

# Design and Analysis of Connecting Rod by Implementing APQP

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**ABSTRACT:** Advanced product Quality Planning is a structured method of defining and establishing the steps necessary to assure that a product satisfies the customer. The variation of dimensional quality of the connecting rod due to variation of temperature at the time of manufacturing, improper deburring operation, improper selection of material and the design is the major issue in connecting rod manufacturing industries. The implementation of APQP in design of connecting rod improved the existing design which enhances the customer satisfaction and safety (increases the factor of safety). The results obtained in finite element method using Ansys software are good agreement with theoretical values.

**KEYWORDS:** APQP, Connecting rod, factor of safety, FEM

## I. INTRODUCTION

### 1.1 Introduction to Advanced Product Quality Planning (APQP)

APQP is a structured method used to assure that a product satisfies the customer. The goal of product quality planning is to facilitate communication with everyone involved to assure that all required steps are completed on time. Each Product Quality Plan is unique. The actual timing and sequence of execution is dependent on customer needs and expectations and/or other practical matters. The earlier work practice, tool, and/or analytical technique can be implemented in the Product Quality Planning Cycle. The important benefits that could be considered in implementing APQP during manufacturing connecting rods are: to direct resources to satisfy the customer, to promote early identification of required changes, to avoid late changes and to provide a quality product on time at the lowest cost.

### 1.2 Phases of APQP

- Plan and Define problem
- Product Design and Analysis
- Product Validation

#### 1.2.1 Plan and Define problem

Inputs:

- Market Research
- Historical Warranty and Quality Information
- Business Plan/Marketing Strategy
- Product/Process Assumptions

Outputs:

- Design Goals
- Reliability & Quality goals

#### 1.2.2 Product Design and Analysis

Inputs:

- Preliminary list of Special Product and Process Characteristics
- Product Assurance Plan
- Preliminary Process Flow Chart

Outputs:

- Design for Failure Mode and Effects Analysis (DFMEA)
- Design Verification
- Design Reviews
- Engineering Drawings (Including Math Data)
- Material Specifications

#### 1.2.3 Product Validation

Inputs:

- FEM(Finite element analysis)
- Analytical Method

Outputs:

- Comparison of results

### 1.3 Timing Chart

The success of any problem depends on meeting customer needs and expectations in a timely manner at a cost that represents value. The Product Quality Planning Timing Chart and the Product Quality Planning Cycle require a

planning team to concentrate its efforts on problem prevention. Problem prevention is driven by simultaneous engineering performed by product and manufacturing engineering activities working concurrently. The organization’s product quality planning team is responsible for assuring that timing meets or exceeds the customer timing plan.

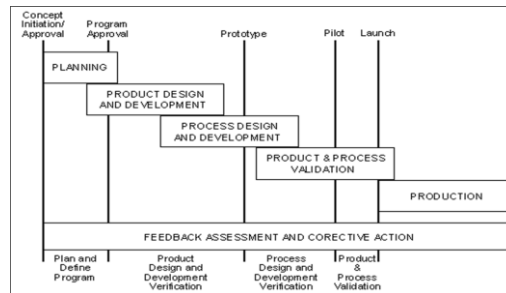


Fig 1.1 Timing chart and phases

#### 1.4 Connecting rod

The intermediate component between crank and piston is known as connecting rod. The objective of Connecting rod is to transmit push & pull from the piston pin to the crank pin and then converts reciprocating motion of the piston into the rotary motion of crank. The components are big shank, a small end and a big end. The cross section of shank may be rectangular, circular, tubular, I- Section or ellipsoidal-Section. It sustains force generated by mass & fuel combustion. The resulting bending stresses appear due to eccentricities, crank shaft, case wall deformation & rotational mass.

