IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 6 Issue 9, September 2019
ISSN (Online) 2348 – 7968 | Impact Factor (2019) – 6.248
www.ijiset.com

Finite Element Analysis of Fatigue Life Prediction for Connecting Rod Using Aluminum and Steel Alloy Materials

Alayu Mekonen[1], Bisrat Yosiph (PhD)[2] and Jonathan B. Dawit[3]

[1]Department of Mechanical Engineering, Institute of Technology, Woldia University
Woldia, Ethiopia

[2]Department of Automotive Engineering, Defense University
Bishoftu, Ethiopia

[3] School of Mechanical and Industrial Engineering, Dire Dawa Institute of Technology, Dire Dewa University,
Diredewa, Ethiopia

Abstract

In an IC engine, the most heavily stressed part is connecting rod. Its functionality is connecting crankshaft and piston, which transfer energy from piston to crankshaft and converts linear piston reciprocating motion into crankshaft rotational motion. Under the engine cyclic process, the connecting rod is subjected to tensile and compressive loading. The main forces occurred on the connecting rod are forces due to maximum gas pressure and the inertia of connecting rod plus reciprocating masses. The connecting rod must have maximum stiffness at the minimal weight.

This research work is focused on modeling and analysis of connecting rod stress, deformation, fatigue strength, and life prediction for Toyota Hilux diesel engine made by four candidate materials (aluminum alloy 7068T6, aluminum alloy 7050 T765, carbon steel C-40 and forged steel 4340). The connecting rod model was done by CATIA V5R20 and Numerical prediction of the desired parameters has been evaluated by considering the maximum compressive load and thermal stress using FEM (ANSYS R-19 commercially available software).

According to static FEA the connecting rod made by aluminum alloy 7068T6 maximum stress concentration without thermal effects about 190.97 MPa and with thermal effects 211.87 MPa also, equivalent elastic strain 1.05e-4 mm/mm are less from steel materials. And better due to factor of safety (3.224) and mass reduction about 63.7 %. Fatigue life of connecting rod made of aluminum alloy 7068T6 without temperature effect exhibited infinite life order of 1×10^7 cycles and with temperature effect exhibited about 8.1×10^6 cycles are better to compared with other materials. It has been found that replacing steel made of connecting rod by aluminum alloy 7068T6 made of connecting rod, has better advantages.

Keywords – Connecting Rod, Physical Modelling, FEA, Fatigue Analysis, Life Prediction

1. Introduction

In an internal combustion engine, there is a beam connect the crankshaft and piston. This beam is called a connecting rod. It converts the translation movement of the piston into a rotational movement of the crankshaft [1]. The main parts for connecting rod are revealed in Figure 1.1; crank end, shank section, and pin end. Crank and pin ends are a pin-hole at lower ends and upper ends are machined for accurate fit bearings. The holes which are the lower and upper end holes are parallel each other. So, the upper end or piston pin end is connecting with piston by piston pin. If locked the piston pin in a piston, it will have a bush or solid bearing on the pin end of connecting rod with similar materials [2]. Due to the upper end forced to turn back to crack end and forward to a piston, the crank end will rotate with the crankshaft. These operations have pressure and temperature effects.

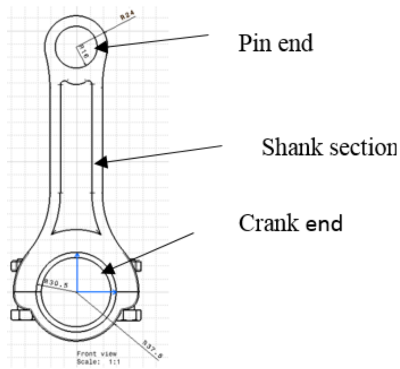


Figure 1.1: Schematic design of connecting rod.

The crank end or big end of connecting rod is split into two parts and clamped around the crankshaft. All parts of connecting rod like a rod, bottom part or cap, and two bolts are made by similar materials. The bearing two parts are positioned in cap and rod by dowel pins, short brass screws, or projections. Split bearings are the precision or semi-precision type. From the viewing platform of functionality, the connecting rods must have lowest weight at maximum possible rigidity [3]. Connecting rod is subjected to millions of tedious cyclic loads and it will fail due to stress induced, crack, bending and fatigue failures conducted in some papers.

Scientists and Engineers are continues studying to identify better material for connecting rods that can resist failure, light in weight and have longer life cycles. Hussin et al. [4] studied Aluminum 7068 T6 as connecting rod materials for Suzuki 150cc-engine automotive. The result showed that Aluminum 7068T6 connecting rod had 11.12×10^3 life cycles, but they didn't include the effect of thermal stress.

This study considers the effect of static and thermal stress on connecting rods that are manufactured from four different materials (Aluminum alloy 7068 T6, Aluminum alloy 7050 T7651, Carbon steel C-40 and Forged steel 4340) for Toyota Hilux 2.5L 2kd engine automotive. The investigation is performed using FEM (ANSYS R-19 commercially available software), to recommend better performance materials that have good fatigue resistance and higher fatigue life with less weight.

