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Comparison of fatigue sensitivity of Ceramic brake pad, Aluminum alloy brake pad and Kevlar brake pad with interface of aluminum metal matrix composite (Al-MMC) brake disc by ANSYS software

Oliyadi Dereje[1#*], Daniel Tilahun [2] and Muluken Maseresha[3]
[1]P.G. Student at School of Mechanical and Industrial Eng., Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia; [#]Lecturer at Department of Mechanical Eng., Faculty of Eng., Mizan Tepi University, Ethiopia
[2]Assoc. Prof. at Rail way Eng. Center; School of Mech. & Indust. Eng., Addis Ababa Institute of Technology, Addis Ababa University, Ethiopia
[3]PhD student at School of Mech. & Indust. Eng., Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia

Abstract*— The comparison of Kevlar brake pad with Al-MMC brake disc, aluminum alloy brake pad with Al-MMC brake disc and ceramic (Al_2O_3) brake pad with Al-MMC brake disc are to evaluate the best service life of brake pad by reducing the fatigue strength (current load) by ANSYS software analysis. The fatigue sensitivity of the material indicates the fatigue results change as a function of the loading at the critical location on the model. The model of available life of Al-MMC brake disc with interface of Kevlar brake pad, Aluminum alloy brake pad and ceramic (Al_2O_3) brake pad strength if the finite element load was 50% of current load, 75% of current load, and 150% of the current load (alternating stress). The Sensitivity can be found for life, damage and safety factor. Hence from the ANSYS software analysis result the highest minimum service life of brake pad and improved service life of brake pad by reducing load by 50% of current load is the Ceramic (Al_2O_3) brake pad with Al-MMC disc brake. That means when reduce the current load by 50% of current load the minimum available life model is $3.9142x10^{+24}$, that means improves minimum available life of Al-MMC brake disc with interface of ceramic brake pad from $1.53x10^{+17}$ cycle to $3.9142x10^{+24}$ cycles.

***Index Terms*—brake pad, brake disc, ANSYS, life and fatigue.**

I. INTRODUCTION

During braking is applied the arrangement of caliper with brake pads are pushed by hydraulic pressure against disc brake stop the movement of vehicle. Thus, during repeated braking is applied fatigue load is happening. For this kind of investigation, the Toyota Hiace 5L automotive disc brake with corresponding brake pads are taken as a sample; because this kind of automotive are many repeated braking are applied rather than the other due to service in City taxi. The data, dimension and necessary information were taken from this kind of automotive. The statement of problem occurred this kind of study by fatigue load was deformation of brake disc, wear of brake pad and fade of brake pad during repeated braking of automotive. The objective of this paper is to compare predict life span of Ceramic (Al_2O_3) brake pad, Kevlar brake pad and aluminum alloy brake pad with interface of Al-MMC brake disc by ANSYS software. The automotive Friction pad wear reduce with increasing the sintering temperature and pressure. Quality of friction pad is predominately affected by molding pressure. Quality of friction pad has been checked using hardness, density, and its wear resistance. Friction brake pad material of automobiles can have good mechanical property, higher thermal expansion, and tightly packed in water and clearly it should have attractive chemical composition [1]. Reducing the filler content in brake pad of automobile increased hardness, wear rate, tensile strength, compressive strength and thermal conductivity of the composite brake pad, while density, coefficient of friction, water and oil absorption capability got increased with increased maize husks filler content in their composition of brake pad. Maize husks particles are an effective replacement for asbestos in automotive brake pad manufacture [2].The development of asbestos-free

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friction material of brake pads for automotive from agro-waste cocoa beans shells (CBS) as filler element cum other additives was undertaken using powder metallurgy technique. The particulate size of the filler material considered was 300µm and epoxy resin was used as binder. A new asbestos free brake pad was developed using an agro waste material of sawdust along with other ingredients. The filler friction materials of brake pad from sawdust composite showed that the finer and the separate size were better properties **[4]**. To reduce weight of automotive disc brake lots field of studies are going on to conventional materials with the composites. Hence to Aluminum based metal matrix composite (Al-MMC) found to be the best alternative for reducing weight of automotive disc brake **[5]**.