##### 1.4.1 Small End and Big End

The small end attaches to the piston pin, gudgeon pin or wrist pin, which is currently most often press fit into the connecting rod but can swivel in the piston. The big end connects to the bearing journal on the crank throw, in most engines running on replaceable bearing shells accessible via the connecting rod bolts which hold the bearing "cap" onto the big end. Typically there is a pinhole bored through the bearing and the big end of the connecting rod so that pressurized lubricating motor oil squirts out onto the thrust side of the cylinder wall to lubricate the travel of the pistons and piston rings. Most small two-stroke engines and some single cylinder four-stroke engines avoid the need for a pumped lubrication system by using a rolling-element bearing instead, however this requires the crankshaft to be pressed apart and then back together in order to replace a connecting rod.

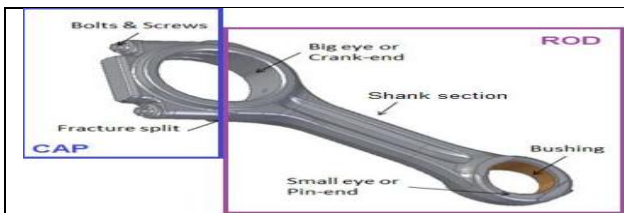


Fig 1.2 Connecting Rod

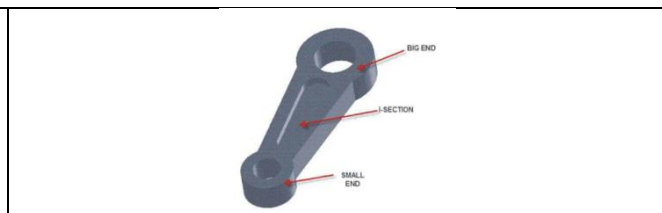


Fig 1.3 Small & Big End of Connecting Rod

##### 1.4 .2 Failure Stress in connecting rod

The connecting rod is under tremendous stress from the reciprocating load exerted by the piston, actually stretching and being compressed with every rotation, the load increases to the square of the engine speed. Failure of a connecting rod, usually called throwing a rod is one of the most common causes of catastrophic engine failure in cars, frequently putting the broken rod through the side of the crankcase and thereby rendering the engine irreparable; it can result from fatigue near a physical defect in the rod, lubrication failure in a bearing due to faulty maintenance, or from failure of the rod bolts from a defect, improper tightening or over-revving of the engine. Re-use of rod bolts is a common practice as long as the bolts meet manufacturer specifications. Despite their frequent occurrence on televised competitive automobile events, such failures are quite rare on production cars during normal daily driving. This is because production auto parts have a much larger factor of safety, and often more systematic quality control.

## II. RELATED WORK

In paper “Failure Analysis of A Fractured Connecting Rod”, M.N. Mohammed1 M.Z. et al. focused on analysis of the connecting rod failure. The studies were carried out by using finite element analysis and metallographic examination.

Based on the experimentation, it was studied that, it is possible to develop a casting defect free connecting rod in combustion engines based on cyclic loading behaviour. Based on findings in experiment the authors recommend that materials with good mechanical properties should be selected and they should be free from manufacturing defects. Finally, lubrication engine system should be regularly checked, and all these are highly recommended to ensure long life of connecting rod in combustion engines.

In the paper “Fatigue Numerical Analysis for Connecting Rod” published by S B Chikalthankar, V M et al., it has been written to demonstrate the analysis of connecting rod used in combustion engines using finite element analysis (FEA). The modified Goodman diagram was used to carry out fatigue study based on stress life (SxN) theory. Based on results obtained, the very high amount of stress was developed in the small end region. Fatigue factors were calculated for almost all critical parts in connecting rod for combustion engines.

Bin Zheng, Yongqi Liu et al. carried out extensive study for stress distribution and fatigue life of connecting rod in combustion engines in light vehicle engines in their paper entitled “Stress and Fatigue of Connecting Rod in Light Vehicle Engine”. The problem was analyzed using the commercial 3D finite element analysis software, ANSYS. It has been seen that maximum stretch occurred at medial surface of smaller end. The stresses were high at the crank of the connecting rod, but because of development and high rigidity material, the stresses were relatively uniform over the medial surface of the connecting rods.