2. Materials and methods

2.1. Selection of Materials and Properties

The material selection is depending on the influence factors has to be considered by cost, durability, weight, easy of manufacturing and availability. Different types of materials are used to manufacture the connecting rod. Based on the application of internal combustion engine can select the materials of connecting rod. Some of the materials used to manufacture the connecting rod are cast iron, aluminum alloys, carbon steel, stainless steel, magnesium, and titanium [5]. But, due to specific requirement (higher stiffness, lightweight and availability) the aluminum alloy (7068 T6 and 7050 T7651) used for this study to replace the materials of connecting rod made by carbon steel C-40 and forged steel 4340 materials. The properties of those materials are tabulated in Table 1.

Table 1: Material properties of selected materials for connecting rods

Sn.	Parameters	Carbon steel C-40	Forged steel 4340	Aluminum alloy 7068T6	Aluminum alloy 7050 T7651
1	Ultimate strength (MPa)	620	745	710	550
2	Yield strength (MPa)	415	470	683	490
3	Young's Modulus (GPa)	200	200	73.1	70
4	Poison's ratio	0.33	0.33	0.33	0.33
5	Density (kg/m^3)	7850	7850	2850	2850
6	Thermal conductivity (W/m. K)	48	44.5	190	153
7	Melting point (℃)	400-1420	427-1427	476-635	488-629.4
8	Specific heat capacity (J/Kg-K)	502.42	477	1050	860
9	Thermal expansion (/℃)	1.2e-5	1.08e-5	2.36e-5	2.36e-5

2.2. Analytical Calculation for Gas Pressure and Dimensions of The Connecting Rod

Using analytical method to know the values of gas pressure and gas force to determine the overall dimensions and configuration of the connecting rod. Those determined values are used for result and discussion constraints as an input value for FEA. The connecting rod model has a periodic external load which involves two situations. Gas force transformed from the piston crown and inertial force from the high-speed moving parts of reciprocating, causing of compressing and stretching the connecting rod respectively [6].
To calculate the gas force at the maximum pressure used the following parameters [4].

Density of diesel = (820–900) $\frac{kg}{m^3}$ @ Temperature of 293.15 K

$$\text{Mass} = \text{Density} \times \text{Volume}$$

$$\text{Molecular weight of diesel} = 0.1683\ \frac{kg}{mole}$$

To calculate gas pressure by using gas equation [4]: $PV = M \times R_{specfic} \times T$

Where: P = Gas pressure (MPa), V = Volume (mm^3), T = Temperature (K), $R_{specfic} = \frac{Ru}{M}$

R_u is universal gas constant and M is the molar mass (also called molecular weight) of the gas. The value of R_u is similar for all substances.

$$P = MR_{spacef} \times \frac{T}{v},\ @\ T = 423.15\ K,\ P_{gas} = 16.9\ MPa$$

Force due to gas pressure: $F_{gas} = \frac{\pi d^2}{4} P_{gas} = 112,344\ N$

Maximum inertial force of reciprocating bodys of the connecting rod is calculated by considering the crank angle θ = 0, length of connecting rod, crank radius, and mass of reciprocating parts with angular velocity to calculate [7]:

$$F_I = Mr(w)^2 r(\cos\theta + \frac{\cos 2\theta}{n}) \rightarrow Mr(w)^2 r(1+\frac{1}{n})\ \ F_I = 951.74\ N$$

When comparing the force acting on the part of connecting rod; the force due to gas pressure was much higher than inertial force. So, all analysis of this study is considering by maximum compressive pressure force about 112.344 N.

2.2.1. Diminsions and configuration of connecting rod

The configuration of connecting rod take it by consider I-section as shown in Figure 1.2, with a standard dimension for connecting rod.

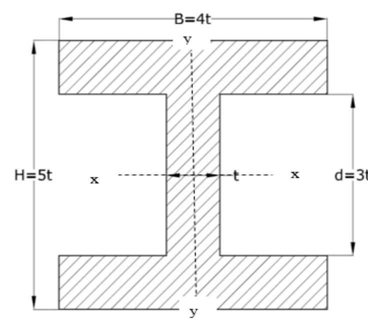


Figure 1.2: Configuration of I-Section connecting rod

Where: t = Flange web thickness, B = 4t, Width of the section, and H = 5t, the height of section
Initially check selected configuration of I-section is satisfy or not. The configuration of I-section has hinged both ends and for buckling about the x-axis and both ends are fixed for buckling about the y-axis. The connecting rod should be equally strong in buckling about either axis. According to Rankin formula, the buckling load [8].
According to Rankin formula, the buckling load is:

$W_B = W_{cr}$ = about x-axis = $\frac{\sigma_c \times A}{1+a\left(\frac{L}{K_{xx}}\right)^2} = \frac{\sigma_c \times A}{1+a\left(\frac{1}{K_{xx}}\right)^2}$, @ both ends hinged, L=l

$W_B = W_{cr}$ = about y-axis = $\frac{\sigma_c \times A}{1 + a\left(\frac{L}{K_{yy}}\right)^2} = \frac{\sigma_c \times A}{1 + a\left(\frac{1}{2K_{yy}}\right)^2}$,@ both ends fixed, L = l/2

Both buckling equally for about x-axis and y-axis: $K_{xx}{}^2 = 4K_{yy}{}^2,\ or\ I_{xx} = 4I_{yy},\ \left[I = A \times K^2\right]$

If $I_{xx} > 4I_{yy}$ buckling about the y-axis, if $I_{xx} < 4I_{yy}$ buckling occurs in the x-axis. But, I_{xx} is slightly less than $4I_{yy}$.

