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Prediction of fatigue life of a connecting rod under variable loading using ansys

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ABSTRACT

The study details the fatigue life prediction of a Connecting rod using finite element method. The objective of the work is to assess the critical fatigue locations of the component due to cyclic loading conditions. The effect of mean stress on the fatigue life has also been investigated. Materials SAE1045-450-QT, SAE1045-595-QT is considered to represent the connecting rod. Total-life approach and Crack initiation approach have been applied to predict the fatigue life of the connecting rod. The comparison between the total–life approach and crack initiation approach were also been investigated.

Keywords: Catia, Analysis, Fatigue life of connecting rod, Variable load

INTRODUCTION

Connecting rods are highly dynamically loaded components used for power transmission in combustion engines. In a reciprocating steamengine, the connecting rod connects the piston to the crank or crankshaft. Together with the crank, they form a simple mechanism that converts reciprocating motion into rotating motion. Connecting rods may also convert rotating motion into linear motion. Historically, before the development of engines, they were first used in this way.

As a connecting rod is rigid, it may transmit either a push or a pull and so the rod may rotate the crank through both halves of a revolution, i.e. piston pushing and piston pulling. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required to push.

Failure of a connecting rod is one of the most common causes of catastrophic engine failure. In modern automotive internal combustion engines, the connecting rods are most usually made of steel for production engines, but can be made of T6-2024and T651-7075aluminium alloys (for lightness and the ability to absorb high impact at the expense of durability) or titanium (for a combination of lightness with strength, at higher cost) for high performance engines, or of cast iron for applications such as motor scooters. They are not rigidly fixed at either end, so that the angle between the connecting rod and the piston can change as the rod moves up and down and rotates around the crankshaft. Connecting rods, especially in racing engines, may be called "billet" rods, if they are machined out of a solid billet of metal, rather than being cast.

Recent engines such as the Ford 4.6 liter engine and the Chrysler 2.0 liter engine have connecting rods made using powder metallurgy, which allows more precise control of size and weight with less machining and less excess mass to be machined off for balancing. The cap is then separated from the rod by a fracturing process, which results in an uneven mating surface due to the grain of the powdered metal. This ensures that upon reassembly, the cap will be perfectly positioned with respect to the rod, compared to the minor misalignments which can occur if the mating surfaces are both flat.

A major source of engine wear is the sideways force exerted on the piston through the connecting rod by the crankshaft, which typically wears the cylinder into an oval cross-section rather than circular, making it impossible for piston rings to correctly seal against the cylinder walls. Geometrically, it can be seen that longer connecting rods will reduce the amount of this sideways force, and therefore lead to longer engine life. However, for a given engine block, the sum of the length of the connecting rod plus the piston stroke is a fixed number, determined by the fixed distance between the crankshaft axis and the top of the cylinder block where the cylinder head fastens; thus, for a given cylinder

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1.1. FINITE ELEMENT BASED FATIGUE ANALYSIS

A number of factors influence the fatigue life of a component in service, viz., i)complex stress cycles ii) engineering design, iii) manufacturing and inspection iv)service conditions v)material of construction.

The basic factors are necessary to cause fatigue failure. These are (1) a maximum tensile stress of sufficiently high value, (2) a large enough variation or fluctuation in the applied stress, and (3) sufficiently large number of cycles of the applied stress.