The compressive strength formulation BP3 (with 10 % coconut fiber) exhibited higher strength to withstand the load application and higher ability to hold the compressive force. From the morphological study of the materials, it was found that the coconut fiber well distributed to the matrix and acts as filler in the friction materials **[6]**. Instead of the conventional material of brake pad if we used the composite material of brake pad the cost, weight can be reduced and the life of that brake pad material can be increased in low cost. We can combine the two or more material and from that the one homogenous material can manufactured and that material shows the superior properties of that combined material **[7]**.

II. METHOD AND METHODOLOGY

The method and methodology that used in this study is explained as following. The initial method is reviewing literature and collects data from industries and different private organization that used for study, then writing governing equation and calculate boundary condition. The next method is developing geometry of disc brake and brake bad by solid work software. Next export the assemble model of disc brake with brake pad to ANSYS software. Next finite element method (FEM) that is includes meshing, contact, applying boundary condition, analysis and solution. Next data collection from the ANSYS software result. Finally, plot the graph and interpret the result of fatigue sensitivity of brake pad.

A. Alternative stress of brake pad with brake disc

Fatigue is weakening of the structure caused by applied cyclic loading. The damage appears after a certain number of load cycles at nominal stress level that is usually far below the static tensile strength of the material. Material fatigue is classified into two: Those are high-cycle fatigue and low-cycle fatigue. The high-cycle fatigue is defined as low stress and high number of loading cycle to failure; as well as low-cycle fatigue is defined as high stress and low number of loading cycle to failure **[8], [9], [10].**

$$\sigma_a = \frac{1}{2}(\sigma_{max} - \sigma_{min})$$

Stress amplitude: $\sigma_a = \frac{1}{2}(\sigma_{max} - \sigma_{min})$

Mean stress: $\sigma_m = \frac{1}{2}(\sigma_{max} + \sigma_{min})$

Where: $\sigma_{max} = \sigma_m + \sigma_a$; $\sigma_{min} = \sigma_m - \sigma_a$

The figure 1 shows that Disc brake – brake pad assembled with applied force and constraints.

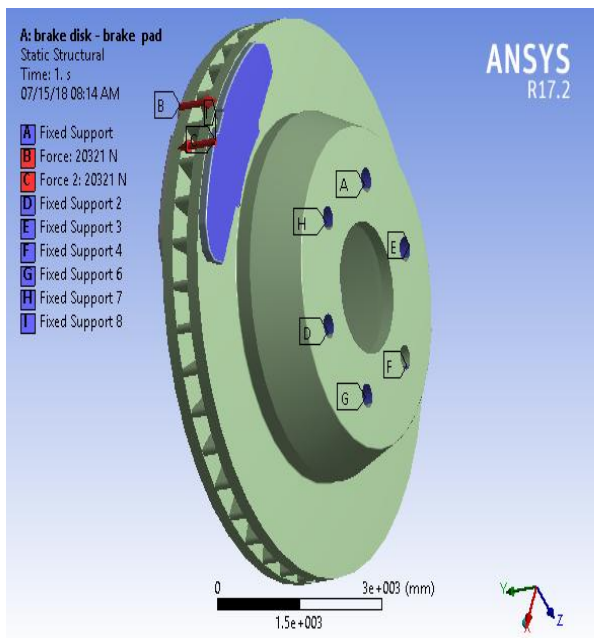

Fig.1: Disc brake – brake pad assembles and force applied with constraints

B. Boundary condition and engineering data aspect

For Fatigue life time estimation, in the cyclic stress- strain and strain life relationships have been introduced with four fatigue properties. Those are:

σ_F' - Fatigue strength coefficient

ε_F' - Fatigue ductility coefficient

b - Fatigue strength exponent

c - Fatigue ductility exponent

$\dot{K}$ - The cycle strength coefficient

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$\dot{n}$ - Cyclic strain hardening exponent

$\sigma_a = \sigma_F'(2N_f)^b$; Where: $\sigma_F' = 1.6\ \sigma_u$

Since, high cycle fatigue is expressed as ($> 10^4$) and low cycle fatigue is expressed as ($<10^4$). Rough estimates of k' and n' can be calculated from the low cycle fatigue properties by using: $k' = \frac{\sigma'_F}{(\varepsilon'_F)^{b/c}}$,

$n' = b/c$

The strain life equation is expressed as;

$$\frac{\Delta\varepsilon}{2} = \varepsilon_a = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\sigma'_F}{2E}(2N_f)^b + \varepsilon'_F(2N_f)^c$$

The stable cyclic stress-strain curve can be represented by the following equation for several metals [**11**].

$$\varepsilon_a = \frac{\Delta\varepsilon}{2} = \frac{\Delta\varepsilon_2}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\Delta\sigma}{2E} + \left(\frac{\Delta\sigma}{2k'}\right)^{1/n'} = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{k'}\right)^{1/n'}$$

Table1: boundary condition for fatigue life analysis

σ'_F (MPa)	ε_F'	k' (MPa)	n'	b	c
772.8	0.5	888.3	0.2	-0.09	-0.5

Table 2: Geometric dimension and other parameters [12].

Item	**Value**
Disk inner radius (mm)	195
Disk outer radius (mm)	295
Pad inner radius (mm)	207.5
Pad outer radius (mm)	282.5
Disk thickness (mm)	24
Cover angle of (θ) of pad	65
Size of pad(L x W x H mm)	75 x 150 x 69
Gross Vehicle Weight (kg)	2,800
Max speed (mph)of Automobile	91
Tire Size	195/70 R15
Effective Radius of Rotor, R_r	122.5
Mass of the disc (kg)	5
Specific Heat(J/kg.K), C_p	800
Acceleration 0-62mph (sec)	22.4

Table 3: Material properties of brake disc (Al-MMC) [13].

S.n	**PROPERTY**	**Al-MMC**
1	Tensile Strength (MPa)	484
2	Yield Strength (MPa)	437
3	Young's Modulus (GPa)	114
4	Poisson's Ratio	0.33
5	Density (gr/cm^{-3})	2.822
6	Thermal Conductivity (W/m.K)	140.2
7	Thermal Expansion Coefficient (C^{-1})	(2.3) x 10^{-5}
8	Specific Heat(J/kg.K)	800

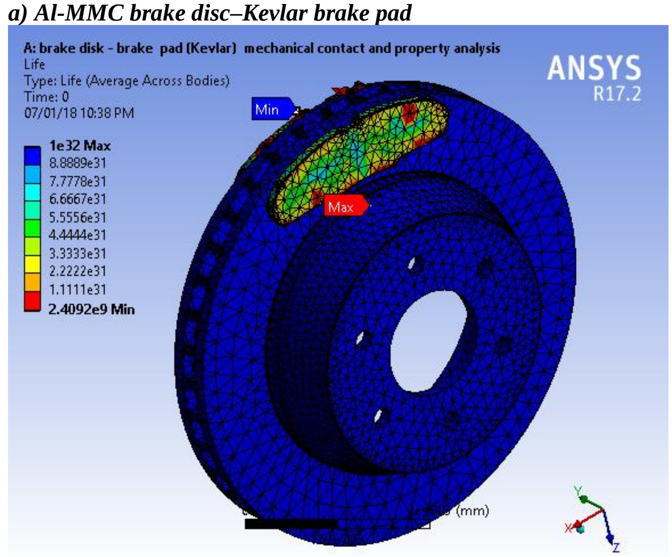
Table 4: Material Properties of brake pads [14].

