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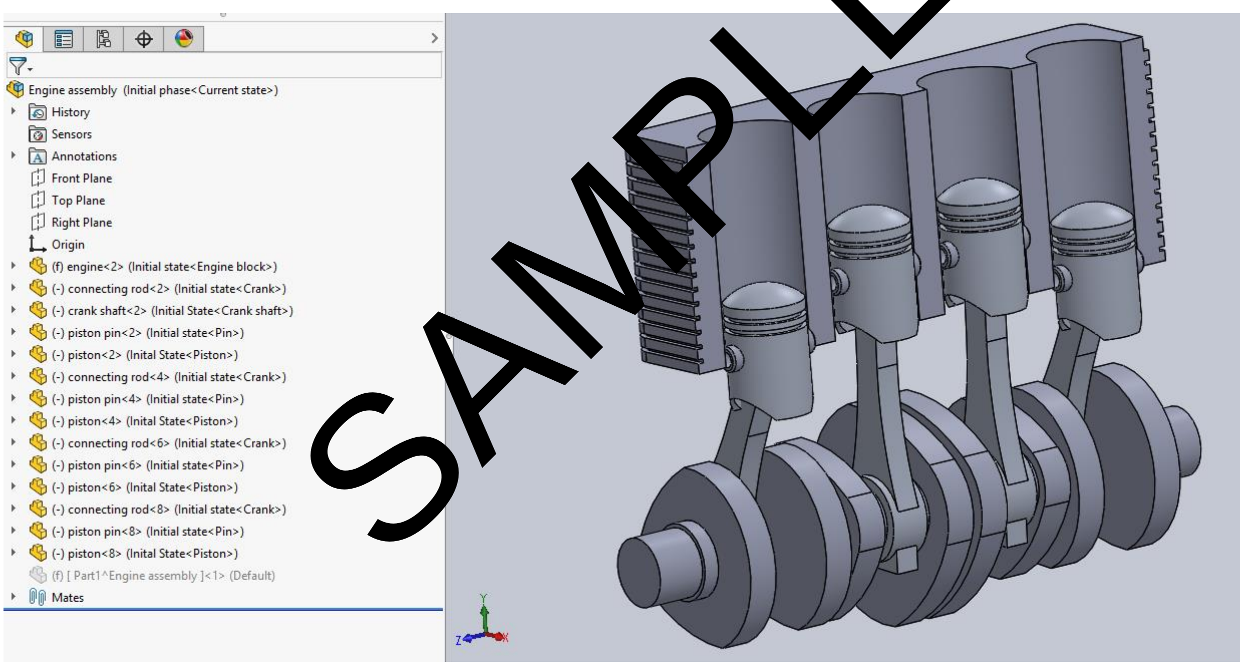
1 Introduction

Main objective of this study is to go through all types of simulations that can be performed using SOLIDWORKS. Engine assembly is most crucial part of the automobile industry. The purpose of study is to get acquainted with how exactly these components work together and how they can be simulated in SOLIDWORKS, considering real life load cases and constraints. Starting with motion analysis of whole assembly then component wise compression, buckling, bending, thermal (steady and transient) analysis and finally design optimization is scope of the study. Simulation is very important phase of designing any equipment. This study provides exposure to all types of simulations and gives brief insights of engine assembly design.

2 Assembly



Engine assembly comprising of crank shaft, piston, piston pin, connecting rod and engine block is made in SOLIDWORKS. All parts are assembled to make configuration named initial state which is then used for motion analysis of the assembly.

3 Load cases analyzed:

Following load cases are analyzed in this project. Detailed simulation setting and results are discussed in subsequent sections

3.1 Motion analysis:

Rotational motion of 10rpm is given to crankshaft and linear and angular displacement, velocity and acceleration plots are studied

3.2 Piston Compression

For piston compression simulation, pressure of 100kPa is considered to be acting on the piston head and piston pin slot is fixed to simulate worst case scenario.

3.3 Connecting rod compression

Pressure of 100kPa is applied on the bottom inner of the small hole on connecting rod and connecting end towards crankshaft is conserved fix.

3.4 Connecting rod bending

Pressure of 100kPa is applied on the side inner faces of the small hole on connecting rod and connecting end towards crankshaft is conserved fix.

3.5 Connecting rod torsion + bending

To simulate torsion and bending load together pressure at two different locations is applied one is in plane (inner walls of small hole) and second is out of plane (side wall of small hole) and fixity is applied at the connecting rod and crankshaft junction

3.6 Thermal steady analysis of piston

Piston is assumed to have thermal load of 1000K and convective heat transfer of 540W/m^2. And steady state thermal analysis is performed to study temperature distribution along piston surface. 3

3.7 Transient thermal analysis of piston

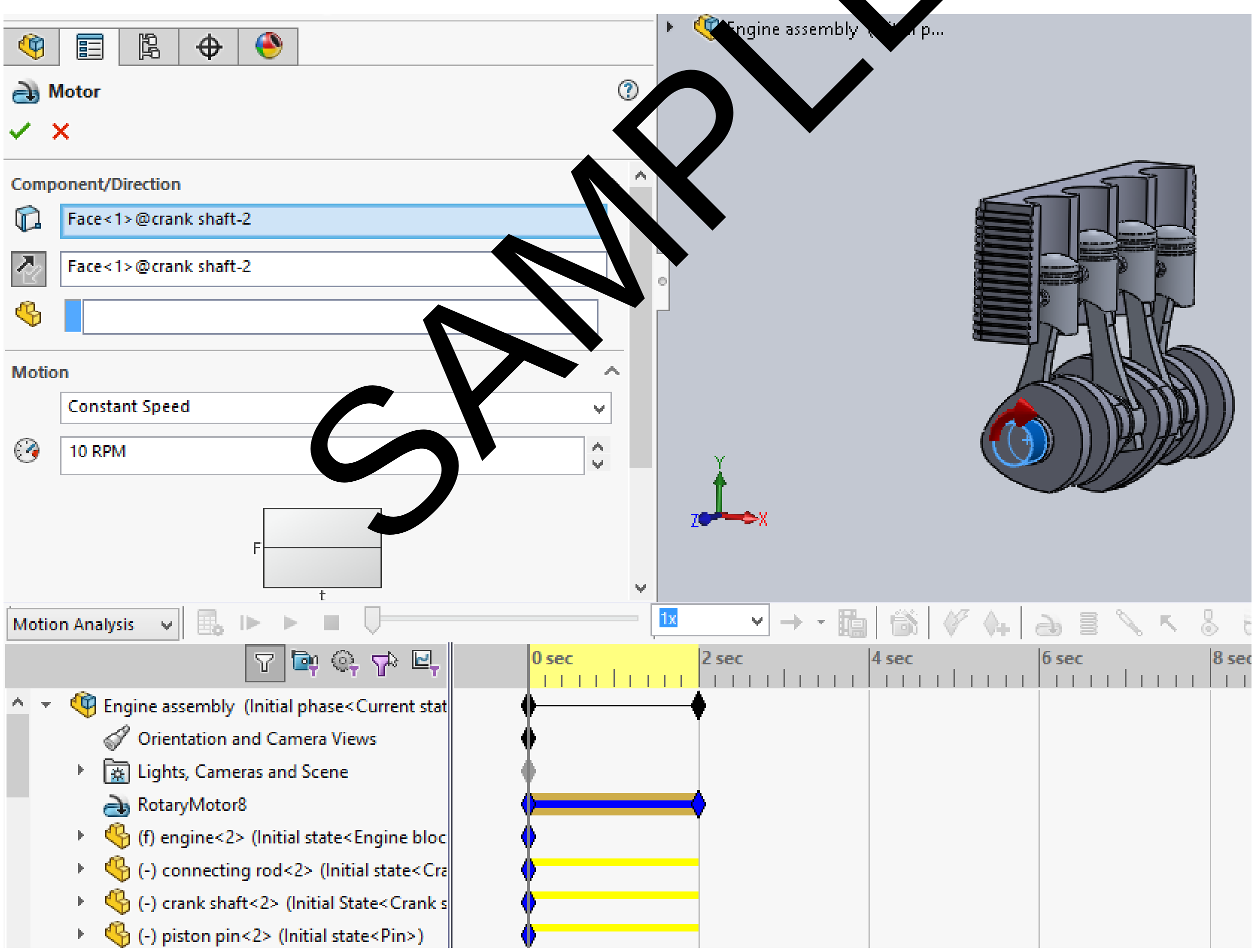
In transient analysis, initial temperature is set to 1000K and simulation time provided is 10sec. all other settings from steady state analysis are carried forward to this analysis.

3.8 Optimization

Optimization is done by two approaches one by manual dimension change and second is with design study to minimize mass of an object.

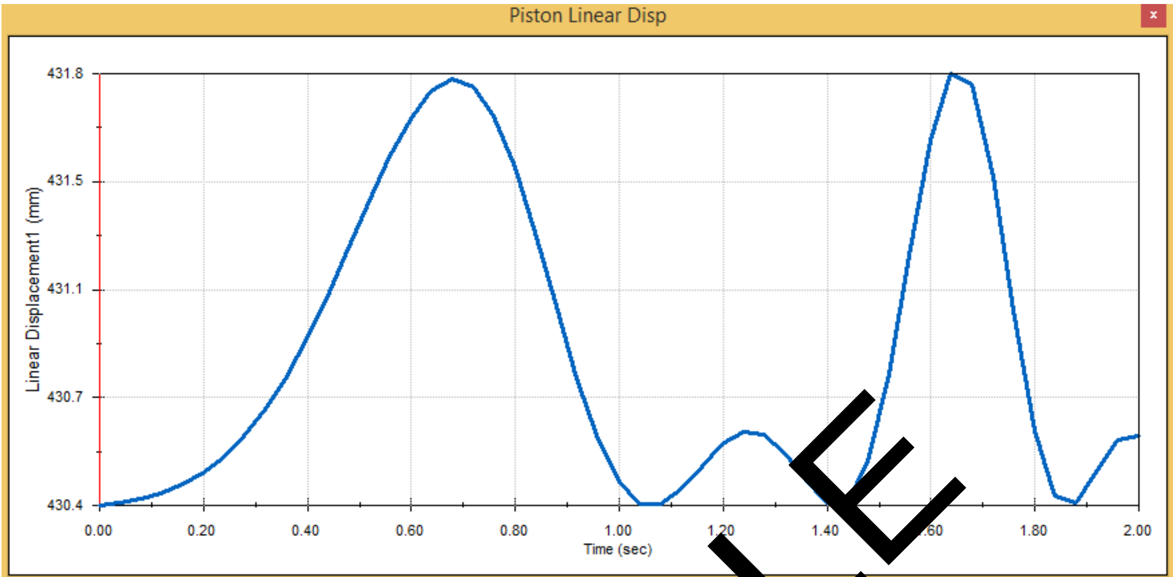
4 Motion analysis

In motion analysis, 10RPM rotary motor is provided to actuate the crankshaft. Red arrow in the diagram below indicates the rotation direction of crankshaft