Cross sectional area = $11t^2$

The ratio of moment of inertia along x-axis and moment of inertia along the y-axis:

$$\frac{I_{xx}}{I_{yy}} = \left[\frac{419}{12}\right] \times \left[\frac{12}{131}\right] = 3.2$$

Since the value of $\frac{I_{xx}}{I_{yy}}$ lies between 3 and 3.5, Therefore, I-section chosen is quite satisfactory. The configuration selection methods also used by A. Hussin et al. [4].

For Aluminum Alloy 7068T6

Buckling load (W_B): max. gas force × f.o.s = 280,860 N

$$W_B = \frac{\sigma_c \times A}{1 + a\left(\frac{1}{K_{xx}}\right)} = 280{,}860 \text{ N}$$

Where: Allowable compressive stress (σ_c) = 478.1 MPa, A = Area of section = $11t^2$, and E = Modulus of elasticity (73.1×10^9 Pa)

$$a = \frac{\sigma_c}{\pi^2 E} = 0.00066$$

L = Length of connecting rod =187.6 mm and K_{xx} = Radius of gyration about x-axis = $\sqrt{\frac{I_{xx}}{A}}$ = 1.78t

Substituting all variable values to equation of buckling and access the thickness (t).

$$W_B = \frac{478.1MPa \times 11t^2}{1 + 0.00066\left(\frac{187.6}{1.78t}\right)^2} = 280{,}860\ N \text{, t = 8 mm}$$

For the remaining three materials also the same calculation to aluminum alloy 7068 T6 and to get the values. For aluminum alloy 7050 T7651, t = 8 mm, for carbon C-40 t = 7 mm, and for forged steel 4340, t = 7 mm. The overall dimension of connecting rod model were calculated and its result is similar with the measured values of the existing connecting rod are listed in Table 2.

Table 2: Dimensional specifications of the connecting rod

No.	**Parameters**	**(mm)**
1	The thickness of the connecting rod (t)	8
2	Width of the section (B = 4t)	32
3	Height of the section (H = 5t)	40
4	Length of connecting rod (L)	187.6
5	Height at the big end	44
6	Height at the small end	36
7	The inner diameter of the small end	32
8	The outer diameter of the small end	48
9	The inner diameter of the big end	61
10	The outer diameter of the big end	75

GENERAL PROCEDURE FOR ANSYS WORKBENCH 19.0: Model of connecting rod drawn by CATIA V5R20 >> 3D Model file of connecting rod imported to ANSYS Workbench >> Select simulation for analysis of connecting rod >>

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 6 Issue 9, September 2019
ISSN (Online) 2348 – 7968 | Impact Factor (2019) – 6.248
www.ijiset.com

Made the connection between the cup of the connecting rod and the whole parts >> Select the mushing method of tetrahedral >> Apply the boundary condition >> Apply the option of simulation >> Select the result of simulation result.

1.3. Modeling of Connecting Rod

The CAD model of connecting rod was drawn by CATIA V5 R20 and then exported to ANSYS R19 Workbench to perform further analysis by standard sized model of the connecting rod as shown in Figure 1.3.

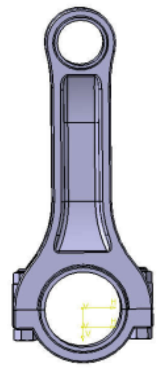


Figure 1.3: Assembly modeling of connecting rod

1.4. Mesh of The Connecting Rod

In order to achieve accurate results in the simulation, it is essential that the finite element model is well prepared, with the appropriate element size and connectors. A too rough mesh will result in incorrectness in the results. On the other side, an overly fine mesh could result in dramatically increased CPU time without corresponding increased accuracy. Therefore, the selection of the correct element size should be carefully reviewed. Also, the element type should be chosen to best capture the natural shape of the model, and avoid appearance distorted elements.
Connecting rod is a component which has complex geometry and uneven shape. So, the model cannot be represented with either 2D shell elements or 1D beam elements and hence a 3-dimensional model has been selected. To reduce the complexity 3-D tetrahedral mesh element was used for connecting rod body and cap. It is a well-known fact that tetrahedrons are constant stress elements and usage of this would result in a highly stiff behavior. Hexahedrons are better suited for structural analyses. But because of connecting rod's complex shape, it is tedious and time-consuming to build on finite element model of the connecting rod with hexahedrons. Hence tetrahedrons were used as illustrated in figure 1.4. This method of meshing also used by **Adila and Afzal** [9].

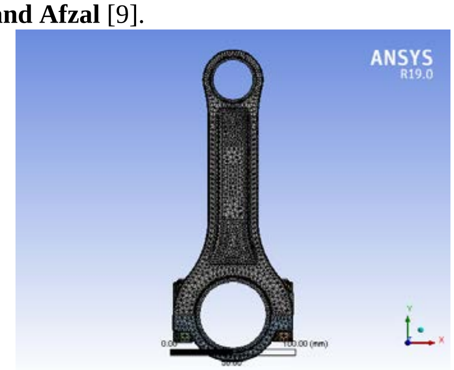


Figure 1.4: Tetrahedron mesh connecting rod

To establish the element size, some simulation was conducted and used the equivalent stress output as a reference to compare the element size by fine mush of relevance center. From figure 1.5: the slop of equivalent stress Vs. element size was approximately horizontal at the value of 2 mm element size mesh and the values of nodes and elements are respectively 107627 and 61000. So, this study used the element size at 2 mm to manipulate the finite element analysis of the connecting rod.