S.n	**Friction component**	**Mass Density (kg/m^3)**	**Elastic Modulus (GPa)**	**Poisson Ratio**
1	Aluminum Alloy	2700	69	0.33
2	Kevlar	1440	71	0.36
3	Ceramic Al_2O_3	3800	325	0.22

C. Modeling ANSYS workbench

The finite element method is analyzed on ANSYS Workbench 17.2. The project schematic on workbench. The geometrical model of Al-MMC brake disc- Kevlar brake pad, Al-MMC brake disc-aluminum alloy brake pad and Al-MMC brake disc-ceramic brake pad were simulated by ANSYS software with life service of brake pad of automotive corresponding to brake disc. The applied clamping force on the brake pad is 20321N. The number of element generated in the mesh is 74784 nodes and 41847 elements.

a) Al-MMC brake disc–Kevlar brake pad



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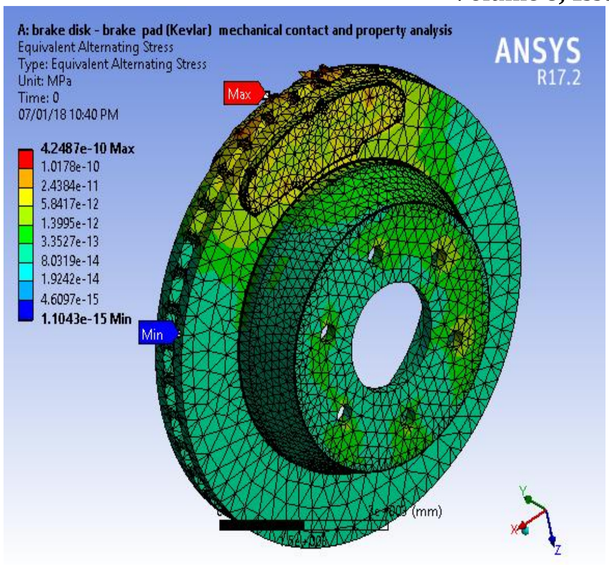
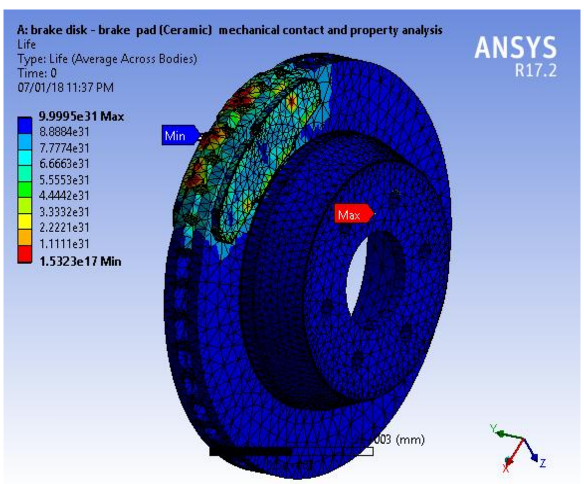
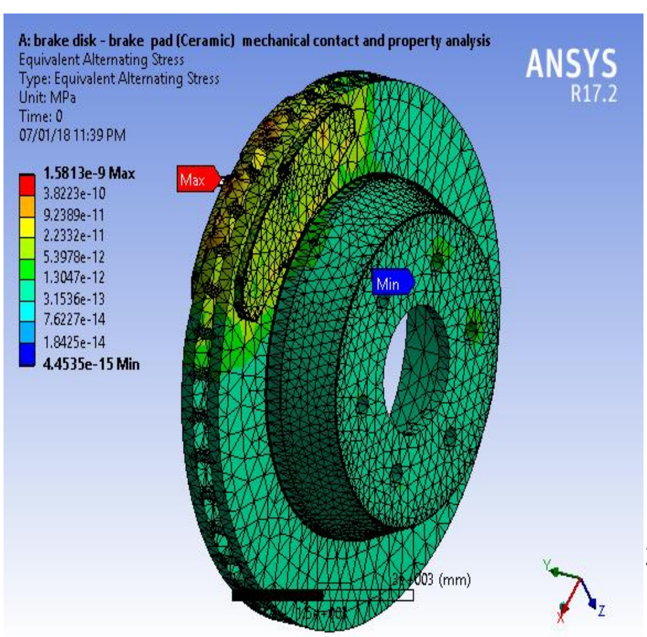
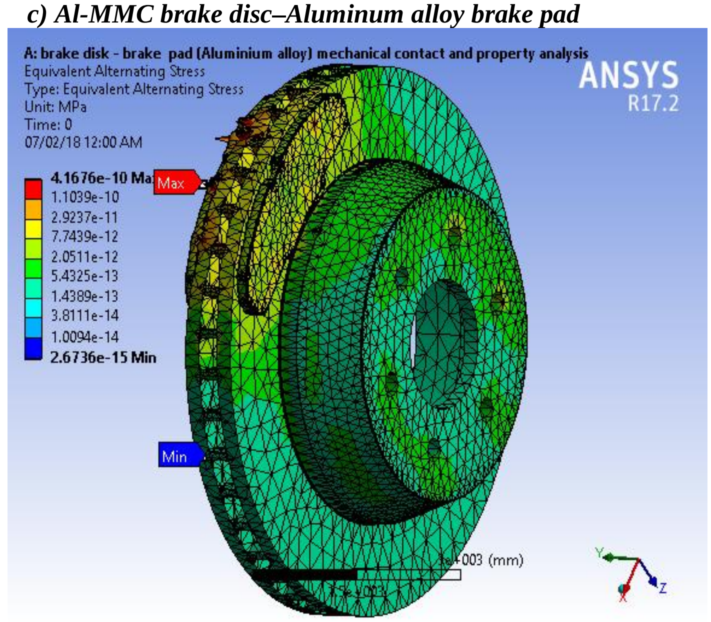