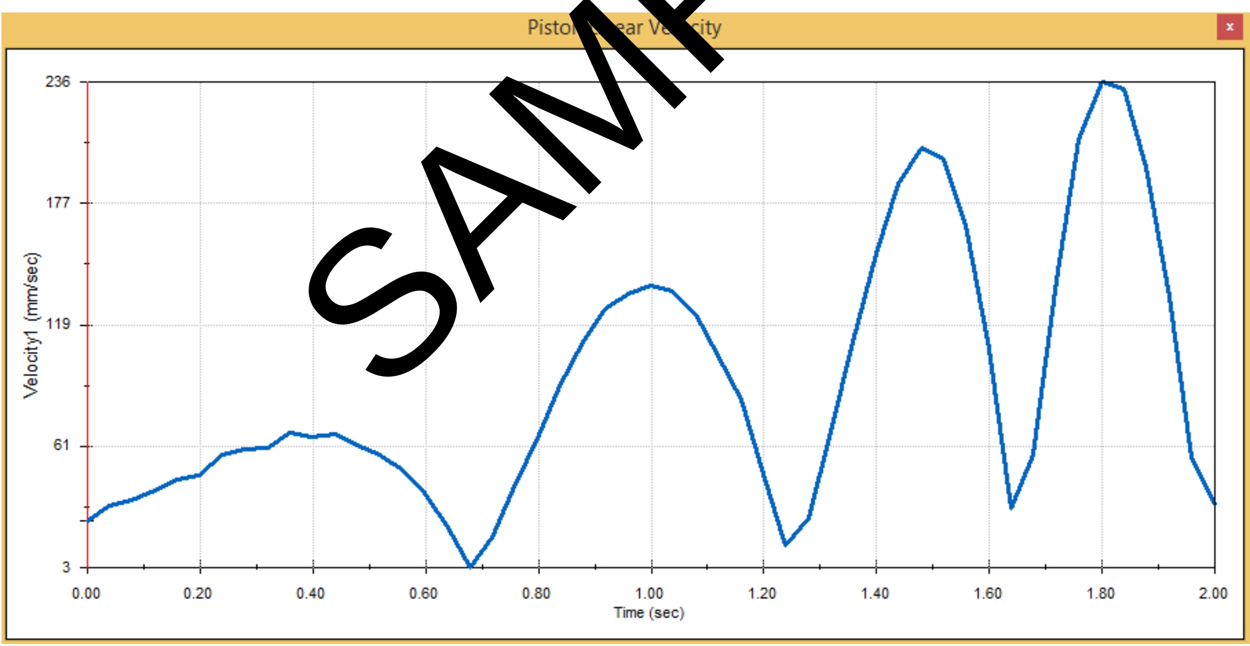


4.1 For piston:

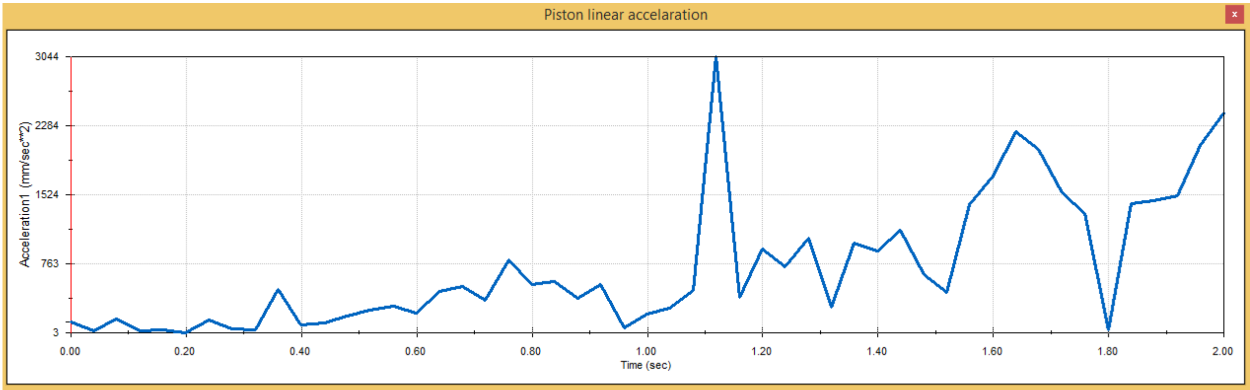
4.1.1 Linear displacement



4.1.2 Linear velocity

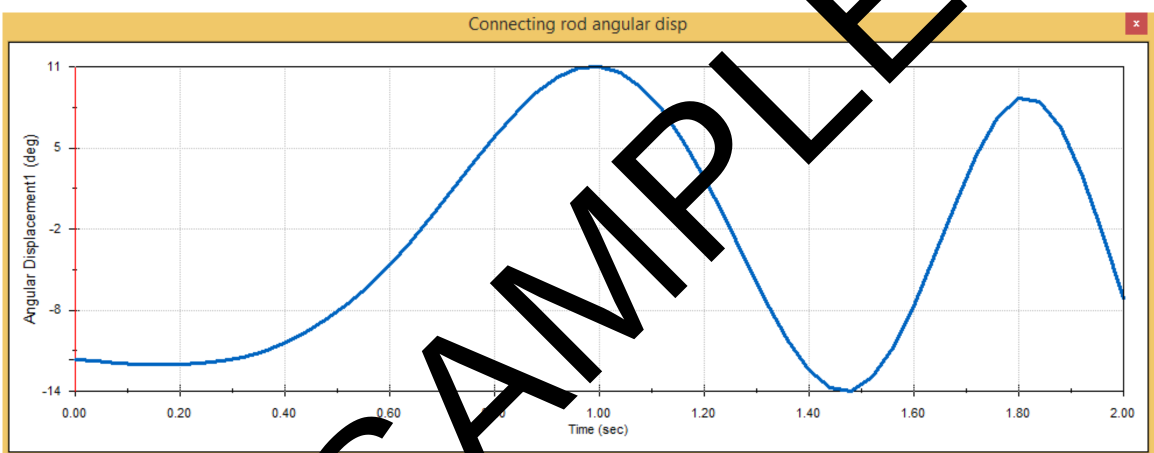


4.1.3 Linear acceleration

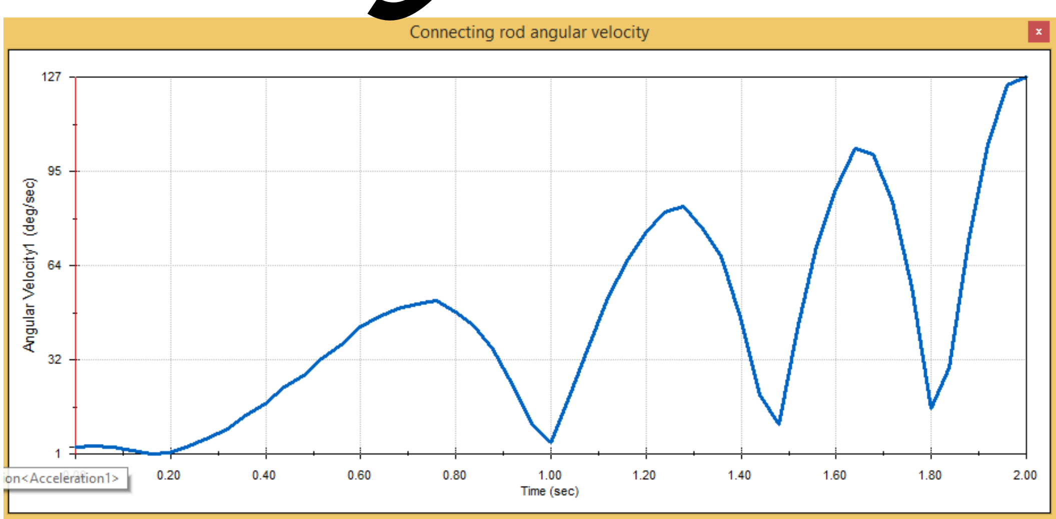


4.2 For connecting rod

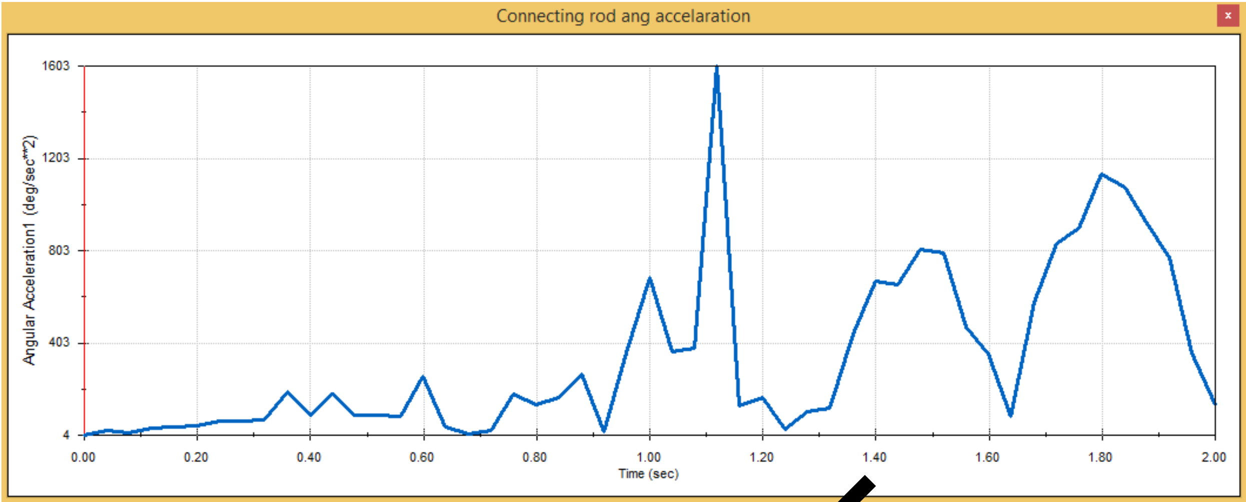
4.2.1 Angular displacement



4.2.2 Angular velocity

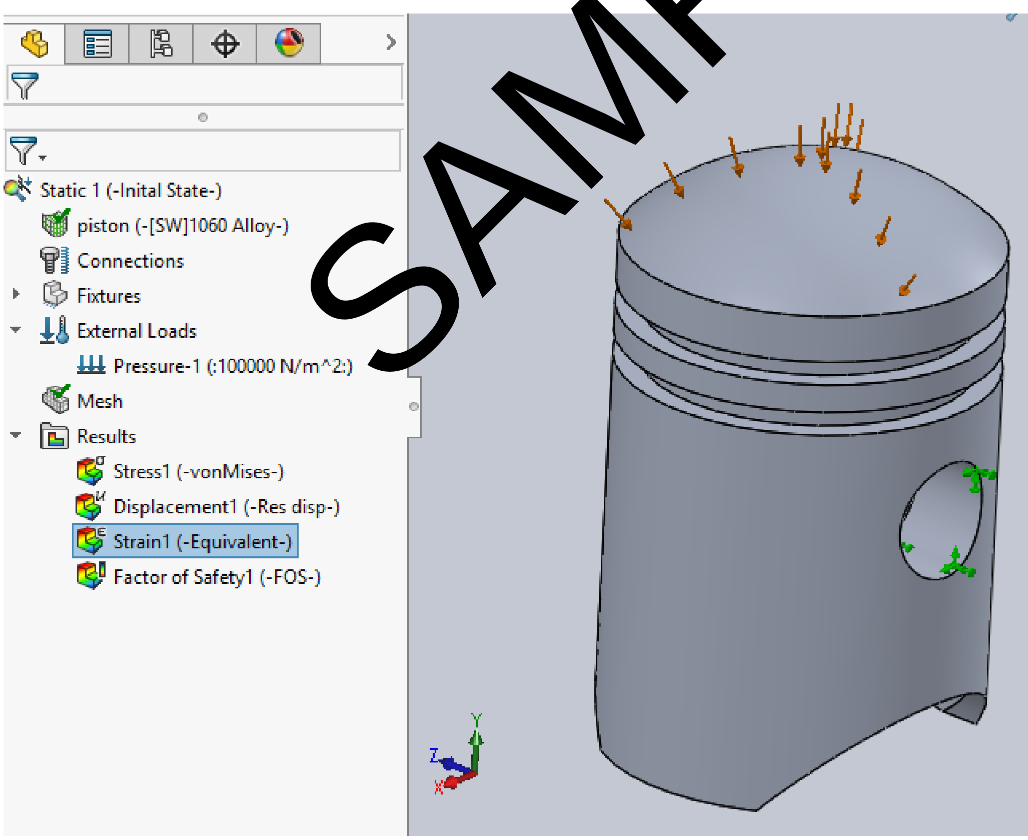


4.2.3 Angular acceleration

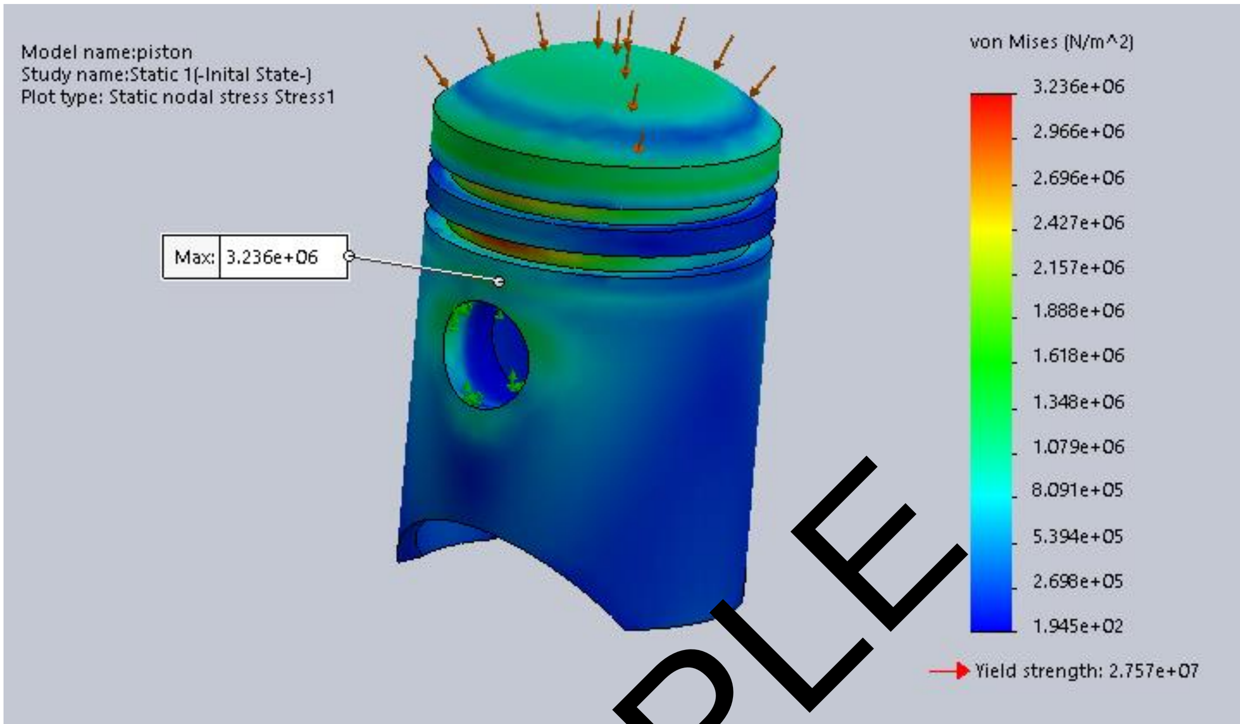


5 Piston Compression study

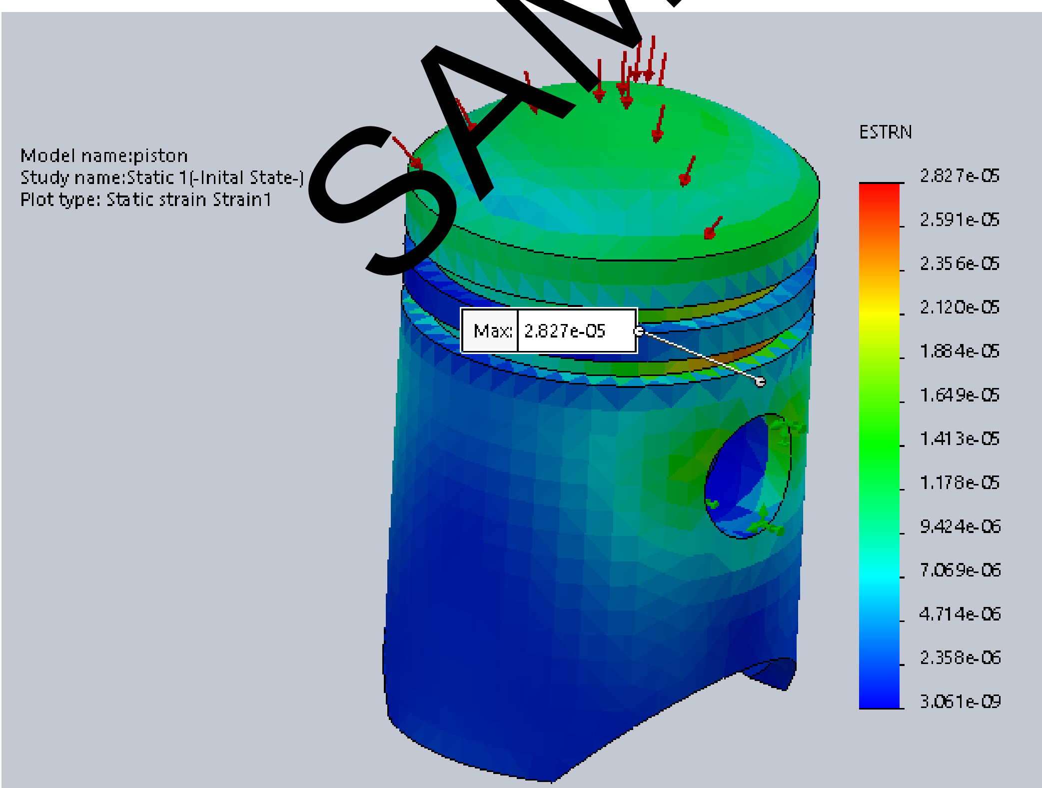
100kPa pressure is applied on the top face of piston and fixity is applied at the piston pin location.