“Design And Finite Element Analysis Of Connecting Rod” by Mohsin Ali. et al. investigated the failure analysis of the connecting rod of the automotive combustion engine. The authors used failure mode analysis. The analysis focused on the frequency of the failure of the connecting rod due to fatigue. Crack in the connecting rod due to excessive fatigue, causes uneven distribution of the stress over growth mechanism. It was concluded that the occurrence of the connecting rod failure was due to the fatigue crack growth mechanism which came as a result of higher stress being combined with the porosity (manufacturing defect) in initiation and growth of a fatigue crack followed by catastrophic failure. The authors highly recommended that lubrication of engine system should be regularly checked to ensure long life connecting rod.

The paper entitled “Stress Analysis of Connecting Rod: A Review” by Fanil Desai et al. concluded, that the stresses on the both end of connecting rods are different and stresses at the small end of the connecting rod are higher than the stresses on the larger end. Therefore risk of failure rod increases at fillet section of both end. Rigidity is the most important factor for the connecting rods and it must possess the highest possible rigidity at lowest possible weight.

### III.METHODOLOGY

Methodology is the deliberate, hypothetical examination of the strategies connected to a field of study. It involves the hypothetical investigation of the assortment of techniques and standards related with a branch of learning. Normally, it envelops ideas, for example, worldview, hypothetical model, stages and quantitative or subjective procedures.



Fig 3.1 Methodology



**IV. PROBLEM IDENTIFICATION AND OBJECTIVES**

4.1 Problem Identification

The variation of dimensional quality of the connecting rod due to variation of temperature at the time of manufacturing, improper deburring operation, improper selection of material and the design is the major issue in connecting rod manufacturing industries. These issues were carefully inspected and recorded.

4.2 Objectives

1. To Design and analyse the connecting rod through implementation of APQP in Manufacturing Industries.
2. To implement Quality Control tools such as DFMEA, Control chart & Process Capability to maintain customer satisfaction

**V. IMPLEMENTATION OF APQP IN CONNECTING ROD**

5.1 Phase 1(capturing voice of customer and raw material study)

Here, customer needs, expectations and specification of connecting rod are essential. After careful survey the C-70 material has been considered during design and development of the connecting rod. The chemical composition and mechanical properties of C70 material is shown in table 5.1 and 5.2 respectively.

C	0.61%
Al	0.095%
Mn	0.82%
Br	0.00097%
Co	7.8%
Fe	75.56%
Mo	3.25%
Cr	0.145%

Table 5.1 Chemical composition of C-70

S.No.	Mechanical Properties	C70 Steel
1.	Density (g/cc)	7.8
2.	Modulus of elasticity (GPa)	221
3.	Yield Strength, S <sub>y</sub> (MPa)	440
4.	Tensile Strength, S <sub>t</sub> (MPa)	672.5
5.	Poisson ratio	0.28

Table 5.2 Mechanical properties of C70 Steel

5.2 Phase 2 (design and optimization of Connecting rod)

5.2.1 Design parameters

1. Fillet radii: The fillets distribute the stress over a broader area and effectively make the parts more durable and capable of bearing larger loads.
2. Web thickness: The web resists shear forces, while the flanges resist most of the bending moment experienced by the beam. Beam theory shows that I-shaped section is very efficient form for carrying both bending and shear loads in the plane of the web.
3. Ratio of length of the connecting rod to the crank radius: When connecting rod is short as compared to the crank radius, it has greater swing, resulting inside thrust on the piston.
  - I. Low-speeds engines L/r ratio varies from 4 to 5.
  - II. High speed engines L/r is generally less than 4.

5.2.2 Loading conditions and constraints

1. The loading conditions are assumed to be static.
2. Two cases were analyzed for each case, one with load applied at the crank end and restrained at the piston pin end, and the other with load applied at the piston pin end and restrained at the crank end.

