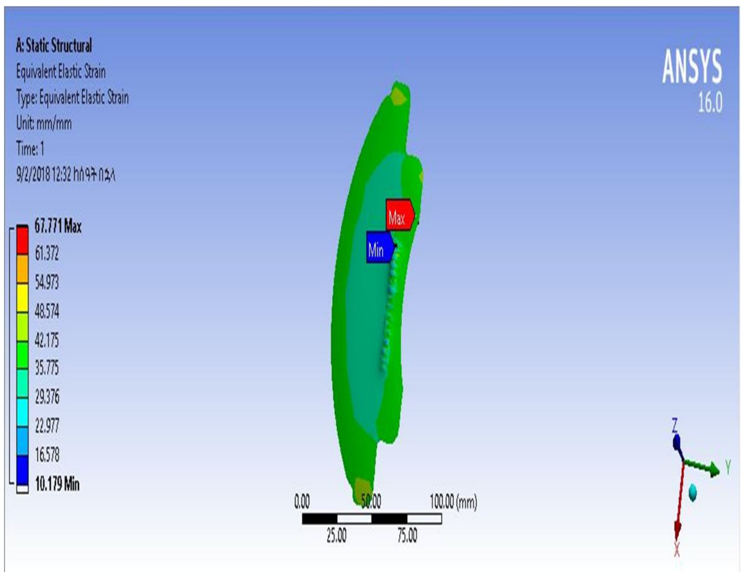

Figure 8 : von-misses strain value for Gray cast Iron

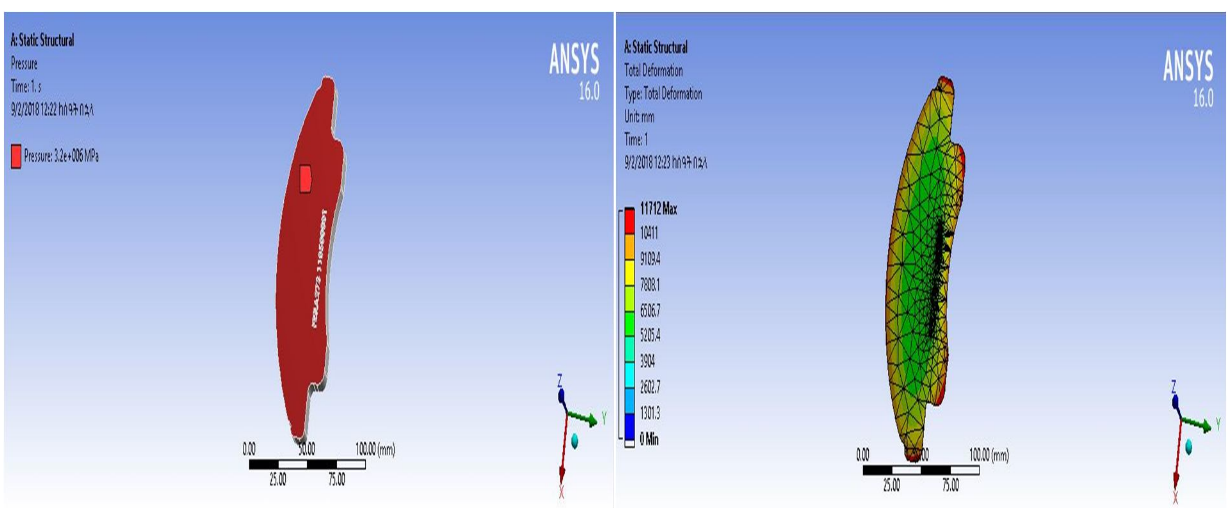

Figure 9: maximum applied pressure and total deformation value for Fiber Reinforced Epoxy