Table 3: Effect of varying grid size on maximum equivalent stress for connecting rod model

Element size (mm)	Equivalent stress (MPa)
3.5	174.77
3.0	182.80
2.5	187.50
2.0	190.97
1.5	196.23

2.5. Boundary Conditions for Stress Analysis

2.5.1. Mechanical Boundary Conditions of Con-Rod

The static load analysis was performed by considering two constraint conditions of boundary conditions. The piston pin end is restrained when the loads are applied at the crank end that results in inertia but the end of the crank is constrained when the piston pin is loaded by gas pressure. For this analysis apply gas force on the small end of connecting rod and fixed at the end of crank as shown Figure 1.5.

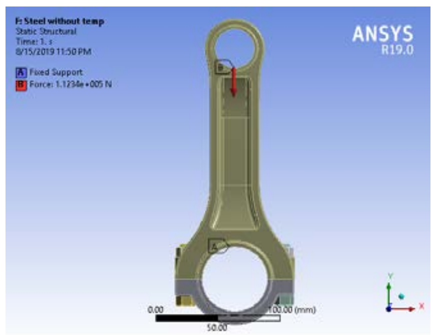


Figure 1.5: Boundary condition of the connecting rod

2.5.2. *Thermal Boundary Conditions of Con-Rod*

The results of stress and fatigue life are affected by temperature stress released from the engine. When increasing the speed of the engine proportionally the temperature will increase. Connecting rod temperature is released from the piston to the whole body of the connecting rod.

In this research work speed are correlated from the authors of M. Kumar [10], M. Srinadh, and R. Babu [11], and J. Agboola et al. [12]. So, the maximum estimated temperature is about 200 ℃ distributed to piston pin or small end of a connecting rod. Figure 1.6 shows the distribution of the temperature through the body of a connecting rod by means of conduction.

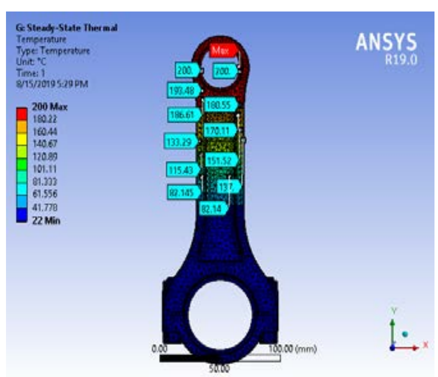
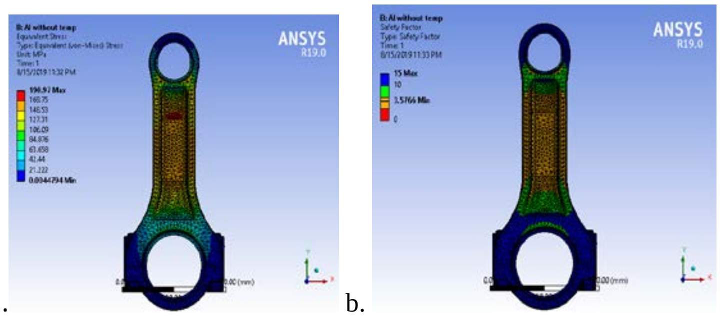


Figure 1.6: Temperature distribution on connecting rod

3. Results And Discussions

3.1. FEA for Connecting Rod Without Thermal Effects

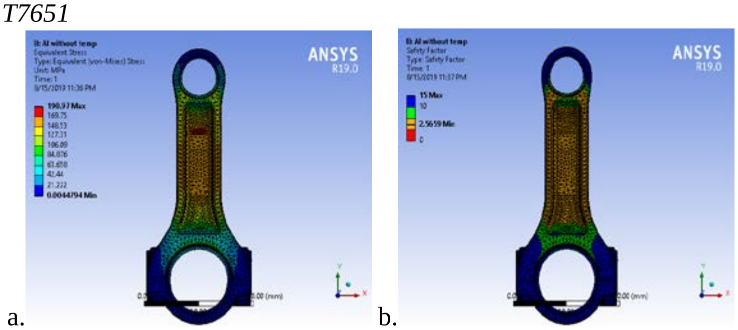
For Aluminium Alloy 7068T6



a. b.

Figure 1.7: a. Von-mises stress, b. Safety factorer

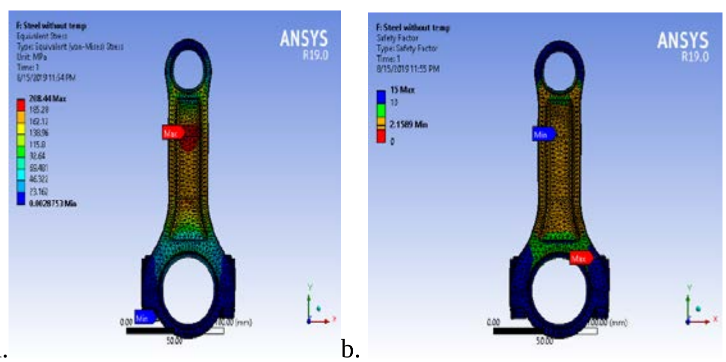
For Aluminium Alloy 7050 T7651



a. b.