2. Material Selection

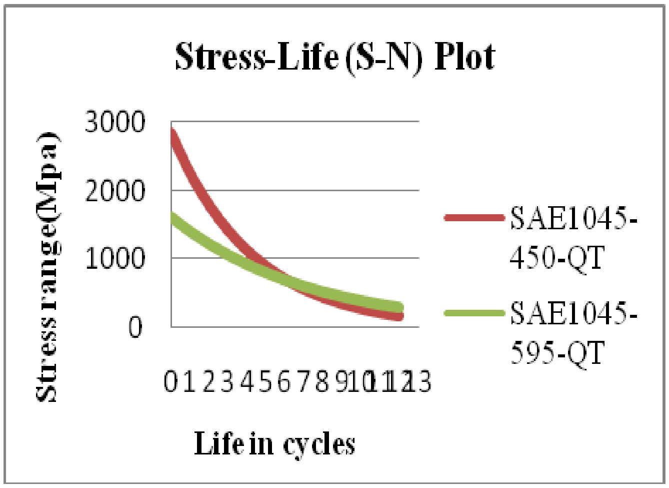
The material data is one of the major input, which is the definite of how a material behaves under the cyclic loading conditions it typically experiences during services operation. Cyclic material properties are used to calculate elastic-plastic stress strain response and the rate at which fatigue cycle. The materials parameters required depend on the analysis methodology being used. Normally these parameters are measured experimentally, and available in various hand books. Different materials were used for this component.SAE1045-450-QT, SAE1045-595-QT,

The mechanical and cyclic properties of materials SAE1045-450-QT and SAE1045-595-QT are shown in table given below.

Table.1 Mechanical & Cyclic Properties of material

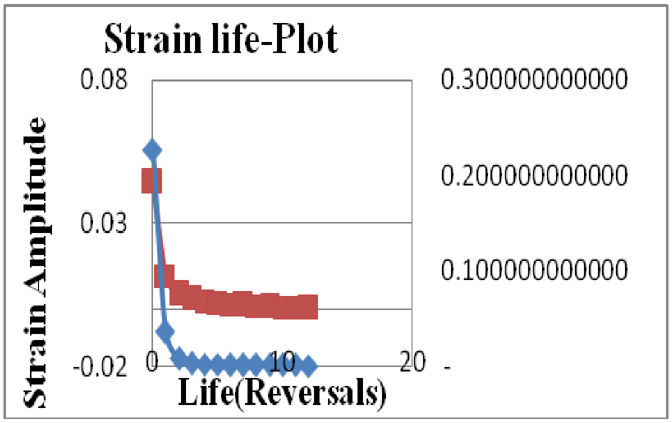
Properties	Materials	
	SAE1045 -450-QT	SAE 1045-595-QT
Yield strength(Mpa)	1515.00	1860.00
Ultimate tensile strength(Mpa)	1584.00	2239.00
Elastic modulus(Mpa)	207000	207000
Fatigue strength coefficient(S_f)	1686.00	3047.00
Fatigue strength exponent(b)	-0.06	-0.10
Fatigue ductility exponent(c)	-0.83	-0.79
Fatigue ductility coefficient(ε_f')	0.79	0.13
Cyclic strain hardening exponent(n')	0.09	0.10
Cyclic strength coefficient(k')	1874.00	3498.00

Graph1 Shows comparison between the two materials with respect to S-N behavior. It can be seen that these curves exhibit different life behavior depending on the stress range experienced. From the figure, it is observed that in the long life area (high cycle fatigue), the different is lower while in the short life area (low cycle fatigue), the difference is higher.



Graph 1: STRESS-LIFE (S-N) PLOT

Graph 2 represents the stain life curve indicating that different fatigue life behavior for both materials. It is plotted based on the Coffin-Manson relationship. From the figure, it can be seen that in long life area (high cycle fatigue) the difference is lower while in the short life area (low cycle fatigue) the difference is higher.



Graph 2: STRAIN-LIFE (S-N) PLOTSAE1045-450-QT VsSAE1045-595-QT

3. Loading information

Loading is another major input for the finite element based fatigue analysis. Unlike static stress, which is analysed with calculations for a single stress state, fatigue damage occurs when stress at a point changes over time. There are essentially four classes of fatigue loading, with the ANSYS Fatigue Module currently supporting the first three:

- Constant amplitude, proportional loading
- Constant amplitude, non-proportional loading
- Non-constant amplitude, proportional loading
- Non-constant amplitude, non-proportional loading