5.2.3 Design of Connecting Rod

A connecting rod is a machine member which is subjected to alternating direct compressive and tensile forces. Since the compressive forces are much higher than the tensile force, therefore the cross-section of the connecting rod is designed as a strut and the Rankin formula is used. A connecting rod subjected to an axial load W may buckle with x-axis as neutral axis in the plane of motion of the connecting rod. The connecting rod is considered like both ends hinged for buckling about x-axis and both ends fixed for buckling about y-axis. A connecting rod should be equally strong in buckling about either axis.

Let,

A = cross sectional area of the connecting rod.

L = length of the connecting rod.  
 C=compressive yield stress.  
 Wcr=cripling or buckling load.  
 Ixx= moment of inertia of the section about x-axis  
 Iyy= moment of inertia of the section about y-axis respectively.  
 Kxx= radius of gyration of the section about x-axis  
 Kyy= radius of gyration of the section about y- axis respectively.  
 D = Diameter of piston, r = Radius of crank  
 Rankine formula =  $(I_{xx}=4I_{yy})$

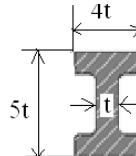


Fig 5.1 Standard dimensions of I-section

Height of section  $H = 5t$

Area of section  $A = 2(4t*t) + 3t*t = 11t^2$

MI of section about x axis:

$$I_{xx} = \frac{1}{12} (4t (5t)^3 - 3t (3t)^3) = 419 \frac{1}{12} t^4$$

MI of section about y axis:

$$I_{yy} = (2 * \frac{1}{12} t (4t)^3 + \frac{1}{12} (3t) t^3) = 131 \frac{1}{12} t^4$$

$$I_{xx} \setminus I_{yy} = 3.2$$

Length of connecting rod (L) = 2 times the stroke=L = 117.2 mm

Buckling load WB = maximum gas force × F.O.S

$$WB = (\sigma_c * A) / (1 + [a * (L / K_{xx})^2]) = 37663$$

$\sigma_c$  = compressive yield stress = 415MPa

$$K_{xx} = I_{xx} \setminus A$$

$$K_{xx} = 1.78t$$

$$A = \sigma_c \setminus \Pi$$

$$a = 0.0002$$

By substituting  $\sigma_c$ , A, a, L,  $K_{xx}$  on WB then  $4565t^4 - 37663t^2 - 81639.46 = 0$

$$t^2 = 10.03$$

$$t = 3.167 \text{ mm}$$

$$t = 3.2 \text{ mm}$$

Width of section  $B = 4t = 12.8 \text{ mm}$

Height of section  $H = 5t = 16 \text{ mm}$

Area  $A = 11t^2 = 112.64 \text{ mm}^2$

Radius of crank (r) = stroke length/2 = 58.6/2 = 29.3

Maximum force on the piston due to pressure  $F_l = \pi/4 * D^2 * p = (\pi/4) * (57)^2 * 15.469 = 39473.16 \text{ N}$

Maximum angular speed  $W_{max} = [2\pi N_{max}] / 60 = [2\pi * 8500] / 60 = 768 \text{ rad/sec}$

Ratio of the length of connecting rod to the radius of crank =  $L/r = 112 / (29.3) = 3.8$

Maximum Inertia force of reciprocating parts

$$F_{im} = Mr (W_{max})^2 r (\cos\theta + \text{COS}2\theta n) \text{ (Or)}$$

$$F_{im} = Mr (W_{max})^2 r (1 + 1/n)$$

$$= 0.11 * (768)^2 * (0.0293) * (1 + (1/3.8)) = 2376.26 \text{ N}$$

Inner diameter of the small end  $d_1 =$

$$= 6277.167 / 12.5 * 1.5 d_1 = 17.94 \text{ mm}$$

Where, Design bearing pressure for small end  $p_{b1} = 12.5$  to  $15.4 \text{ N/mm}^2$