Figure 1.8: a. Von-mises stress, b. Safety facter

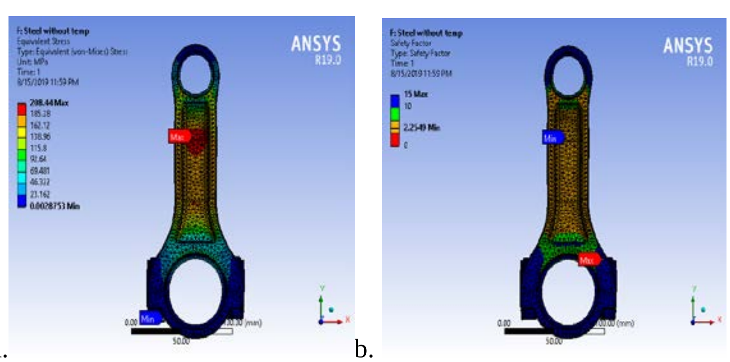
For Carbon Steel C-40



a. b.

Figure 1.9: a. Von-mises stress, b. Safety facter

For Forged Steel 4340



a. b.

Figure 1.10: a. Von-mises stress, b. Equivalent elastic strain

The FEA without thermal effect result for static analysis i.e. The Von-mises stress, Equivalent elastic strain, Total deformation and Safety factor of four materials which are shown figure 1.7 to 1.10 and as a summery on Table 3.

Table 3: Summery on results of the FEA without thermal effects

		Aluminum Alloy 7068T6		Aluminum alloy 7050T7651		Carbon steel C-40		Forged steel 4340	
Sn.	Types	Max	Min	Max	Min	Max	Min	Max	Min
1	Equivalent stress (MPa)	190.97	4.47e-3	190.97	4.47e-3	208.44	2.87e-3	208.44	2.87e-3
2	Equivalent elastic strain (mm/mm)	9.56e-4	3.46e-8	9.56e-4	3.46e-8	1.04e-3	3.13e-8	1.04e-4	3.13e-8
3	Total deformation (mm)	0.104	0	0.104	0	0.116	0	0.116	0
4	Safety factor	15	3.57	15	2.56	15	2.15	15	2.25

Results are compared on static FEA without thermal effects which illustrate that insures that have better design than existing. The connecting rod manufactured by the aluminium alloy 7068 T6 is better from other materials. It has greater safety factor (3.57) But, the maximum stress of connecting rod made by carbon steel and forged steel 4340 was greater than another connecting rod made by the aluminium ally 7068 T6 and 7050 T7651 (208.44 MPa > 190.97 MPa).

3.2. FEA With Thermal Effects for Connecting Rod

Table 4: FEA with thermal effect for connecting rod model

		Aluminum alloy 7068T6		Aluminum alloy 7050 T7651		Carbon steel C-40		Forged steel 4340	
Sn.	Types	Max	Min	Max	Min	Max	Min	Max	Min
1	Von-mises stress (MPa)	211.87	3.33e-3	211.87	3.33e-3	218.51	2.99e-3	218.51	2.99e-3
2	Equivalent elastic strain (mm/mm)	1.05e-4	3.09e-8	1.05e-4	3.09e-8	1.09e-3	3.16e-8	1.09e-3	3.16e-8
3	Thermal strain (mm/mm)	4.09e-3	-1.06e-6	4.09e-3	-1.06e-6	2.13e-3	-2.8e-6	2.13e-3	-2.8e-6
4	Safety factor	15	3.22	15	2.31	15	2.15	15	2.1

Table 4 illustrates the result of static FEA with thermal effects. The overall values of the result with thermal effects are increased. The stress of the connecting rod made by aluminum alloy was an increase from 190.97 MPa to 211.87 MPa and the steel material was increased from 194.26 MPa to 218.51 MPa. Due to the rise of stress, the safety factor was decreased. From the numerical analysis, the result observed that the medial surface of shank will critical surface. Where the damage will initiate at the extreme stretch condition. The connecting rod stress distribution is relatively uniform. But the maximum stresses are developed at the fillet section of shank region.
Stress distributions are symmetric over the whole body of connecting rod since geometry and loading were proportional or symmetrical. The stress obtained is below the yield strength, which occurs in the elastic region. therefore, the relation between load and stress is linear.

4. Analytical Calculation of Fatigue Life of Connecting Rod

4.1. Fatigue Life Calculation Without Thermal Effects

For aluminum alloy 7068 T6

$$\sigma_m = \frac{(\sigma_{\max} + \sigma_{\min})}{2} = 95.48 \text{ MPa}, \quad \sigma_v = \frac{(\sigma_{\max} - \sigma_{\min})}{2} = 95.48 \text{ MPa}$$

Ultimate stress → σ_{ut} = 710 MPa, Yield stress → σ_y = 683 MPa
So, mean and variable stress is respectively.
Endurance limit due to ultimate stress: $\sigma_e = 0.4 \times \sigma_{ut}$ = 284 MPa
Load correction factor for revised axial load (K_a) = 0.8, Surface finish factor (K_{sr}) = 1.2, Size factor (K_{sz}) = 1
Endurance limite for variable axial stress is: $\sigma'_e = \sigma_e \times K_a \times K_{sr} \times K_{sz}$ = 272.64 MPa
The criteria of design by considering the yield stress and factor of safety. And the factor of safety is f.s = 2.1005

$$S_f = \frac{f.s \times \sigma_v}{1 - \frac{f.s \times \sigma_m}{\sigma_{ut}}} = 279.56 \text{ MPa}, \quad N = 1000\left(\frac{s_f}{0.9\sigma_u}\right)^{\frac{3}{\log \frac{\sigma'_e}{0.9\sigma_u}}} \rightarrow N = 1.2\times10^7 \ cycles$$