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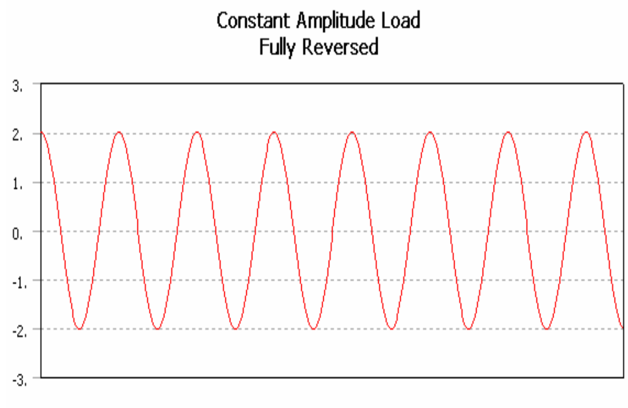


Figure 1: CONSTANT AMPLITUDE LOAD FULLY REVERSED

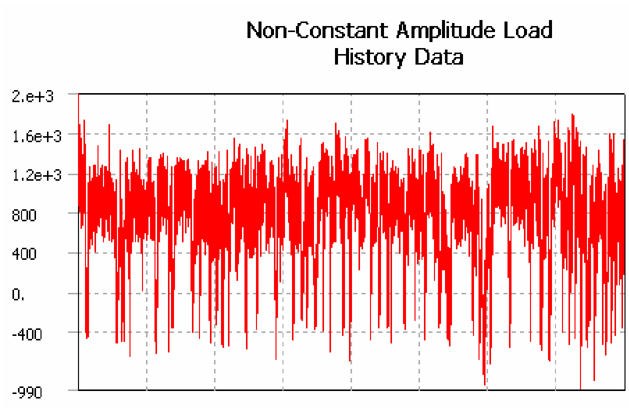


Figure 2: NON CONSTANT AMPLITUDE LOADING

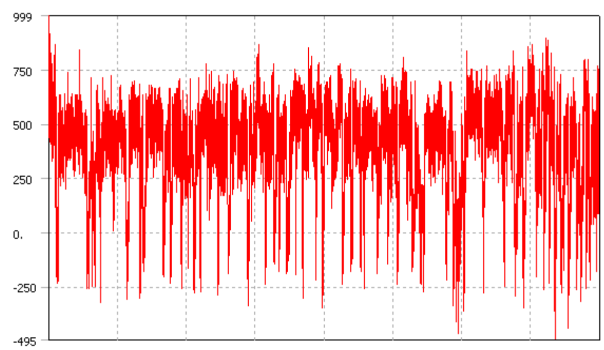


Figure 3: TRANSMISSION LOADING HISTORIES

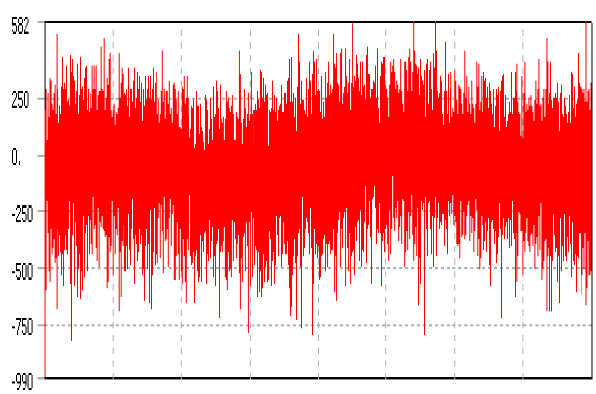
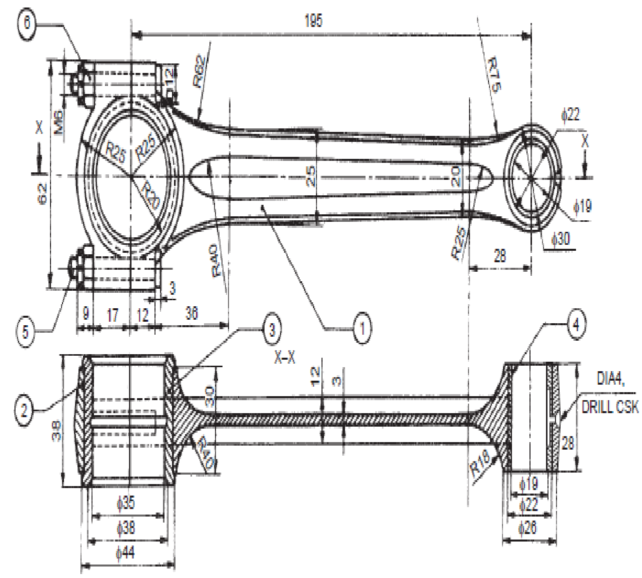