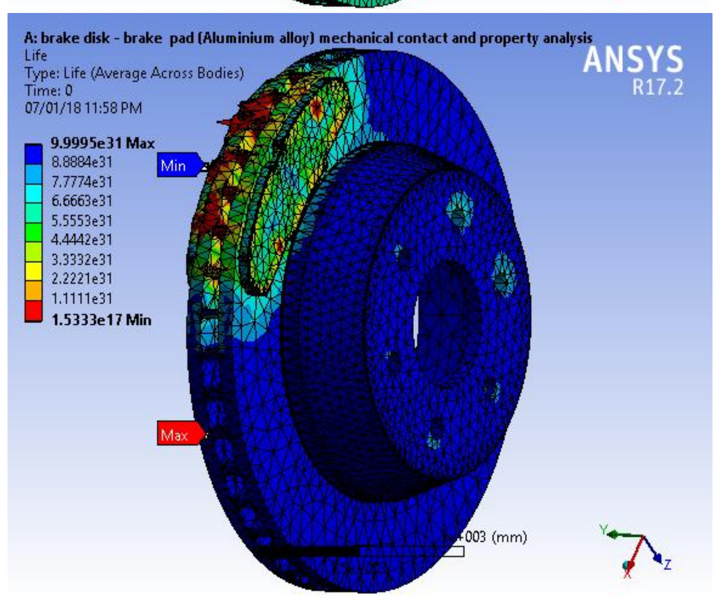
b) Al-MMC brake disc – Ceramic (Al_2O_3) brake pad





c) Al-MMC brake disc–Aluminum alloy brake pad





III. RESULT AND DISCUSSION

1) *Fatigue Sensitivity for available life of Al-MMC brake disc with Kevlar brake pad*