Similarly,
For aluminum alloy 7050 T7651 $\rightarrow N = 1.059\times10^{6}$ *cycles*

Carbon steel C-40 $\rightarrow$ $N = 7.264\times10^{6}$ *cycles*, and

For forged steel 4340 $\rightarrow$ $N = 1.078\times10^{7}$ *cycles*

The result of fatigue life without thermal effects for the connecting rod made by aluminum alloy 7068 T6 is about 1.2×10^{7} cycles. Similarly, the connecting rod made of aluminum alloy 7050 T7651 have 1.059×10^{6} cycles. The result of fatigue life of connecting rod manufactured by carbon steel C-40 is 7.264×10^{6} cycles and forged steel 4340 is 1.07×10^{7} cycles. When comparing result of fatigue life of the materials of the connecting rod manufactured by aluminum alloy 7068 T6 was greater than aluminum alloy 7050 T7651 and other two materials.

4.2. Fatigue Calculation with Thermal Effects

For aluminum alloy 7068 T6

Due to thermal effects the stress was increased from 190.97 MPa to 211.87 MPa, besides the fatigue life will decrease.
Temprature factor (K_{tm}) = 1.94 @ maximum temprature values.
Simillarly, to the fatigue life calculation without thermal effects execpt stress and temprature factor have the life of the connecting rod.

$$s_f = \frac{f.s\times\sigma_v}{1-\frac{f.s\times\sigma_m}{\sigma_u}} = 277.8\ MPa \quad \text{So,} \quad N = 1000\left(\frac{s_f}{0.9\times\sigma_{ut}}\right)^{\frac{3}{\log\frac{\sigma'_e}{0.9\sigma_u}}} \rightarrow \text{N} = 1.05\times10^{6} \text{ cycles}$$

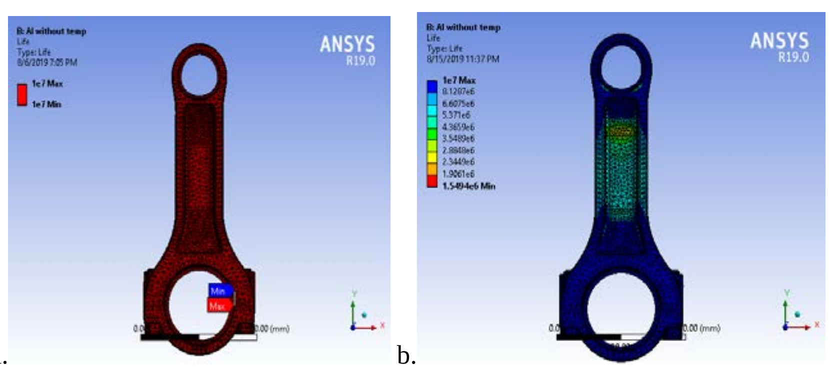
Similarly,
For aluminum alloy 7050 T7651 $\rightarrow$ N = 8.04×10^{5} cycles,
For carbon steel C-40 $\rightarrow$ $N = 6.44\times10^{5}$ *cycle*, and

For forged steel 4340 $\rightarrow$ $N = 4.36\times10^{5}$ *cycles*

From the above fatigue life calculation observed that the estimation of fatigue life due to the effects of both gas force and thermal stress. Connecting rod made by aluminum alloy 7068 T6 is better due to its fatigue life with thermal effects. The result of fatigue life with thermal effects are decreased. Because the stress on the connecting rod was increased due to the thermal effects.

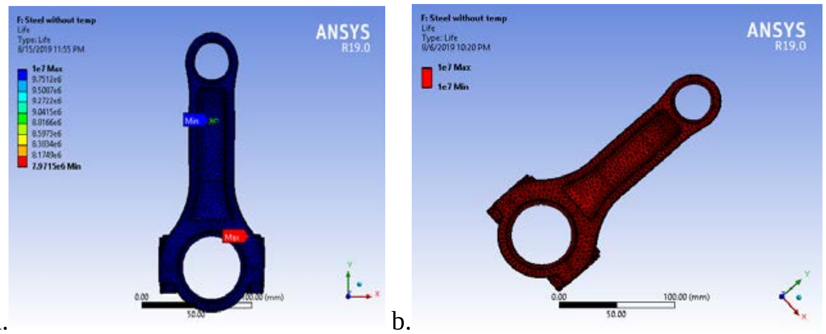
5. FEA of Fatigue life Prediction for Connecting Rod

5.1. FEA without thermal Effects



a. b.

Figure 1.11: a. Fatigue life of aluminium alloy 7068, b. Faitgue life of aluminum alloy 7050T7651



a. b.