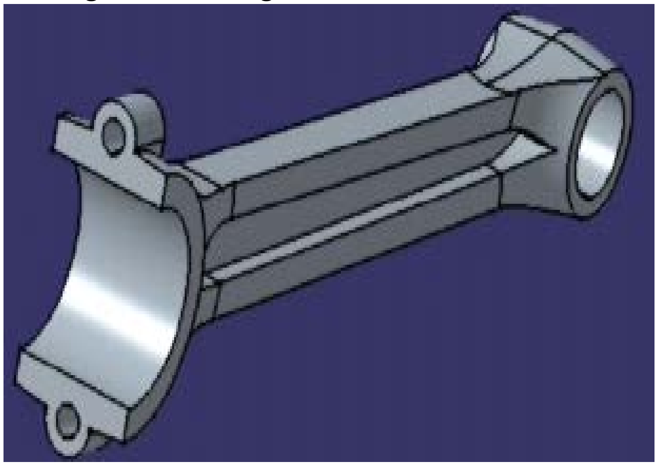
Figure 4: BRACKET LOADING HISTORIES

4. DESIGN, MODELING & ANALYSIS OF CONNECTING ROD

Design of Connecting rod:



Modeling of Connecting rod:



Analysis of Connecting rod:

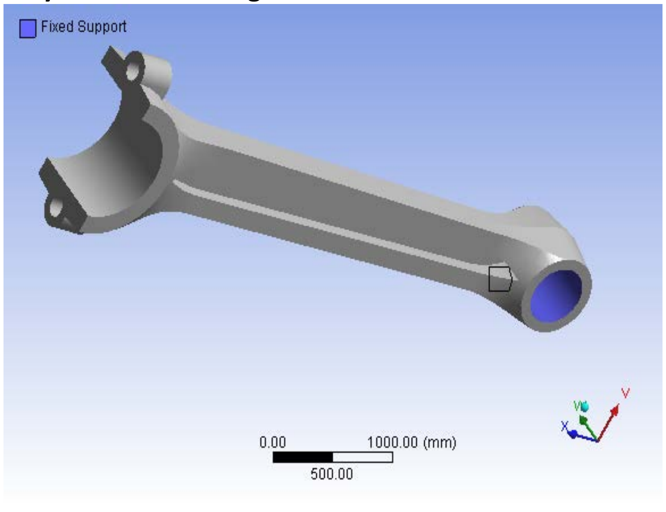


Figure 5: CONSTRAINED OF MODEL

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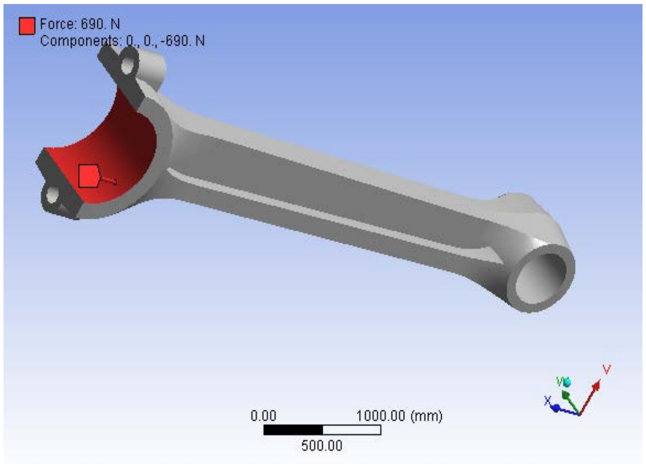

Figure 6: LOADING OF MODEL

5. RESULTS AND DISCUSSIONS

Object Name	Equivalent Stress	Total Deformation
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Results		
Minimum	2.1803e-002 MPa	0. mm
Maximum	21.468 MPa	0.13146 mm

The rear ends of connecting rod found to be maximum and minimum stresses. The von- misses equivalent stresses are used for subsequent fatigue life analysis and comparisons. From the analysis results, the maximum von misses stress of 21.468 MPa was obtained.