Length of the piston pin  $l_1 = (1.5 \text{ to } 2) d_1$

Outer diameter of the small end =  $d_1 + 2t_b + 2t_m$

$$= 17.94 + [2 * 2] + [2 * 5] = 31.94 \text{ mm}$$

Where, Thickness of the bush ( $t_b$ ) = 2 to 5 mm

Marginal thickness ( $t_m$ ) = 5 to 15 mm

Inner diameter of the big end  $d_2 = F_g / P_{b2} * l_2$

$$= 6277.167 / 10.8 * 1.0 d_1 = 23.88 \text{ mm}$$

Design bearing pressure for big end  $p_{b2} = 10.8$  to  $12.6 \text{ N/mm}^2$

Length of the crank pin  $l_2 = (1.0 \text{ to } 1.25) d_2$

Root diameter of the bolt =  $(2F_{im}(\pi \cdot St)) / (1/2)$   
 $= (2 \cdot 6277.167 \pi \cdot 56.667) / (1/2) = 4 \text{ mm}$   
 Outer diameter of the big end =  $d_2 + 2t_b + 2d_b + 2t_m = 23.88 + 2 \cdot 2 + 2 \cdot 4 + 2 \cdot 5 = 47.72 \text{ mm}$   
 Where, Thickness of the bush  $[t_b] = 2 \text{ to } 5 \text{ mm}$   
 Marginal thickness  $[t_m] = 5 \text{ to } 15 \text{ mm}$   
 Nominal diameter of bolt  $[d_b] = 1.2 \times \text{root diameter of the bolt} = 1.2 \times 4 = 4.8 \text{ mm}$   
 Height at the big end (crank end) =  $H_2 = 1.1H \text{ to } 1.25H, H_2 = 17.6 \text{ mm}$   
 Height at the small end (piston end) =  $0.9H - 0.75H, H_1 = 14.4 \text{ mm}$

5.2.4 Modelling and Analysis of Connecting rod

Modelling of the connecting rod is done using CATIA V5. Finite element model is done in ANSYS 14.0. After importing solid model from Catia V5 in IGES format, 3D mesh has been generated. The mesh model of connecting rod is as shown in fig 5.2

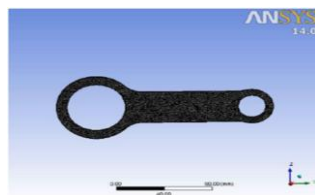


Fig 5.2 Meshing of Solid model

- Element type is “Tetrahedrons”
- Element Size = 0.650 mm
- Total number of elements = 73755
- Total number of nodes = 129793

Meshing of the model:

Dividing the continuum into finite elements is called meshing. In solid finite element modelling we have only two types of elements, namely, **i.** Hex **ii.** Tetra. In solid meshing there are three types of planers namely, (i) Solid-45, (ii) Solid-95, (iii) Solid-92. In solid-92 the number of nodes is 10 and it has two degrees of freedom per node. In solid-95 the number of nodes is 20 and it has two degrees of freedom.

Influence of mesh type

The tetrahedral meshing approach is employed for the meshing of the solid region geometry. Tetrahedral meshing produces high quality meshing for boundary representation of solid structural model. Since the tetrahedral is found to be the best meshing technique, TET4 was used for the initial analysis. The comparison then is made between the TET4 and the 10 nodes tetrahedral (TET10) element mesh while using the same global mesh length for the highest loading conditions. Material properties play an important role in the result of the FE analysis. The material properties are one of the major inputs to perform the FEM.

Boundary conditions

Arrest the degrees of freedom of bigger end of the connecting rod and then apply the loads on the small end of the connecting rod at different areas. After solving the model von Mises stress produced in the connecting rod has been recorded.