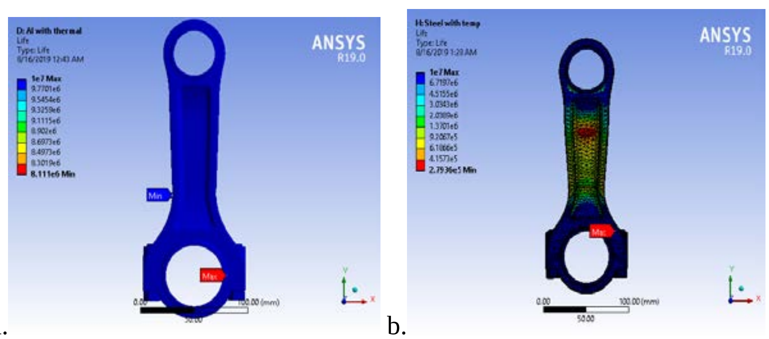
Figure 1.12: Fatigue life of carbon steel C-40, b. Fatigue life of forged Steel 4340

Based on stress life (SxN) theory employment to evaluate the connecting rod fatigue life. It involves that the component will have infinite life for a number of cycles greater than 10^7 Cycles. So, FEA results were illustrated on figure 1.11 and Figure 1.12, or as a summary on Table 5 which was indicated that the connecting rod has an infinite life and there is no damage due to the pressure force of 112,344 N for aluminum alloy 7068 T6 and forged steel 4340. Also, the aluminum alloy 7050 T7651 and carbon steel C40 have high fatigue life of about 1×10^7 cycles and 1×10^7 cycles respectively.

Table 5: Summary of FEA of fatigue life without thermal effect

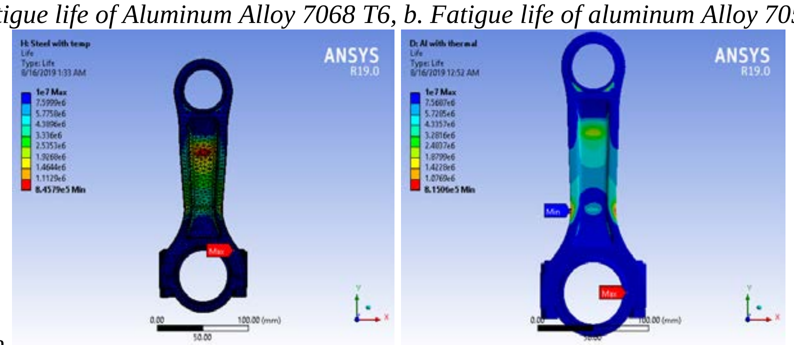
	Aluminum alloy 7068 T6		Aluminum alloy 7050 T7651		Carbon steel C40		Forged steel 4340	
	Min	Max	Min	Max	Min	Max	Min	Max
Life (Cycles)	1×10^7	1×10^7	1.54e6	1×10^7	7.97e6	1×10^7	1×10^7	1×10^7
Damage	100	100	100	645	100	125	100	100
Biaxiality indication	0.99	-0.99	0.99	-0.99	0.99	-0.99	0.99	-0.99

5.2. FEA of Fatigue Life with Thermal Effects



a. b.

Figure 1.13: a. Fatigue life of Aluminum Alloy 7068 T6, b. Fatigue life of aluminum Alloy 7050T7651



a.

Figure 1.14: a. Fatigue life of carbon Steel C-40, b. Fiatige life of orged Steel 4340

For all four-materials fatigue life indicates above figure 1.13 and 1.14 and as a summary on Table 6, illustrates that fatigue life, damage and biaxial induction of the connecting rod analysis with thermal stress effects. The fatigue life of the Aluminum alloy 7050 T7651 material connecting rod is lower than the other three materials of the connecting rods. Because of the ultimate strength of this material is lower than the others. Aluminum alloy 7050 T7651 material connecting rod damage 403.33 will occurs at minimum values of fatigue life. The result shows the connecting rod made by AL 7068 T6 is greater than other three materials.

Fatigue damage of the connecting rod is defined as the ratio of ***design life/available life.***
The result of stress Biaxiality contour plot over the model gives a qualitative measure of the stress state throughout the body. Biaxiality of '0' defined as uniaxial stress, '-1' as pure shear and '1' equivalent to pure biaxial state.

Table 6: Summary of FEA of fatigue life with temperature effects

	Aluminum alloy 7068 T6		Aluminum alloy 7050 T7651		Carbon steel C40		Forged steel 4340	
	Max	Min	Max	Min	Max	Min	Max	Min
Life (cycle)	1×10^7	8.1×10^6	1×10^7	8.15×10^5	1×10^7	2.79×10^5	1×10^7	$8.45\text{x}10^5$
Damage	123.29	100	1226.9	100	3579	100	1182	100
Biaxial induction	0.999	0.999	0.999	0.999	0.994	0.999	0.984	0.999

Table 7: shows the fatigue life of connecting rod with and without thermal effects by means of both analytical and numerical results. Result shows that fatigue life with analytical and numerical results are correlated each other. Fatigue results with thermal effects are lower than without thermal effects. Generally, the value of aluminum alloy 7068 T6 have better fatigue life both with and without thermal effects.