Under this analysis of brake disc with brake pad; the maximum fatigue strength of Kevlar brake pad at 5.80 X 10^{-14} Cycle is 8.50 X 10^{-10} Mpa and the minimum fatigue strength at 1 x 10^{+32} Cycle is 3.81 x 10^{-15}Mpa. and the maximum fatigue strength of Al-MMC brake disc with the interface of Kevlar brake pad at 2.41 X 10^{+9} Cycle is 4.25X 10^{-10} Mpa and the minimum fatigue strength at 1 x 10^{+32} Cycle is1.9 x

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10^{-15} Mpa. The fatigue sensitivity of the material indicates the fatigue results change as a function of the loading at the critical location on the model and model available life of Al-MMC brake disc with interface of Kevlar brake pad service life improved from minimum life of 2.41 X 10^{+9} Cycle load to 4.9079 x10^{+20} by reducing load by 50% of current load.

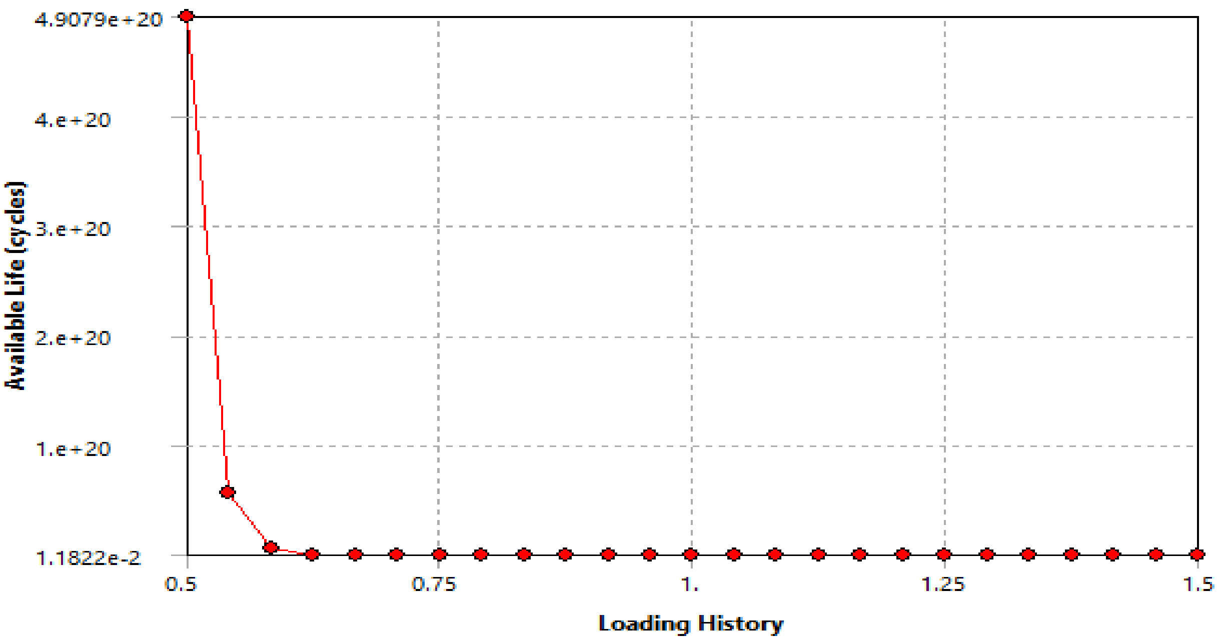

Fig 2: Fatigue sensitivity of Al-MMC brake - disc-ceramic brake pad

2) Fatigue sensitivity of Al-MMC brake disc with aluminum alloy brake pad