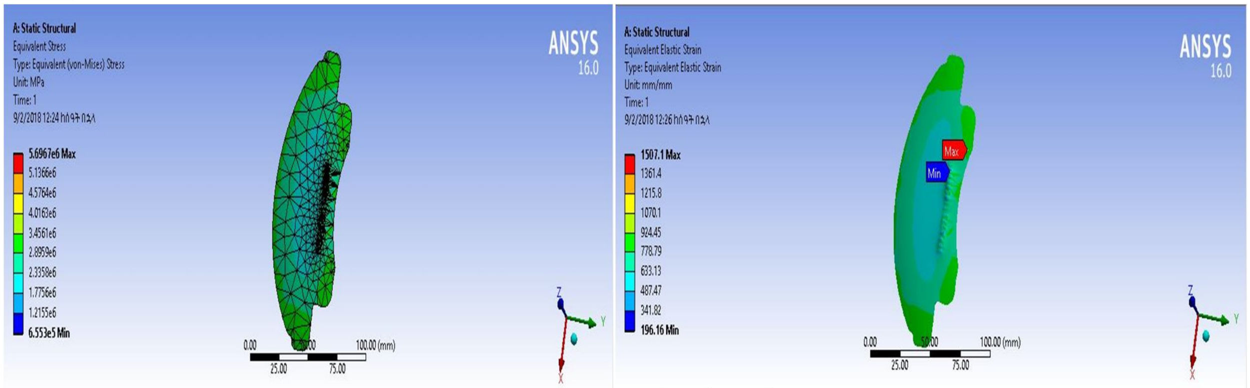

Figure 10: Von-misses stress and strain value for Fiber Reinforced Epoxy

IV. RESULTS

After analysis results have been tabulated below

Table 2 ANSYS and Analytical analysis results

Selected materials	Analysis type	Total deformation (mm)	Equivalent strain (mm/mm)	Stress (N/mm^2)
Gray Cast Iron	ANSYS result	$0.533 * 10^{-3}$	$0.67 * 10^{-2}$	$1.5 * 10^{-6}$
	Analytical result	$1.47 * 10^{-7}$	$3.28 * 10^{-7}$	0.045
Fiber re enforced Epoxy	ANSYS result	$0.12 * 10^{-5}$	$1.5 * 10^{-3}$	$5.69 * 10^{6}$
	Analytical result	$2.1 * 10^{-9}$	$8.7 * 10^{-9}$	0.0044

V. DISCUSSION

In brake system, friction disc and brake pads plays very important role in controlling the vehicles speed. So the friction material property is very important in brake pad design. By observing the static analysis results from table 2, the analysed stress values of Fiber re enforced Epoxy Material are less than the respective yield stress values of Cast Iron. So using Fiber re enforced Epoxy Material for manufacturing brake pad is safe and more advantageous. Theoretical calculations are also done to determine stresses for two materials. By observing the results, the stress values are less than the respective allowable stress values of Cast Iron. By observing table 2 for Fiber re enforced Epoxy Material results, the stress value is less. It is also clear that Fiber re enforced Epoxy Material is a better friction material than cast iron. It is also observed that total deformation, equivalent strain and equivalent stress of Fiber re enforced Epoxy Materials are in the permissible range for the ideal friction material. Fiber re enforced Epoxy Material has the low total deformation when compared to the conventional cast Iron friction material. Hence, it is concluded that Fiber re enforced Epoxy Material serves as a better friction material than cast Iron and gives better braking performance.

VI. CONCLUSION

In this paper, better material for brake pad to be used for countries with hilly surface texture like Ethiopia, especially for the rural areas with rough roads and harsh environmental condition is selected using FEA and Ansys 16 software. In the country currently used material for brake pad is Asbestos free. In this paper, it is replaced with Fiber re enforced Epoxy Material after comparison. The advantage of using Fiber re enforced Epoxy Material is their strength to weight ratio, hardness and low wear rate. The analysis provided valuable insight on the effect of dry sliding friction between the pad and disc. Based on the analysis herein, the ceramic pad material possesses the greatest braking performance in this study. So it can be concluded that by analytical and theoretical results, Fiber re enforced Epoxy Material is better material for developing a brake pads.