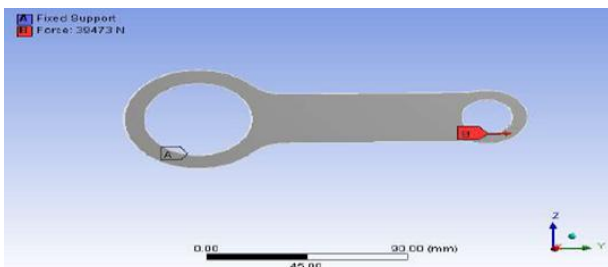


Fig 5.3 Applying loads at small end & fixing the big end

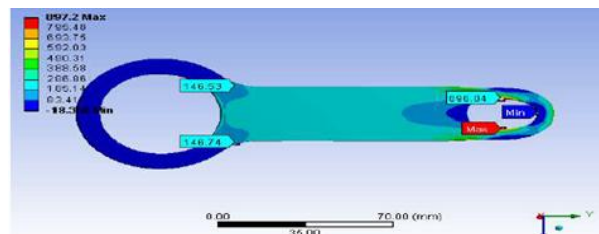


Fig 5.4 Maximum principal stress at 39473.16 N



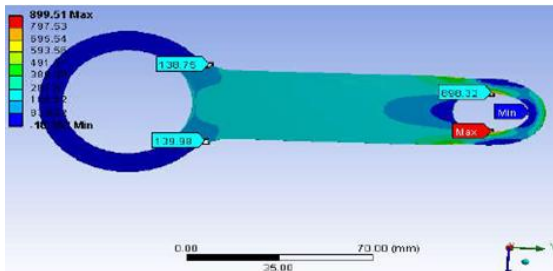


Fig 5.5 Maximum Principal Stress at 39575N

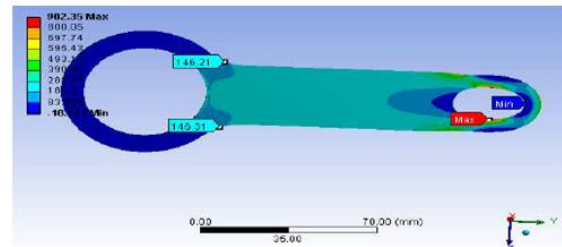


Fig 5.6 Maximum Principal Stress at 39700N

Calculation for factor of safety of connecting rod

f.s= factor of safety

$\sigma_m$ = mean stress

$\sigma_y$ = yield stress

$\sigma_v$ = variable stress

$\sigma_e$ = endurance stress

$$1/f.s = (\sigma_m/\sigma_y) + (\sigma_v/\sigma_e)$$

For C70 Steel

$$\sigma_{max} = 35.665 \text{ MPa}, \sigma_{min} = 3.7371 \times 10^{-12} \text{ MPa}$$

$$\sigma_m = (\sigma_{max} + \sigma_{min})/2 = 17.83 \text{ MPa}$$

$$\sigma_y = 440 \text{ MPa}$$

$$\sigma_v = (\sigma_{max} - \sigma_{min})/2 = 17.83 \text{ MPa}$$

$$\sigma_e = 0.5 \times 440 = 220 \text{ MPa}$$

$$\text{Factor of safety} = 8.225$$

### Fatigue Life calculation

$$N = 1000 \times (sf/0.9 \times \sigma_u)^{3 \log(0.9)}$$

Where,

N = No. of cycles

$\sigma_e$  = Endurance Limit

$\sigma_u$  = Ultimate Tensile Stress

$\sigma_a$  = Endurance limit for variable axial stress

$k_a$  = Load correction factor for reversed axial load = 0.8

$k_{sr}$  = Surface finish factor = 1.2

$k_{sz}$  = Size factor = 1

$$\sigma_e = \frac{1}{2} \times \sigma_u \times k_a \times k_{sr} \times k_{sz}$$

For C70 Steel

$$\sigma_u = 672.5 \text{ MPa}$$

$$\sigma_e = \frac{1}{2} \times 672.5 \times 0.8 \times 1.2 \times 1$$

$$= 322.896 \text{ MPa}$$

$$sf = f.s \times \sigma_v / [1 - f.s \times (\sigma_m/\sigma_u)]$$

$$= 8.2225 \times 17.83 / [1 - 8.2225 \times (17.83/672.5)]$$

$$= 146.65/0.78$$

$$= 187.5 \text{ MPa}$$

$$N = 1000 \times [(326.713 / (0.9 \times 827))]^{3 \log(0.9)} \times [396.96 / (0.9 \times 827)]$$

$$= 8.5 \times 10^5 \text{ cycles}$$

### 5.3 Phase-3 (validation of the model)

The connecting rod is analyzed by two methods i.e.

i) Theoretical method.

ii) Numerical method (Finite Element Analysis).