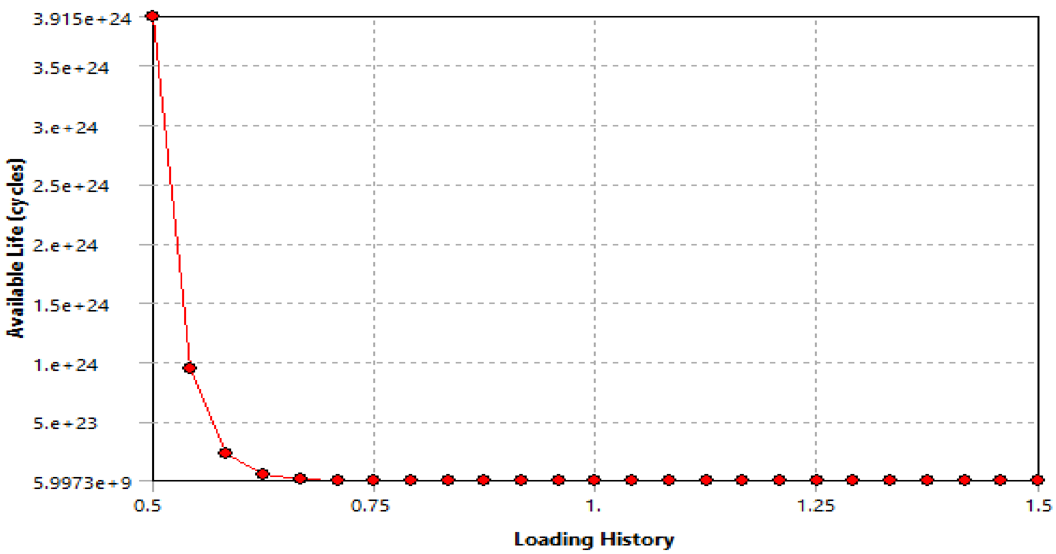

Fig 3: Fatigue sensitivity of Al-M Al-MMC brake disc – aluminum alloy brake pad.

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The number of cycle of the aluminum alloy brake pad material is depend on fatigue strength of the material, thus as fatigue strength of the material is decrease the number of cycle to failure is increase. Under this analysis of brake disc with brake pad; the maximum fatigue strength of aluminum alloy brake pad at 234.8 Cycle is 8.34 X 10^{-10} Mpa and the minimum fatigue strength at 1 x 10^{+32} Cycle is 4.08 x 10^{-15} Mpa. And the maximum fatigue strength of Al-MMC brake disc with interface of aluminum alloy brake pad at 1.53x10^{+17} Cycle is 4.16 X 10^{-10} Mpa and the minimum fatigue strength at 1 x 10^{+32} Cycle is 2.04 x 10^{-15} Mpa. The sensitivity of available life of Al-MMC brake disc with interface of aluminum alloy brake pad by reducing load 50% of current load, improved from minimum life of 1.53x10^{+17} Cycle to 3.915 x10^{+24}cycle.