The fatigue life of the connecting rod is obtained using variable amplitude loading conditions by mean of SAETRN and SAEBRAKT data set. The fatigue life prediction results of connecting rod were shown in the following figure for corresponding to SAETRN load history.

It can be observed that the predicted fatigue life at most critical location near the rare end of connecting rod is 3.1343e+005 seconds when using SAE1045-450-QT material with no mean stress. The fatigue equivalent unit is 3000 cpm (cycles per min) of time history

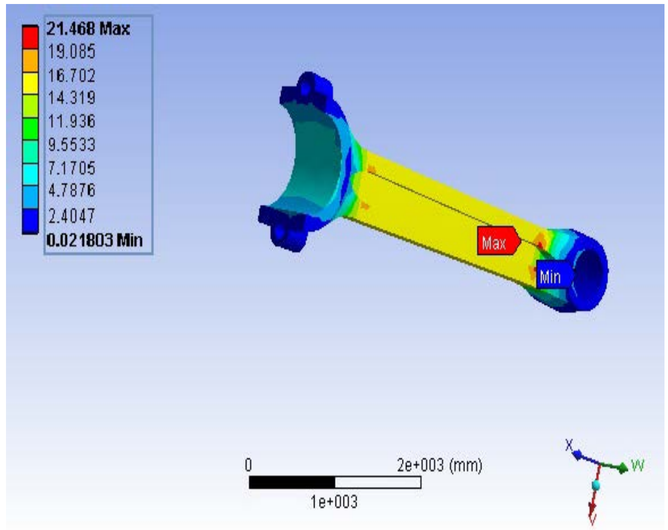

Figure 7: VON MISSES STRESSES DISTRIBUTION

Table 2: MODEL > STATIC STRUCTURAL > SOLUTION > FATIGUE TOOLS

Object Name	Fatigue Tool
State	Solved
Materials	
Fatigue Strength Factor (Kf)	0.8
Loading	
Type	History Data
History Data Location	C:\Program Files\Ansys
Scale Factor	1.e-002
Definition	
Display Time	End Time
Options	
Analysis Type	Stress Life
Mean Stress Theory	None
Stress Component	Equivalent (Von Mises)
Bin Size	32
Use Quick Rainflow Counting	Yes
Infinite Life	1.e+009 seconds
Maximum Data Points To Plot	5000.
Life Units	
Units Name	seconds
1 block is equal to	3000. seconds

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Table 3: MODEL > STATIC STRUCTURAL > SOLUTION > FATIGUE TOOL > RESULTS

Object Name	Life	Damage	Safety Factor
State	Solved		
Scope			
Geometry	All Bodies		
Definition			
Type	Life	Damage	Safety Factor
Design Life		1.e+009 seconds	
Results			
Minimum	3.1343e+005 seconds		0.
Maximum		1.171e+006	