Table 7: Comparative result of fatigue life

	Fatigue life without thermal effects (cycles)			Fatigue life with thermal effects (cycles)	
	Analytical	FEA		Analytical	FEA
Aluminum alloy 7068 T6	1.2×10^7	1×10^7		1.05×10^6	8.1×10^6
Aluminum alloy 7050 T7651	1.059×10^6	1.54×10^6		8.04×10^5	8.15×10^5
Carbon steel C-40	7.264×10^6	7.97×10^6		6.44×10^5	2.79×10^5
Forged steel 4340	1.07×10^7	1×10^7		4.36×10^5	$8.45\text{x}10^5$

6. Weight Reduction of Connecting Rod

The result of weight reduction for the connecting rod is by considering the existing mass of single connecting rod measured value about 1.02 Kg.
Density of carbon steel C-40 and forged steel 4340 = 7850 kg/cm^3
Volume of connecting rod for Carbon steel C-40 and Forged steel 4340 is:
Mass = Density × Volume So, 1.02 kg = 7850 kg/m^3 × v, v = 129.9 cm^3. The volume of the connecting rod for all materials are must be equal.
Innovative connecting rod or aluminum alloy 7068 T6 and aluminum alloy 7050 T7651 is: density = 2.85 kg/cm^3
Mass = 2.85 g/cm^3 × 129.9cm^3 = 370.215 g or 0.3702 kg

Mass reduction of the connecting rod by percentage is: $\frac{\text{Mof steel} - \text{M of Al}}{\text{M of steel}} \times 100\% = 63.7\%$

7. Conclusion Weight Reduction of Connecting Rod

From static FEA result Aluminum alloy connecting rod lighter than other steel materials of connecting rod within the same load applied and the same operation system. Weight of the connecting rod was performed to the greatest redaction about 63.7 % of connecting rod subjected to cyclic load including the peak compressive gas and thermal loads.
Static FEA of connecting rod have been done with both mechanical and thermal stress effects. The connecting rod made by aluminum alloy has the Max. stress 211.87 MPa was lower than other steel materials of Max. stress 218.51 MPa and aluminum alloy has the maximum factor of safety 3.224 due to the maximum values of yield strength. Also, the fatigue life of aluminum alloy 7068 T6 is maximum 1×10^7 cycles and minimum values of 1.05×10^6 cycles. It has an infinite life. But, the fatigue life of carbon steel C-40 and forged steel 4340 minimum value is 6.44×10^5 cycles and 4.36×10^5 cycles respectively.
The result obtained to illustrate that von-mises stress, equivalent elastic strain, deformation, and fatigue strength analysis to the connecting rod for four different materials comparison was presented. Steel material connecting rod was replaced by aluminum alloy 7068 T6 connecting rod, this aluminum material is the strongest and commercially available.

Acknowledgment

This research work was sponsored by ministry of education, Ethiopia. We would like to thanks the college of Electrical and Mechanical Engineering in Addis Ababa science and Technology University (AASTU) to provide scientific insight to advised for this research work.

References

[1] Are and Nøst, "https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2454112," 2017. [Online]. Available: http://hdl.handle.net/11250/2454112. [Accessed 12 February 2019].

[2] G. Charkha and B. Jaju, "Analysis & optimization of connecting rod," in *International Conference on Emerging Trends in Engineering & Technology*, Washington, DC, USA, 2009.

[3] C. Pathade, B. Patle, and N. Ingale, "Stress analysis of IC engine connecting rod by FEM," *International Journal of Mechanical Engineering and Technology (IJ MET),* vol. 1, no. 3, pp. 2277-3754, 2012.

[4] A. Hussin, Er. Prabhat, K. Sinha, and S. Darbari, "Design and analysis of connecting rod," *International Journal of Mechanical Engineering and Technology (IJMET),* vol. 5, no. 10, pp. 57-69, 2014.

[5] A. Somani, "Comparative study on different materials for connecting rod," *International Journal of Innovations in Engineering and Technology,* vol. 6, no. 3, pp. 183-187, 2016.

[6] M. Jian, L. Yong, L. Rui-Xiang, and Z. Bin, "Finite element analysis and structural improvement of diesel engine connecting rod in computer modeling and simulation," in *2nd International Conference on Information Engineering and Computer Science*, Bejing, China, 2010.

[7] K. Vegi and G. Vegi, "Design and analysis of connecting rod using forged steel," *International Journal of Scientific & Engineering Research,* vol. 4, no. 6, pp. 2229-5518, 2013.

[8] A. Hussin, Er. Prabhat, K. Sinha, and S. Darbari, "Design and analysis of connecting rod," *International Journal of Mechanical Engineering and Technology (IJMET),* vol. 5, no. 10, pp. 57-69, 2014.

[9] Adila and Afzal, "Fatigue behavior and life predictions of forged steel and powder metal connecting rods," *"Master Thesis," "Mechanical Engineering," University of Toledo,* 2004.

[10] Dr T. Nageswara Rao, K. Vasudev Rao, V. Ananta Rahul, G. Rajesh, P. Surya Sowgandh, "Design, analysis and optimization of gas/petrol," *International Journal of Latest Technology in Engineering, Management & Applied Science,* 2018.

[11] S. Furuhama. Y. OYA and H. Sasaki, "Tempreture measurement of the connecting rod, piston pin and crank bearing of an automobile Gasoline Engine," *Bulletin of JSME,* vol. 9, no. 33, pp. 181-189, 1966.

[12] J. Agboola, T. Lebele-alawa, and B. Nkoi, "Study of combustion temperature distribution In the cylinder of compression ignition engine," *American Journal of Engineering Research*, vol. 7, no. 11, pp. 304-312, 2018.