3) Fatigue sensitivity of Al-MMC brake disc with interface of ceramic brake pad

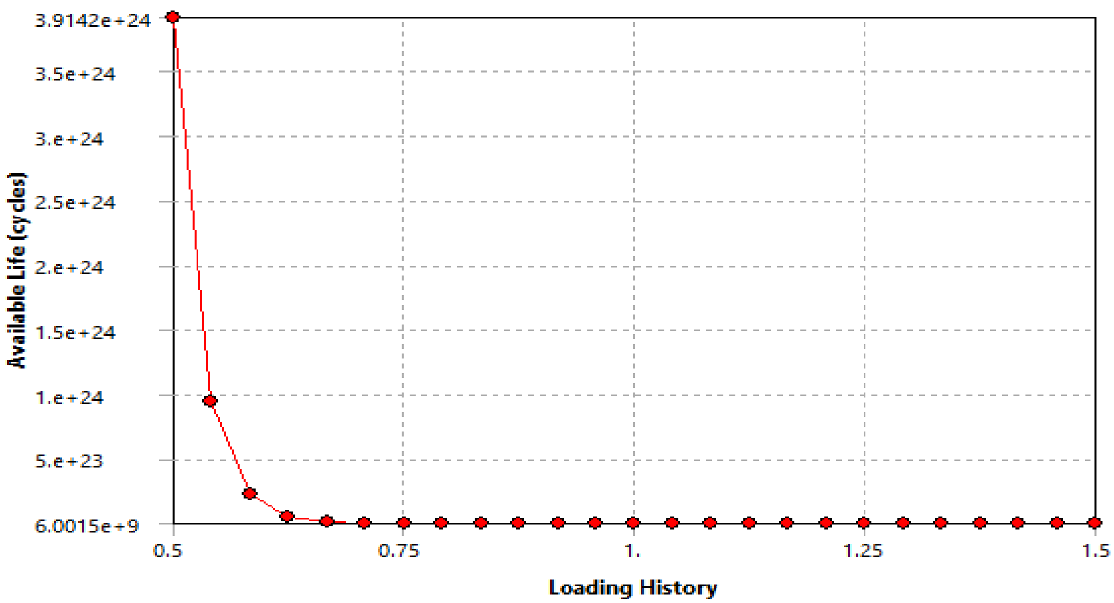

Fig 4: Fatigue sensitivity of Al-MMC brake disc-ceramic brake pad

The maximum fatigue strength of ceramic brake pad at 234.8 Cycle is 3.16x10^{-9} Mpa and the minimum fatigue strength at 1 x 10^{+32} Cycle is 4.2x10^{-15} Mpa. And the maximum fatigue strength of Al-MMC brake disc with interface of ceramic brake pad at 1.53x10^{+17} Cycle is 1.58x10^{-9} Mpa and the minimum fatigue strength at 1 x 10^{+32} Cycle is 2.1x10^{-15} Mpa. Which is implies that as the fatigue strength of the material is decrease, the number of cycle is increase. Model fatigue sensitivity of available life for Al-MMC brake disc with interface of ceramic brake pad if the FE load was 50% of current load, can be increased from minimum life cycle of 1.53x10^{+17} Cycle to 3.9134 x 10^{24} cycle.

IV. CONCLUSION

The service life of brake pad is increase with decreasing fatigue strength, thus among three brake pad model with brake disc the ceramic brake pad has relatively highest lifecycle, that means the life cycle of ceramic brake pad at highest fatigue strength of 3.16x10^{-9} Mpa has the minimum life cycle of 234.8 cycle. And the maximum fatigue strength of Al-MMC brake disc with interface of ceramic brake pad at 1.581x10^{-9} Mpa has 1.53x10^{+17} cycle. In the case of modeling the fatigue sensitivity for available life, the ceramic brake pad interface with Al-MMC brake disc has services long life rather than other brake pad interface when reduce the current load (fatigue strength) by 50%.

V. FUTURE WORK

1. Effect of types of friction material of brake pad composition on brake disc of automotive and environmental pollution.

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2. Wear analysis of automotive brake pad at warm environmental condition.
3. Noise analysis between brake disc and Metallic brake pad of automotive by FEM.
4. Fatigue analysis of brake pad with brake disc of automobiles based on thermal distribution between their interface.

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AUTHOR BIOGRAPHY

Oliyadi Dereje is Graduate from Addis Ababa Institute of Technology (AAiT), Addis Ababa University in School of Mechanical and industrial Engineering by Master of Science in mechanical Design, Ethiopia and Lecturer at Mizan Tepi University in faculty of Engineering, Ethiopia. His Research work is enclosed Analysis of mechanical properties of automotive Disc Brake by Finite element method; for the future achievement, he is planning to work research on Modeling of Seed and fertilizer sowing machine with the help of commercial software in the case of topography of Ethiopia; Design and Developing material the body of light Automotive Cabin; investing Accident happen due to automotive Braking performance and interest to applying his intelligence on automatic recording faulty of driver on automotive dashboard.