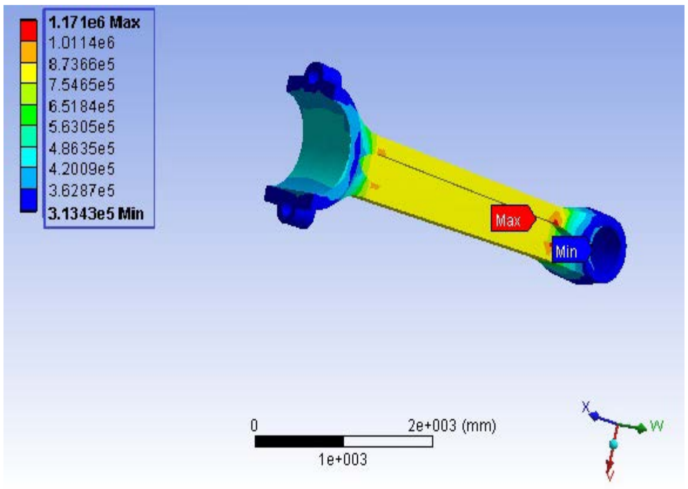

Figure 8: FATIGUE LIFE OF CONNECTING ROD IN STRESS LIFE METHOD

The three-dimensional cycle histogram and correspond-ding damage histogram for materials SAE1045-450-QT using SAETRN loading histories is shown in the figures 9 and 10 given below. Fig: 10 shows the results of the rain flow cycle count for the component.

Table 4: MODEL> STATIC STRUCTURAL> SOLUTION> FATIGUE TOOL > RESULT CHARTS

Object Name	Life	Damage	Biaxiality Indication
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Life	Damage	Biaxiality Indication
Identifier			
Design Life		1.e+009 seconds	
Results			
Minimum	3.1343e+005 seconds		-0.99961
Maximum		1.171e+006	0.98451
Object Name	Rain flow Matrix	Damage Matrix	Fatigue Sensitivity
State	Solved		
Scope			
Geometry	All Bodies		
Options			
Chart Viewing Style	Three Dimensional		Linear
Lower Variation			50. %
Upper Variation			150. %
Number of Fill Points			25
Results			
Minimum Range	0. MPa		
Maximum Range	786.47 MPa		
Minimum Mean	-521.16 MPa		
Maximum Mean	1051.8 MPa		
Definition			
Design Life		1.e+009 seconds	
Sensitivity For			Life

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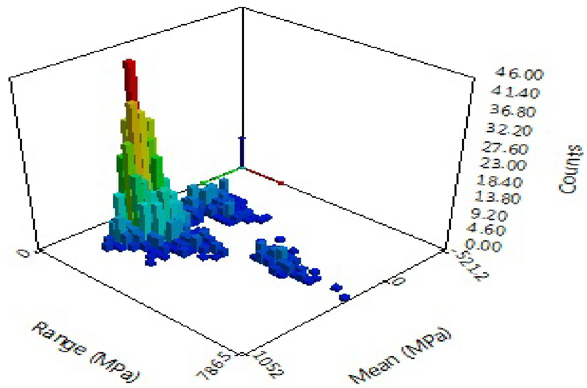
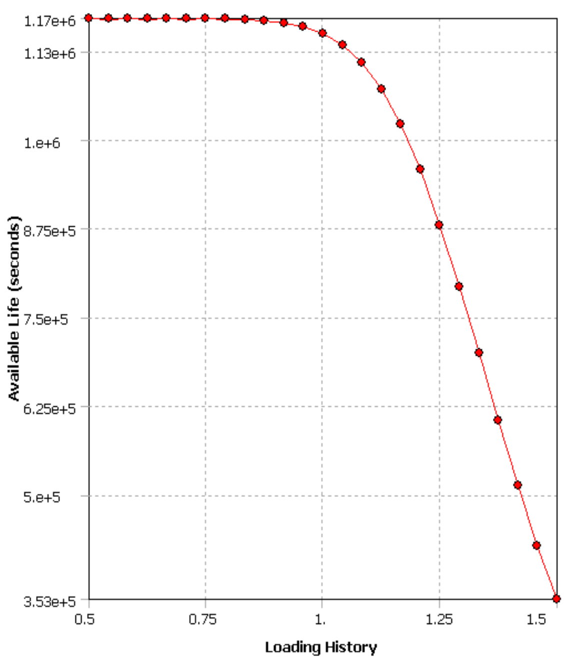