The results obtained by the above two methods are compared at two critical areas of the connecting rod or two different sections of connecting rod where the connecting rod is likely to fail. The two areas or sections of connecting rod where results are compared are:

i) Sec D-D at the Small End

ii) Sec B-B at the root of Big End

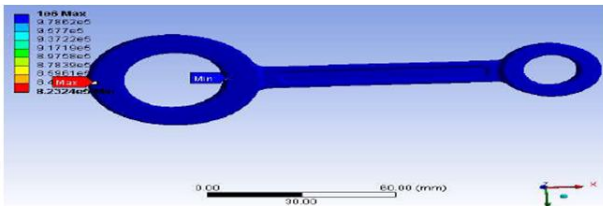


Fig 5.7 Fatigue Life of Connecting Rod

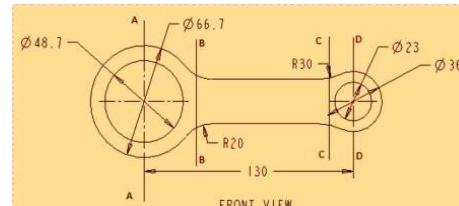


Fig 5.8 Different Sections for Analysis

5.3.1 Calculations for finding maximum principal stress theoretically

- Stresses along section A-A

$$\sigma = P/(b-d)*t$$

For P = 39473N

$$\sigma = 39473/(66-48)*6$$

$$= 275.96N/mm^2$$

- Stresses along section B-B

For P = 39473.16N

$$\sigma = 182.746N/mm^2$$

- Stresses along section C-C

For P = 39473.16N

$$\sigma = 822.35N/mm^2$$

- Stresses along section D-D

For, P = 39473.16 N

$$\sigma = 1012.132N/mm^2$$

Similarly for P=39575N & 39700 N

LOAD P (N)	COMPUTED VALUES OF TENSILE STRESSE (MPA)			
	FOR SECTION B- B		FOR SECTION D-D	
	THEORETI CAL	FEA	THEORET ICAL	FEA
39473.16	182.746	146.56	1012.13	897.2
39575	183.2	138.75	1014.74	899.51
39700	183.7	146.21	1017.948	902.35

Table 5.3 Comparison of tensile stress between Theoretical and Finite Element Analysis Result

S.No.	Type	Theoretical	Finite element analysis (Ansys)
1.	Factor of safety	8.25	12.337
2.	Fatigue life	8.5*10 <sup>6</sup> Cycles	8.23*10 <sup>6</sup> Cycles

Table 5.4 comparison between theoretical and finite element analysis value for factor of safety and Fatigue life

VI. DISCUSSION

APQP process results in the on-time delivery of a quality product at the lowest cost. This means that a having a satisfied customer the first time around leads to cost savings. The required design planning, production tests, and process capability verification contributes to this realization. Connecting rod has been designed based on the prerequisites which ensure non-failure of the rod during the application.

VII. CONCLUSION

From Finite Element Analysis it is found that the stress induced in the small end of the connecting rod is greater than the stresses induced at the big end. Therefore, the chances of failure of the connecting rod may be at fillet section of both ends. Validation of the model ensures the acceptance of the design of connecting rod. There will be slight variation in fatigue life between theoretical and finite element analysis. However factor of safety shows little more difference. This is due to geometrical assumptions in theoretical model. Therefore by implementing APQP, the connecting rod has been designed which satisfies the customer need.





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