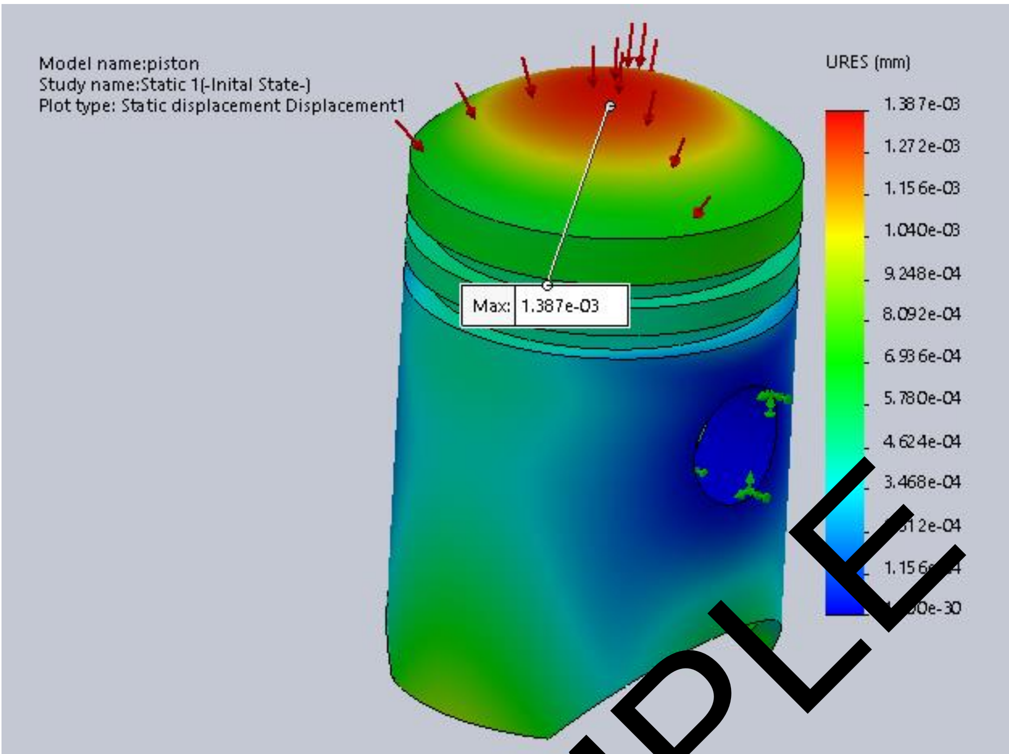
5.1 Stress plot



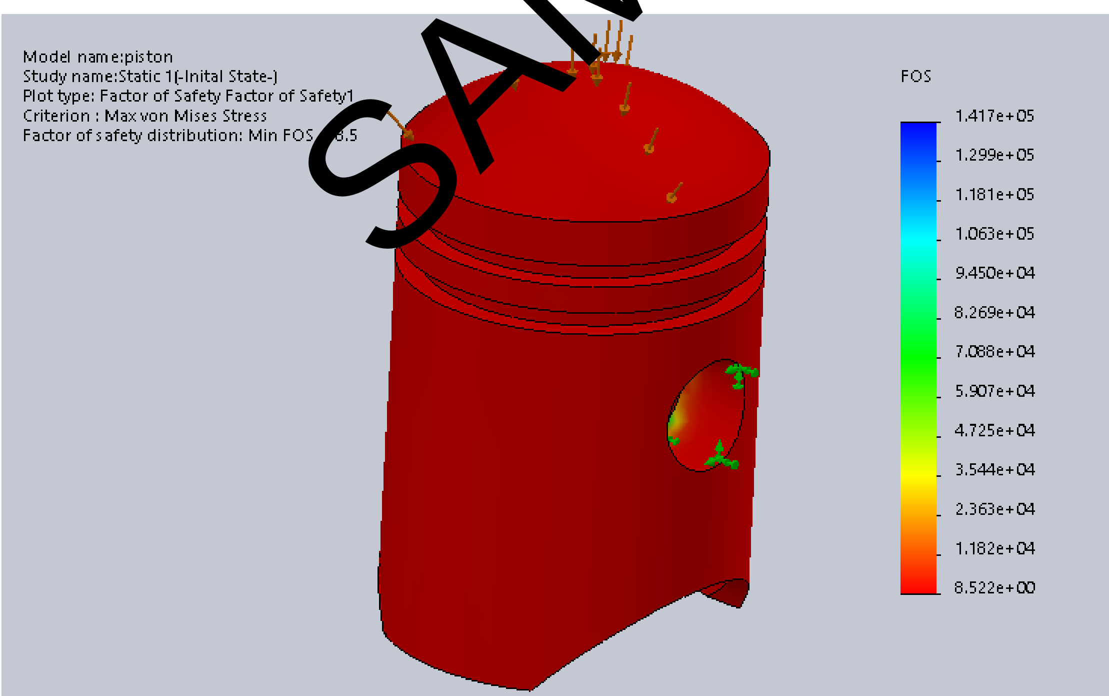
5.2 Strain plot



5.3 Deformation plot

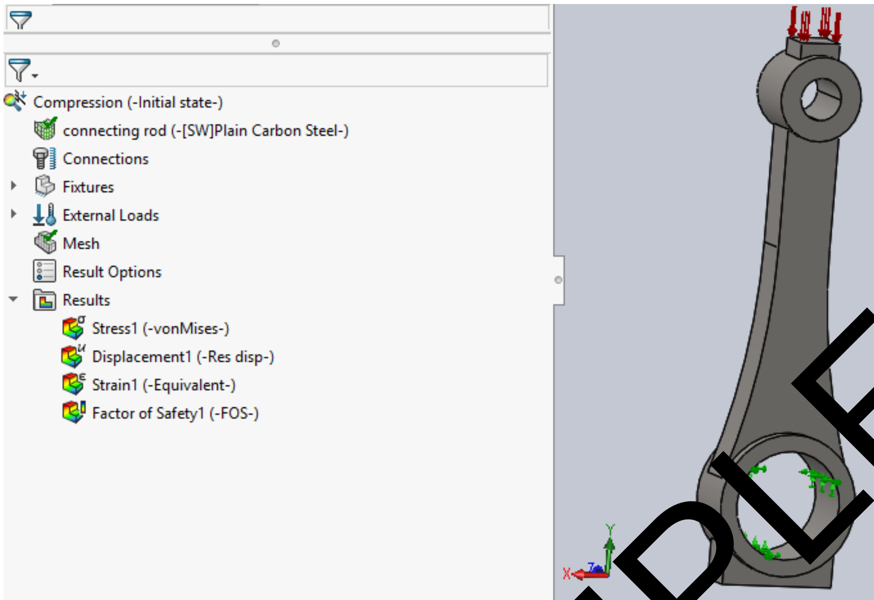


5.4 Factor of safety

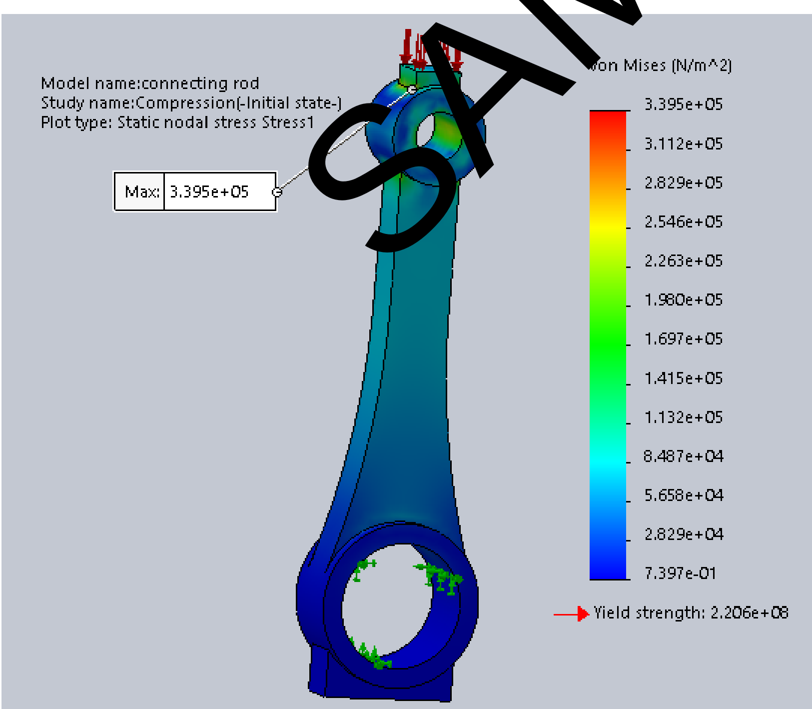


6 Connecting rod Compression study

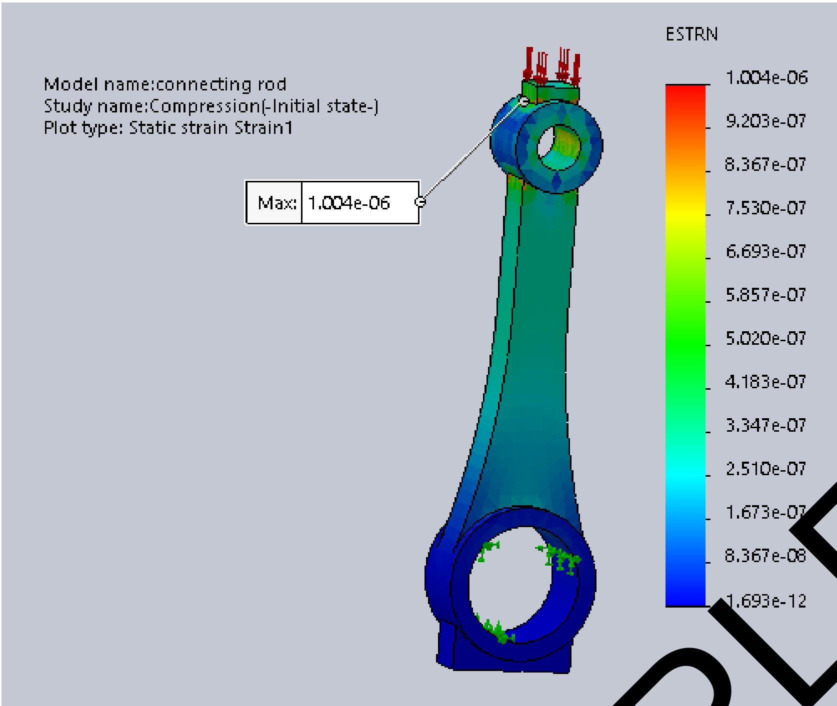
Compressive load of 100kPa is applied on the top face of connecting rod and fixed support is provided along the inner face of large hole.