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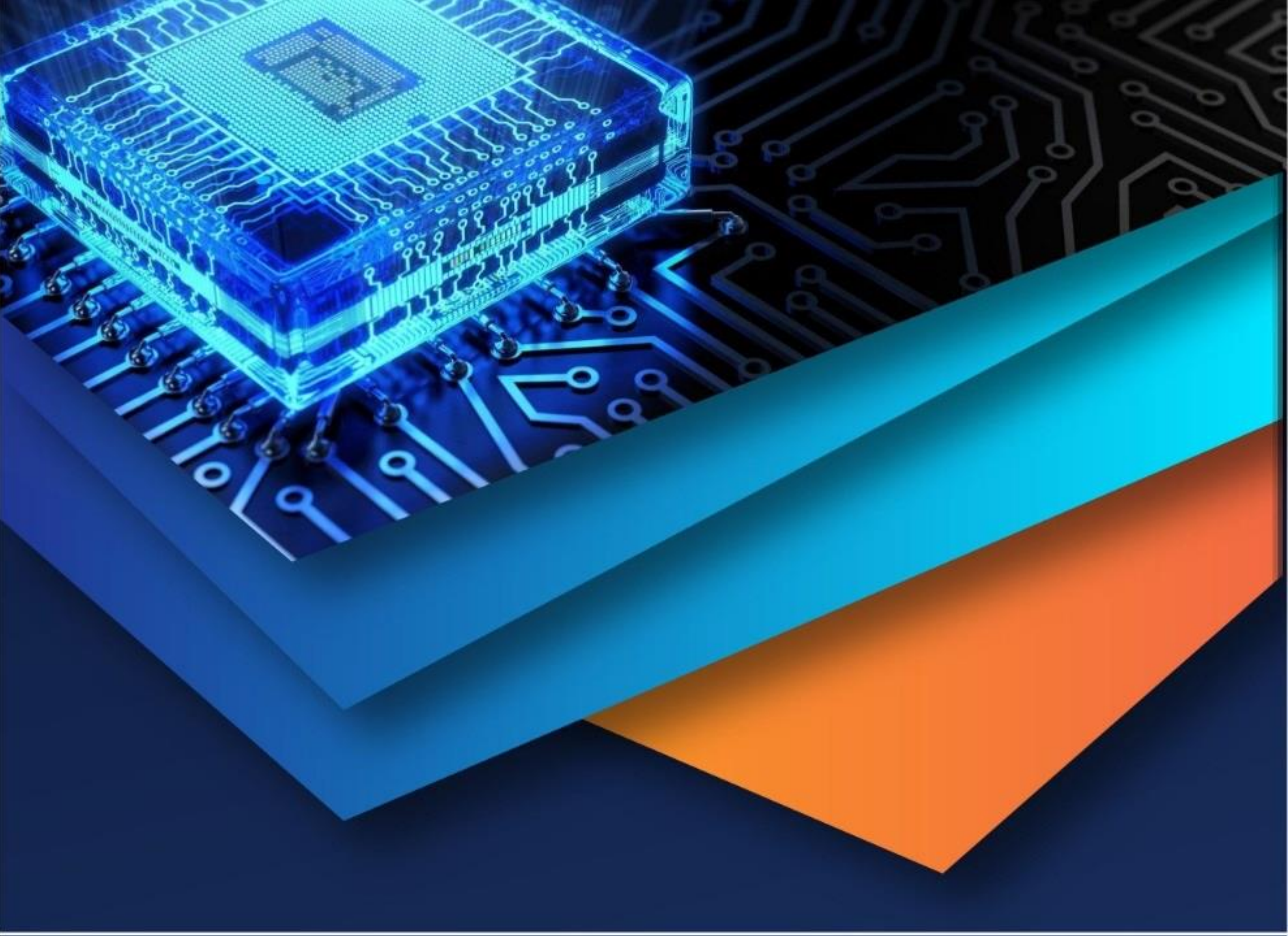
Appendix

Equation for forming average emissions of car accidents

```
y = 2009.2010:2016;
D =3*y + 1000;
plot(y, D)
grid on
xlabel('Time,y')
ylabel('Input, Response,D/y')
title('level of vehicles accidents in Ethiopia from 2009-2016')
gtext('output')
gtext('Input')
```

10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

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