Figure 9: MODEL > STATIC STRUCTURAL > SOLUTION > FATIGUE TOOL > RAIN FLOW MATRIX



Graph 3: MODEL > STATIC STRUCTURAL > SOLUTION > FATIGUE TOOL > FATIGUE SENSITIVITY

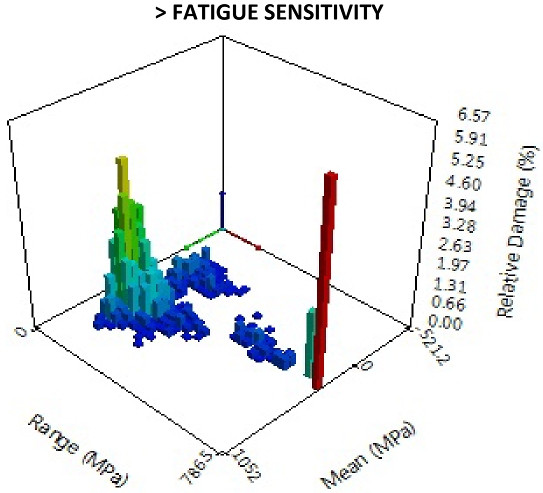


Figure 10: MODEL> STATIC STRUCTURAL > SOLUTION > FATIGUE TOOL > DAMAGE MATRIX

Four types of mean stress correction method are considered in this study i.e. Goodman and Gerber correction methods for total-life approach and SWT and Marrow methods for crack initiation approach. The predicted fatigue life at most critical locations are tabulated in table 5and 6respectively, using different materials and approaches

Predicted life (10e5 sec)

Table 5: PREDICTED FATIGUE LIFE USING TOTAL-LIFE APPROACH

Loading conditions	SAE1045-450-QT			SAE1045-595-QT		
	No mean	Goodman	Gerber	No mean	Goodman	Gerber
SAETRN	3.1343	2.9201	5.9807	7.7826	4.3696	8.2723
SAEBRAKT	4.4635	4.463	4.4087	6.2998	6.2996	6.2923

Table 6: PREDICTED FATIGUE LIFE USING CRACK-INITIATION APPROACH

Loading conditions	SAE1045-450-QT			SAE1045-595-QT		
	No mean	Marrow	SWT	No mean	Marrow	SWT
SAETRN	18.98	12.452	25.713	42.518	24.716	32.17
SAEBRAKT	120.19	32.864	50.694	218.81	59.072	117.29

It is difficult to 1categorically select one procedure in the preference to the other. However, intable 5, it can be seen that when using the loading sequences are predominantly tensile in the nature; the Goodman approach is more conservative. Gerber mean stress correction has been found to give conservative when the time histories predominantly zero mean.

From the table 6, it is also seen that two mean stress methods, SWT and Marrow give lives less than that achieved using no mean stress correction with the Marrow method being the most conservative for loading

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sequences which are predominantly tensile in nature. When using the time history has a roughly zero mean (SAEBRAKT) then two methods have been given approximately the same results. It can be also seen that SAE1045-595-QT is consistently higher life thanSAE1045-450-QT for all loading conditions.

5. CONCLUSIONS

A computational numerical model for the fatigue life assessment of connecting rod is presented in this study. Through the study, several conclusions can be drawn with regard to the fatigue life of a component when subjected to complex variable amplitude loading conditions.

- It can be seen that when using the loading sequences are predominantly tensile in the nature; the life of connecting rod in Goodman approach is 2.9201×10^5 sec which is more conservative.
- It can be seen that when using the loading sequences are predominantly zero mean (SAEBRAKT), the value of life of the connecting rod is 4.4087×10^5 sec in Gerber mean stress correction which has found to be more sensitive.
- It can be concluded that the influence of mean stress correction is more sensitive to tensile mean stress for total life approach.
- It is also seen that the two mean stress methods give lives less than that achieved using no mean stress correction.
- It is concluded for crack initiation approach that when the loading is predominantly tensile in nature, the life of the component in Morrow approach is 24.716×10^5sec which is more sensitive and is therefore recommended.
- When using the time histories has zero mean (SAEBRAKT) then all three methods have been given approximately the same results.
- From results it is shown that the material SAE 1045-595-QT gives constantly higher life than other materials for all loading conditions.

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