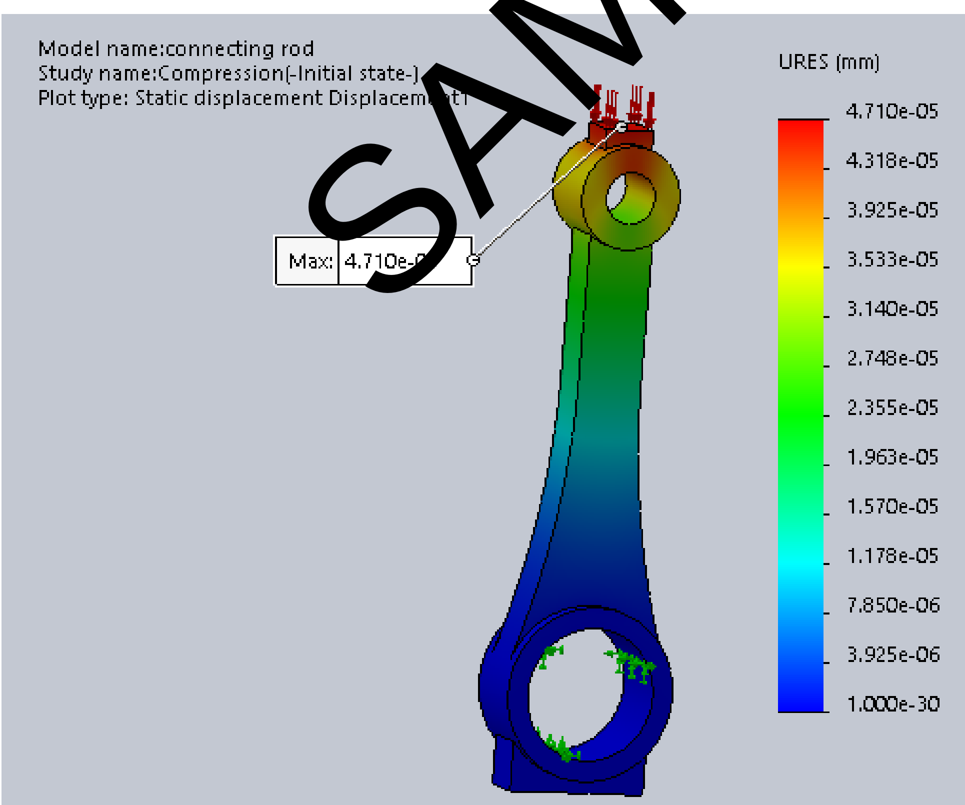
6.1 Stress plot



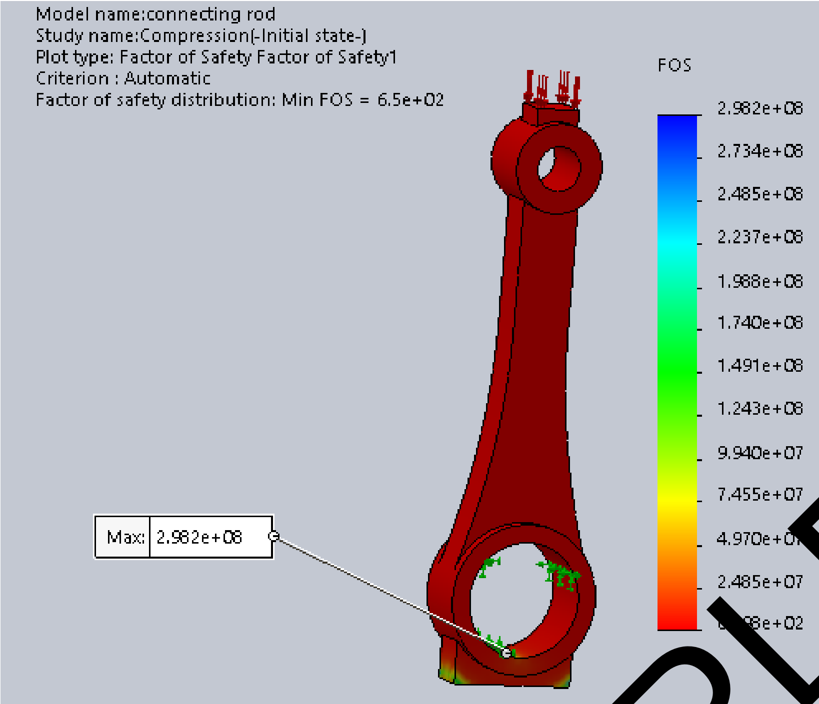
6.2 Strain plot



6.3 Deformation plot

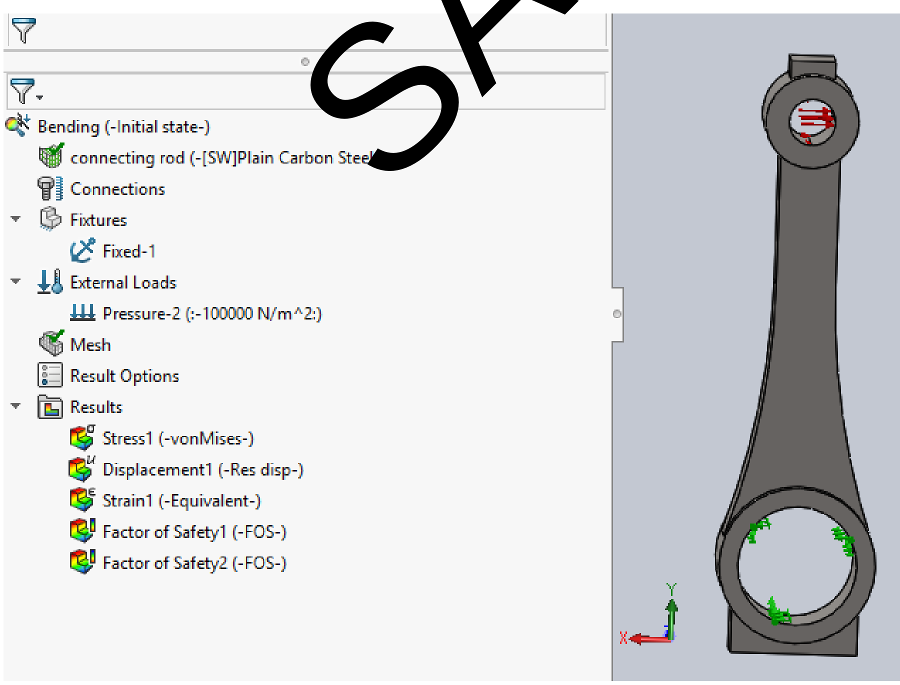


6.4 Factor of safety

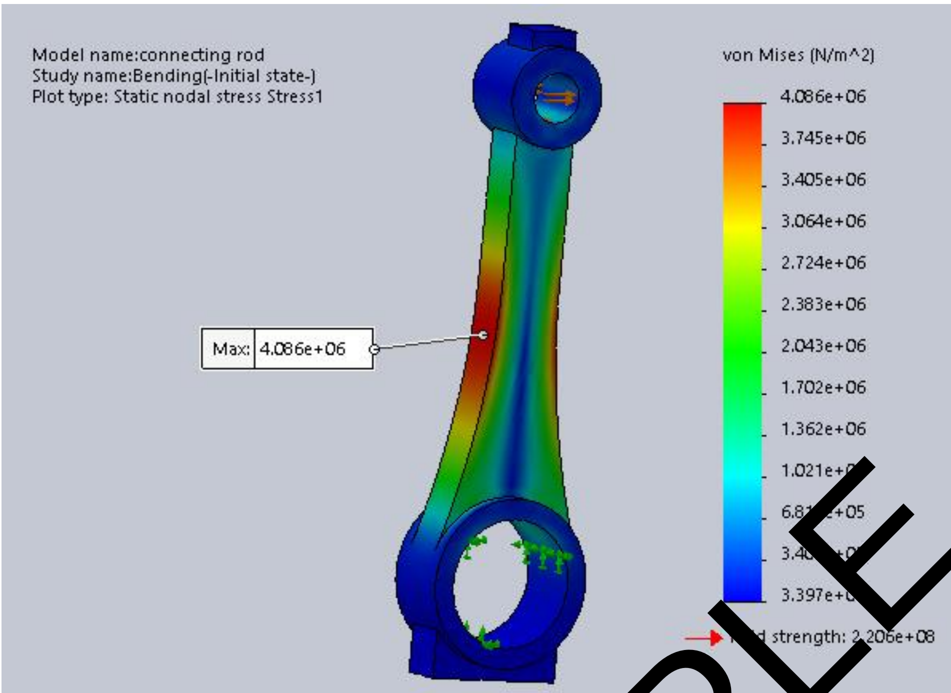


7 Connecting rod bending study

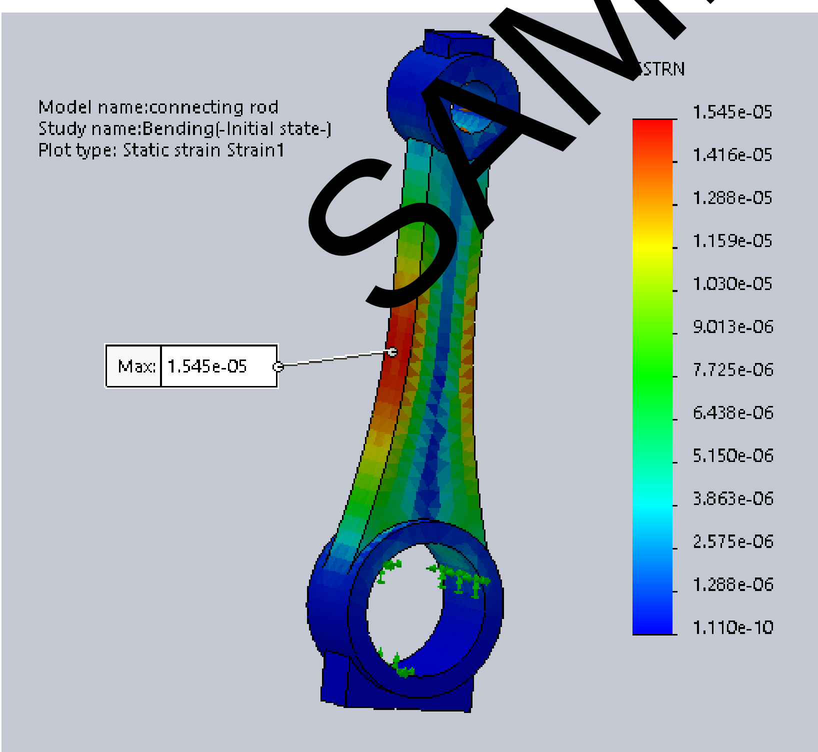
Bending load of 100kPa is applied on the inner faces of connecting rod and fixity is applied along the inner face of large hole.



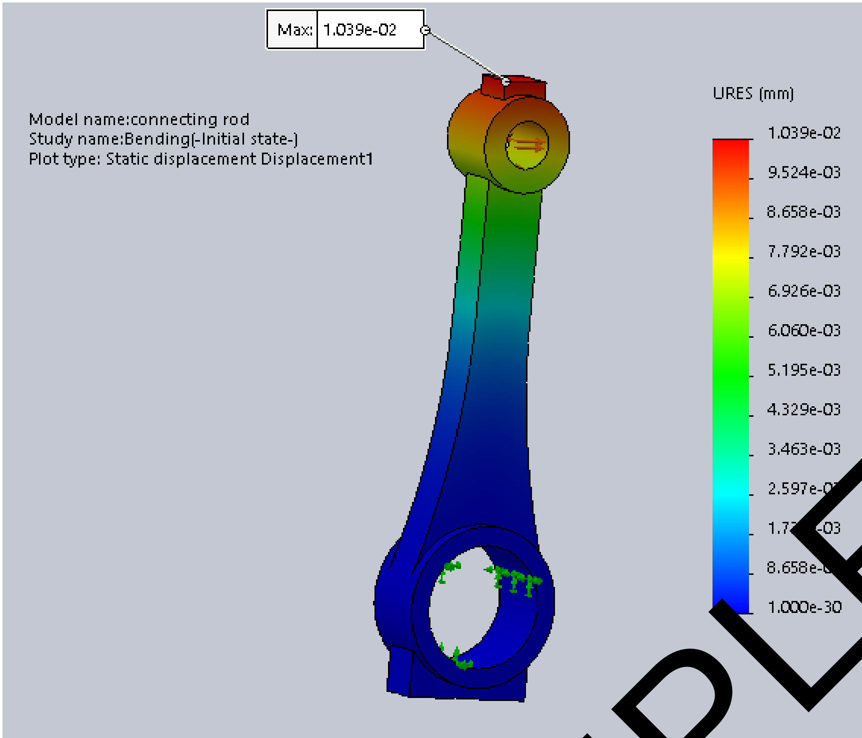
7.1 Stress plot



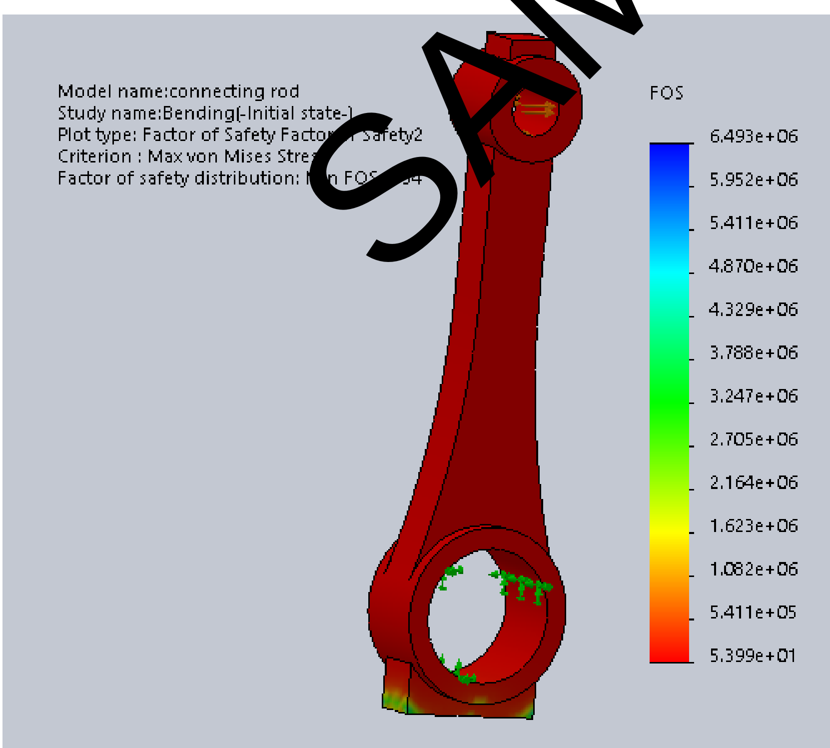
7.2 Strain plot



7.3 Deformation plot

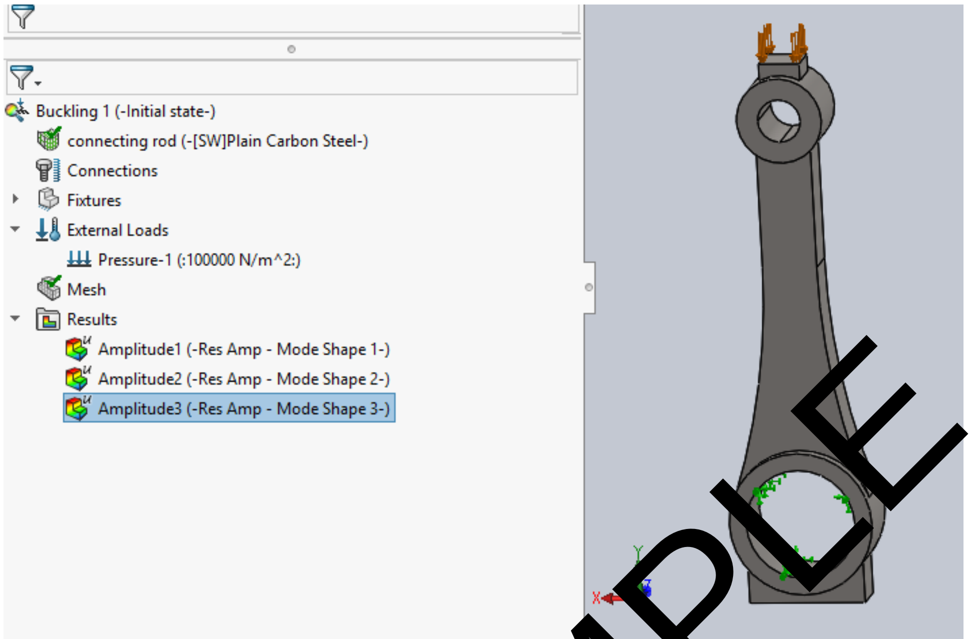


7.4 Factor of safety

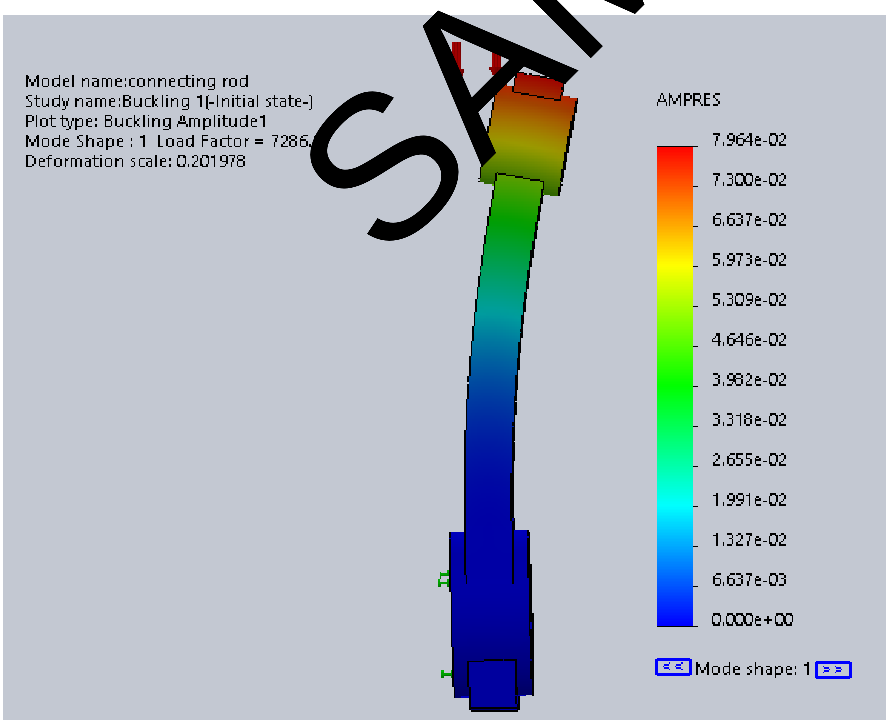


8 Connecting rod buckling study

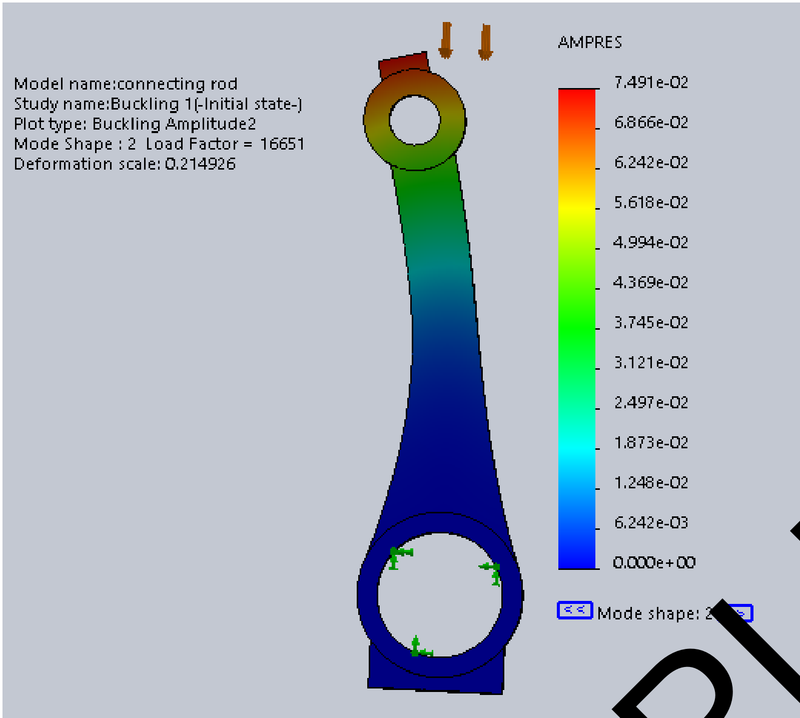
For buckling same loading and boundary as of compression load test are taken into consideration. Three mode shapes are acquired and presented in the next section.



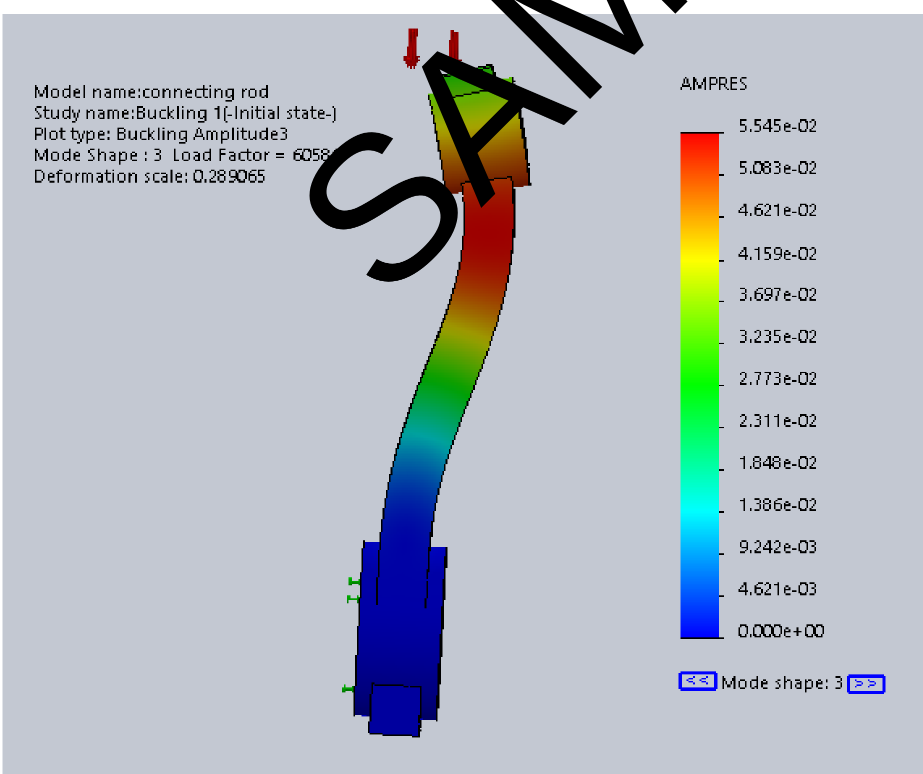
8.1 Mode shape 1



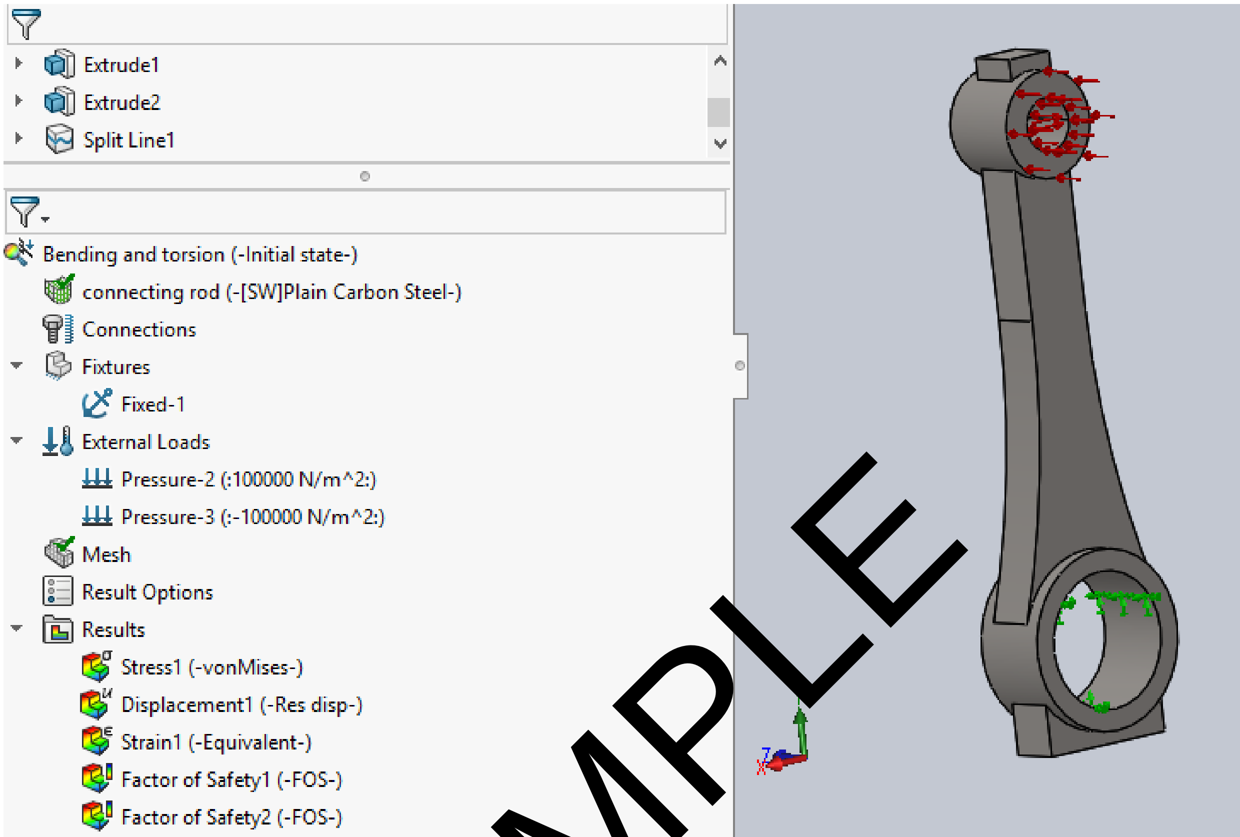
8.2 Mode shape 2



8.3 Mode shape 3



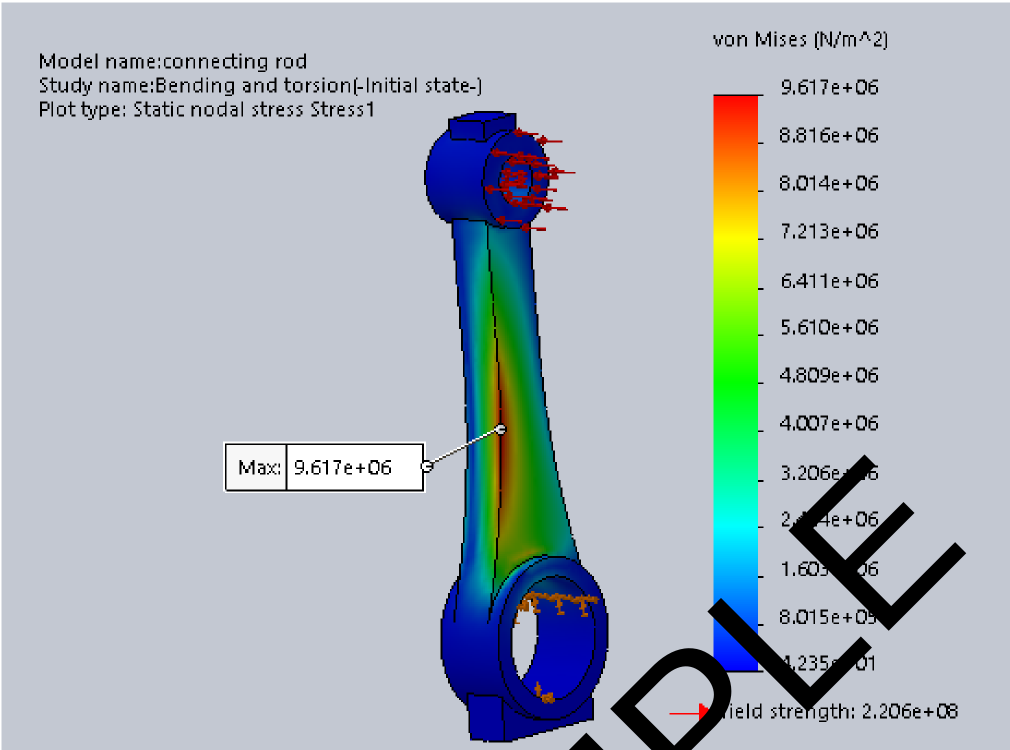
9 Crankshaft bending + torsion study



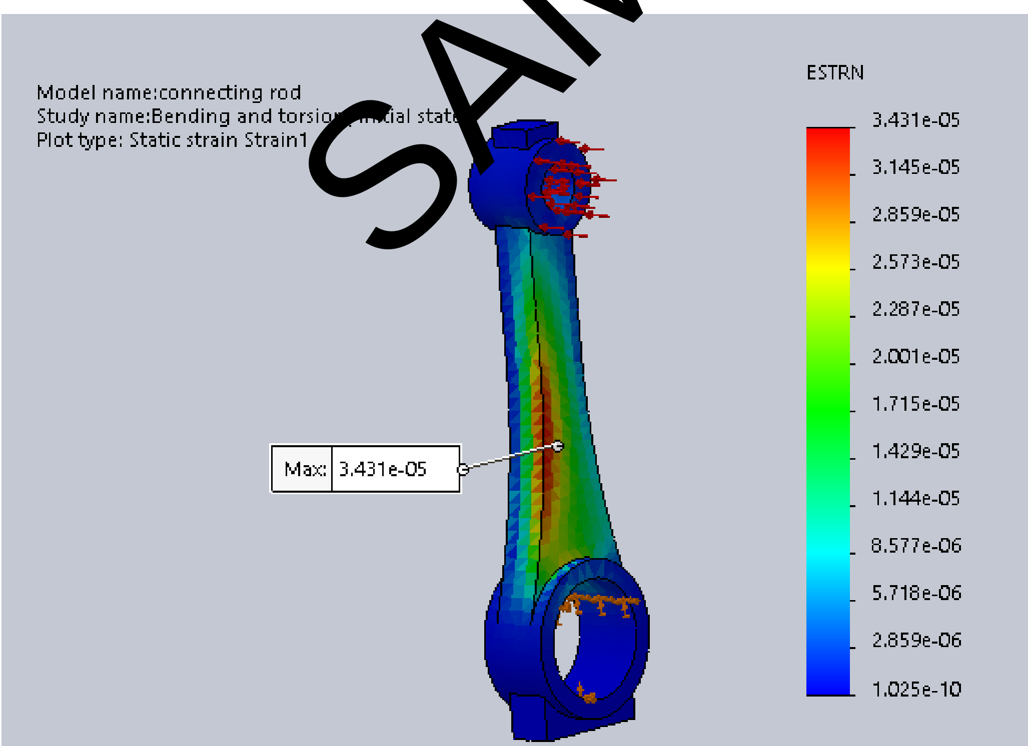
To simulate torsion and bending together pressure of 100kPa is applied on side face of small hole and inner face of small hole for crankshaft. Fixity is applied at the large hole inner face location. Worst case scenario of choking of connecting rod is considered where crank shaft will try to rotate the connecting rod but connecting rod gets stuck within cylinder.

Simulation settings are displayed in the image shown above.

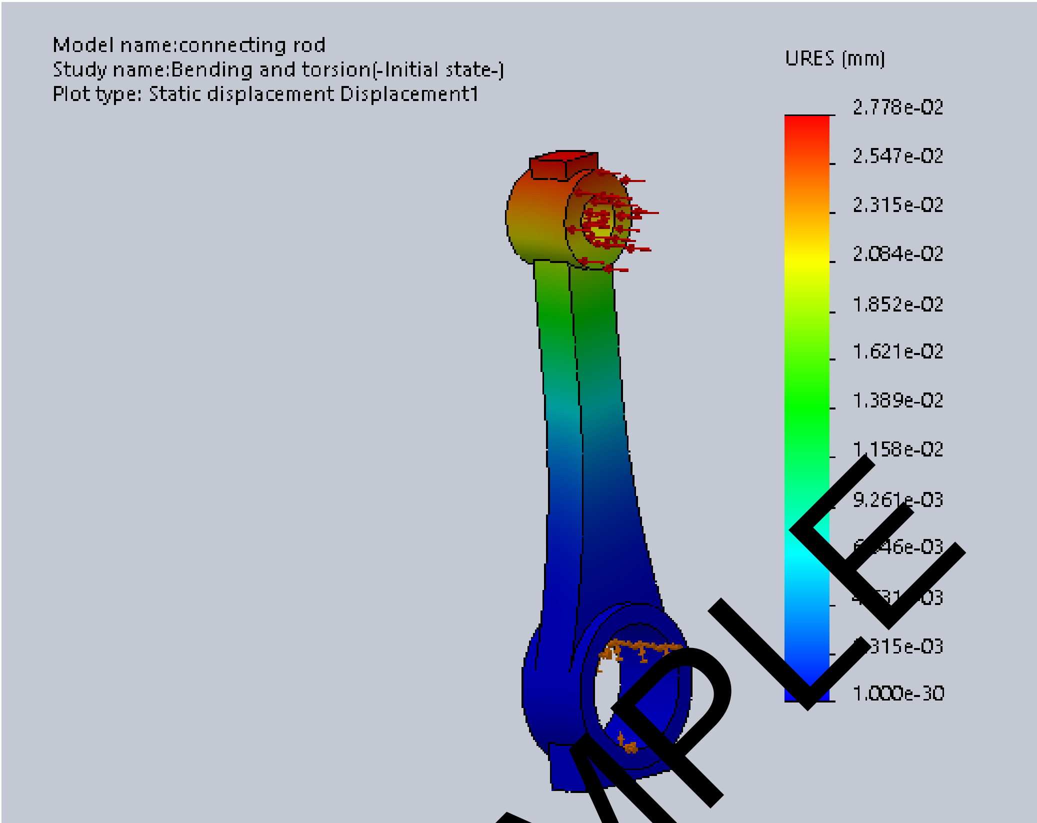
9.1 Stress plot



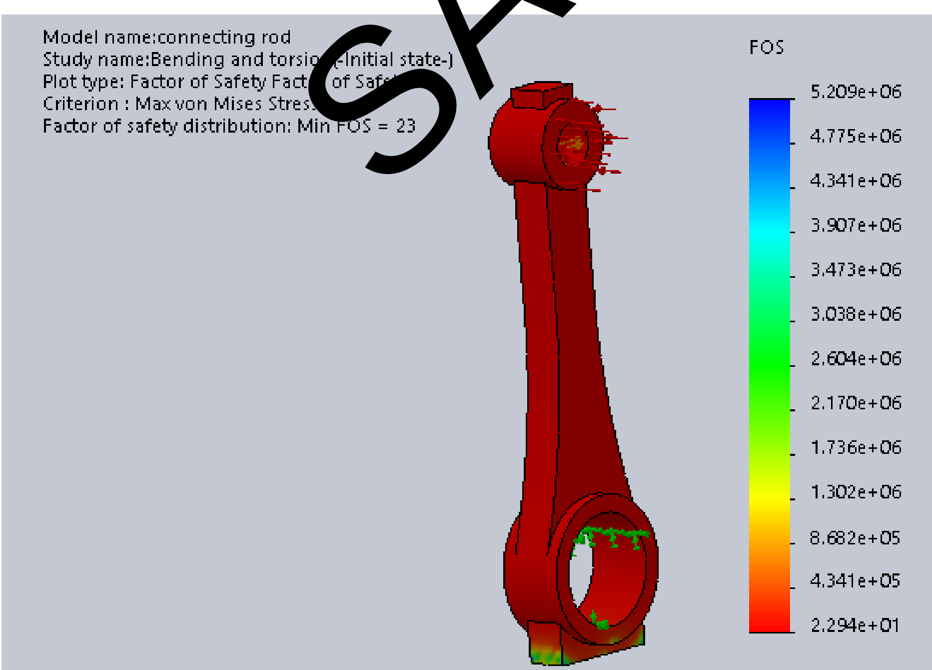
9.2 Strain plot



9.3 Deformation plot



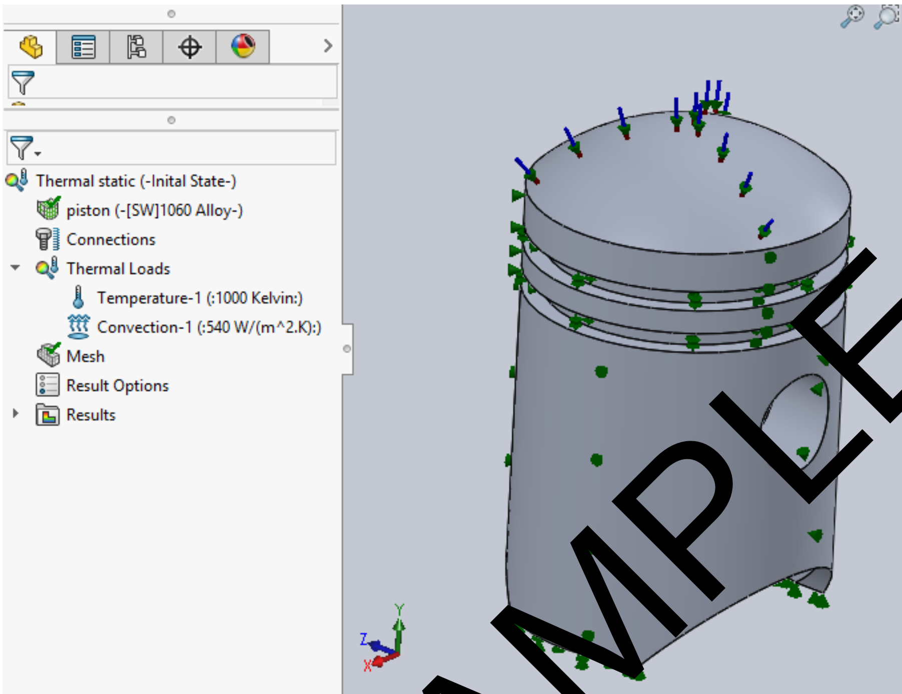
9.4 Factor of safety



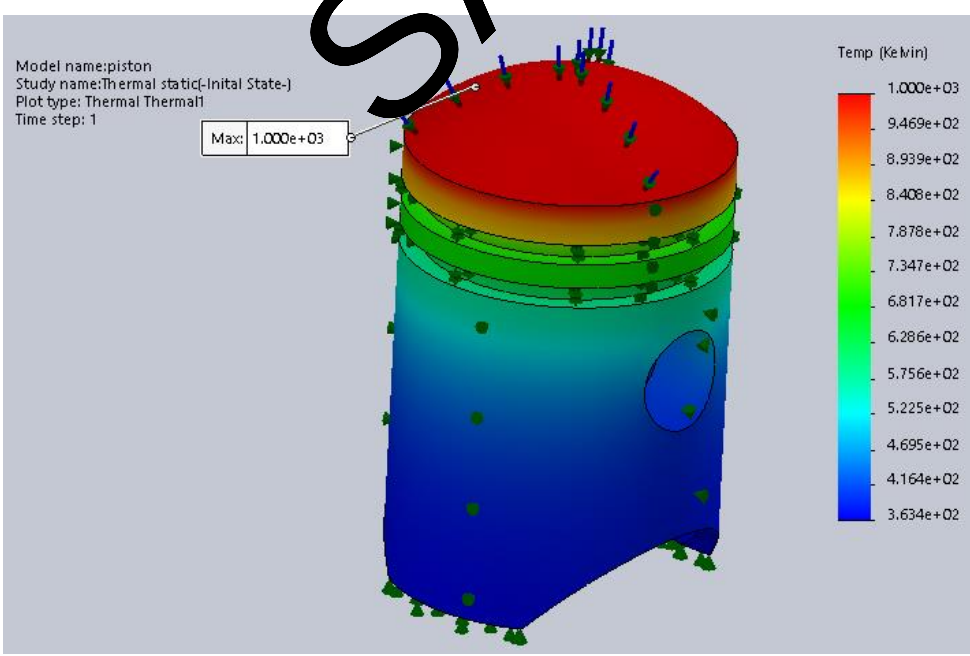
10 Piston thermal analysis

Convective heat transfer of 540W/m^2 is applied in addition to temperature of 1000K to top surface of piston.

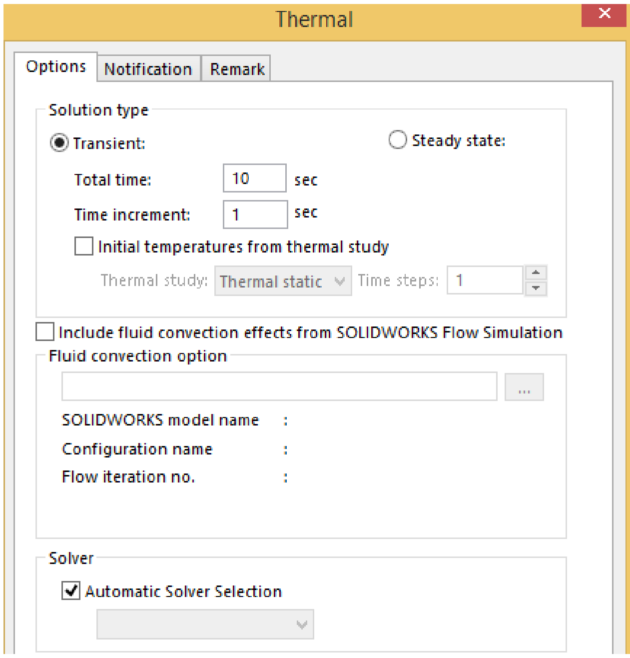
10.1 Steady state heat transfer

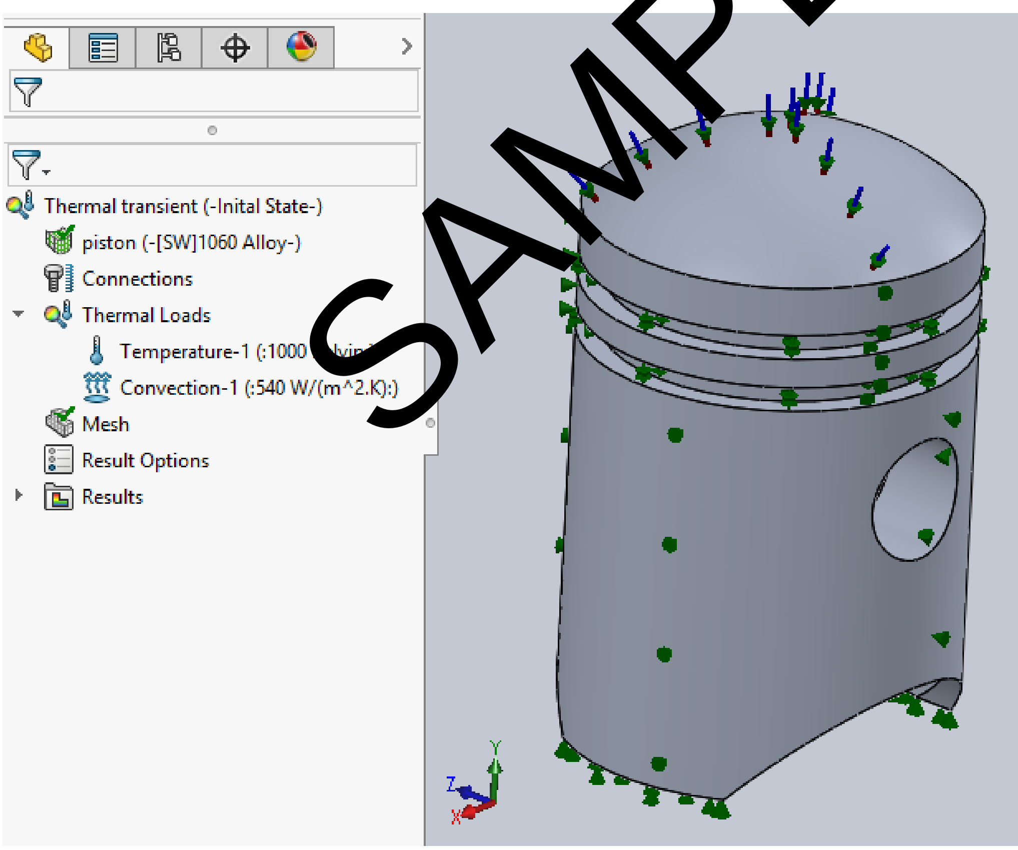


10.1.1 Temperature distribution

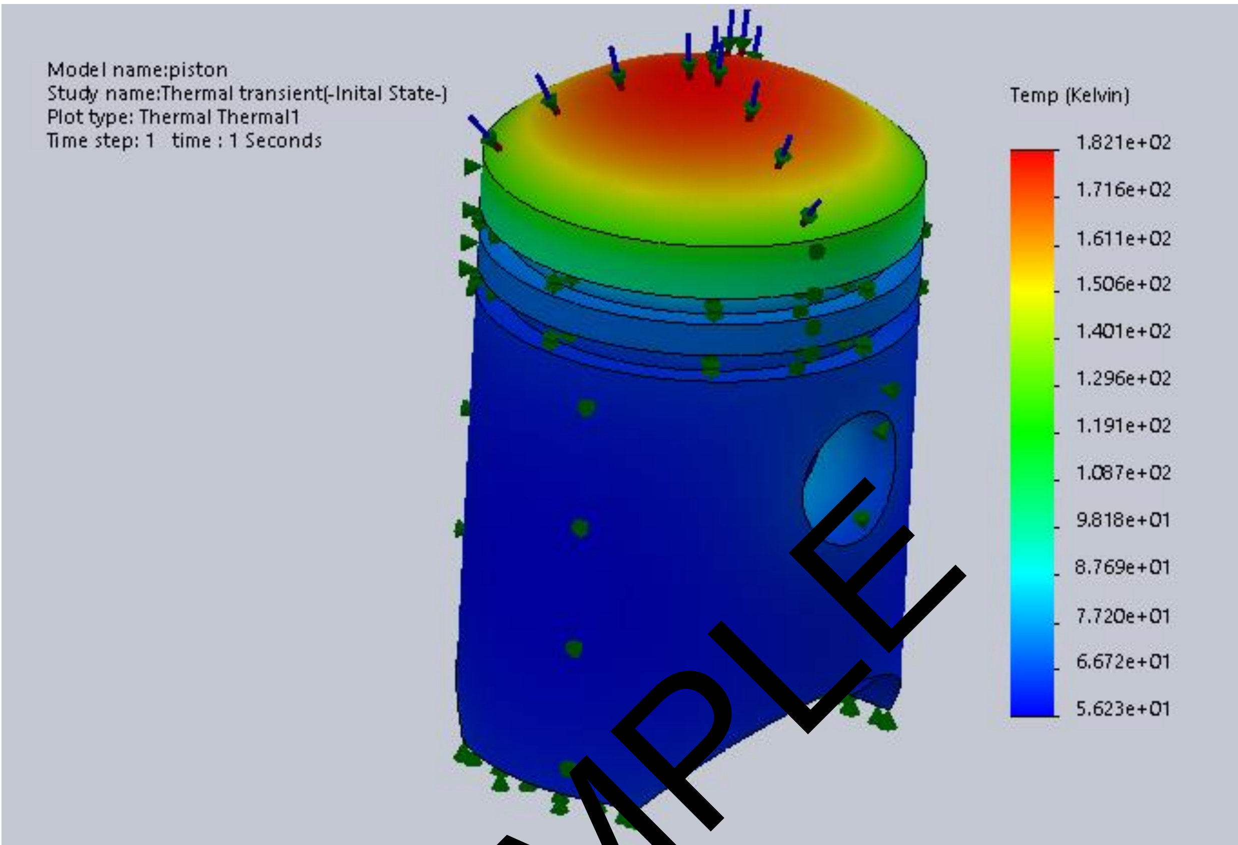


10.2 Transient heat transfer





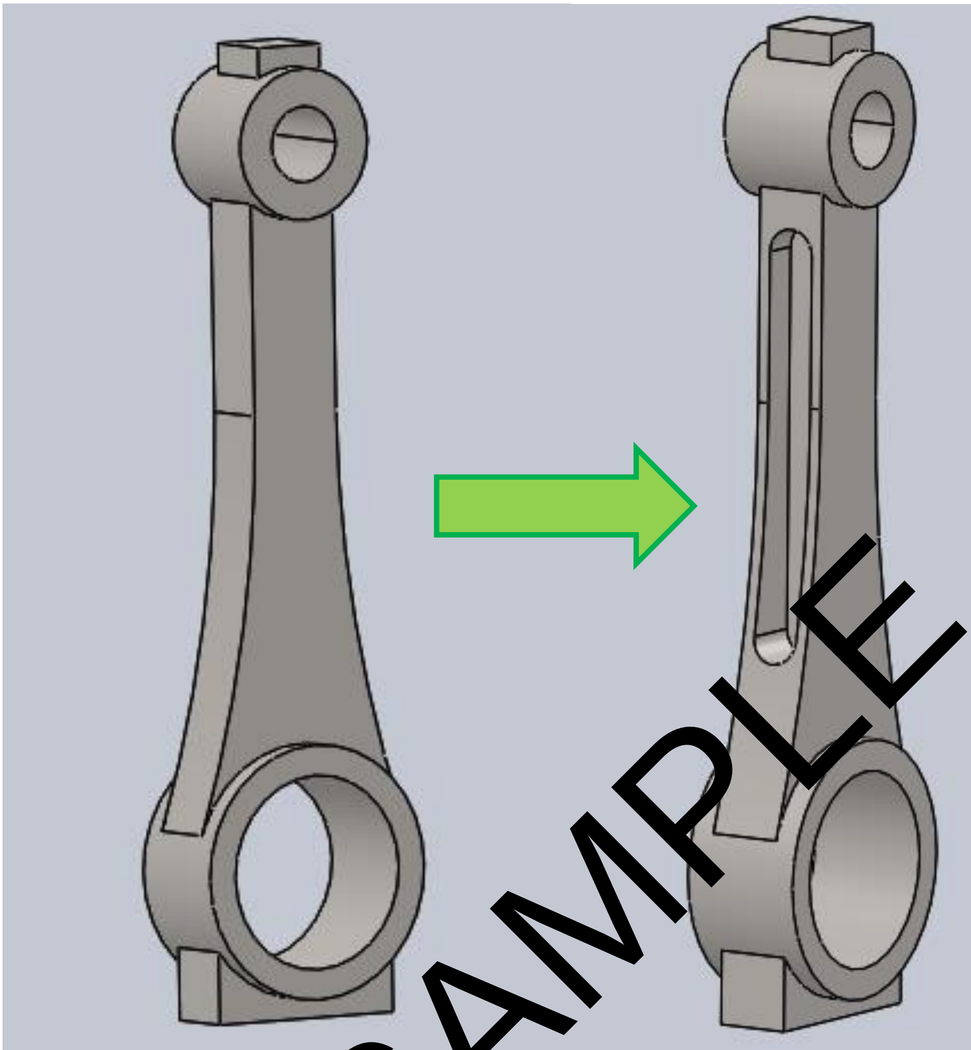
10.2.1 Temperature distribution



In transient thermal analysis, piston gets more cooled than in case of steady state thermal analysis. Even though both analysis shows same sort of temperature distribution pattern, temperature difference observed in both the cases is quite different.

11 Design optimization

Design optimization is carried by two ways, manually changing geometry and second by design study in solidworks. In first case, to reduce weight of connecting rod, a vertical slot is made in the original design. Updated design is checked for torsion + bending case only as it is the most critical case (least FOS) for connecting rod.



Mass properties of connecting rod
Configuration: Initial state
Coordinate system: -- default --

Density = 0.01 grams per cubic millimeter

Mass = 335.22 grams

Volume = 42976.83 cubic millimeters

Surface area = 14922.23 square millimeters

Center of mass: (millimeters)
X = 0.00
Y = -70.57
Z = 0.00

Mass properties of connecting rod_optimised
Configuration: Initial state
Coordinate system: -- default --

Density = 0.01 grams per cubic millimeter

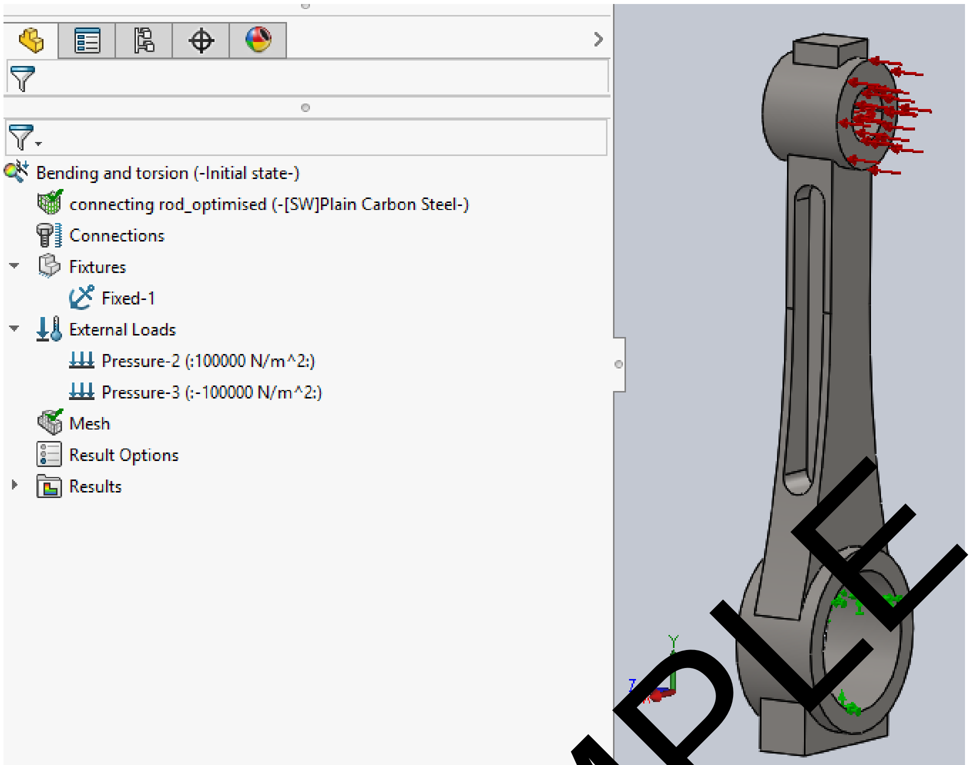
Mass = 277.25 grams

Volume = 35545.00 cubic millimeters

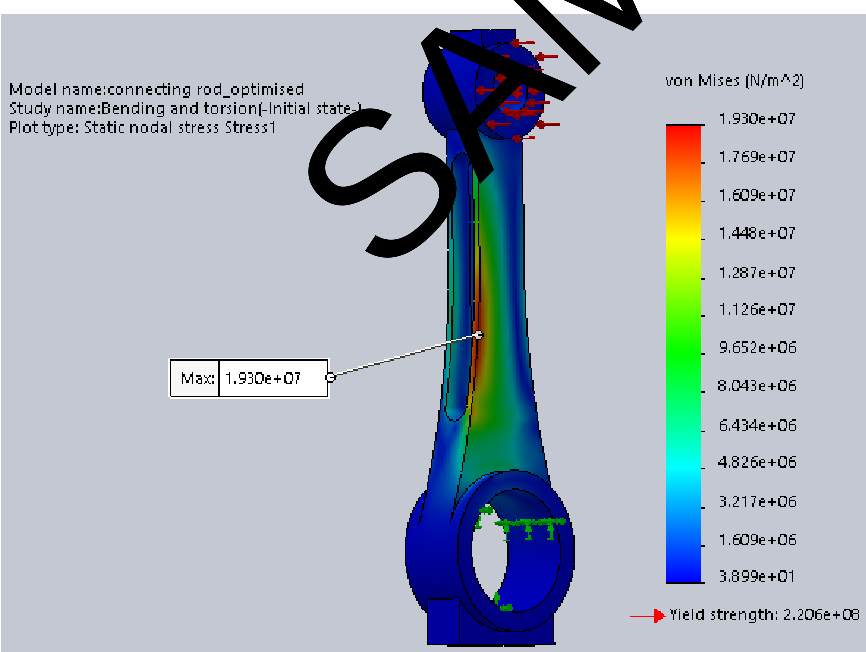
Surface area = 16978.41 square millimeters

Center of mass: (millimeters)
X = 0.00
Y = -74.07
Z = 0.00

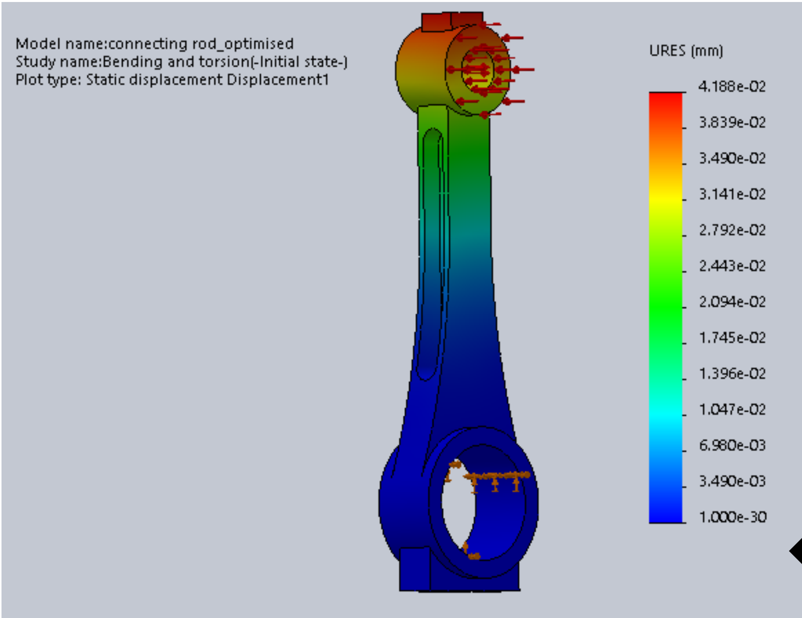
11.1 Revised analysis



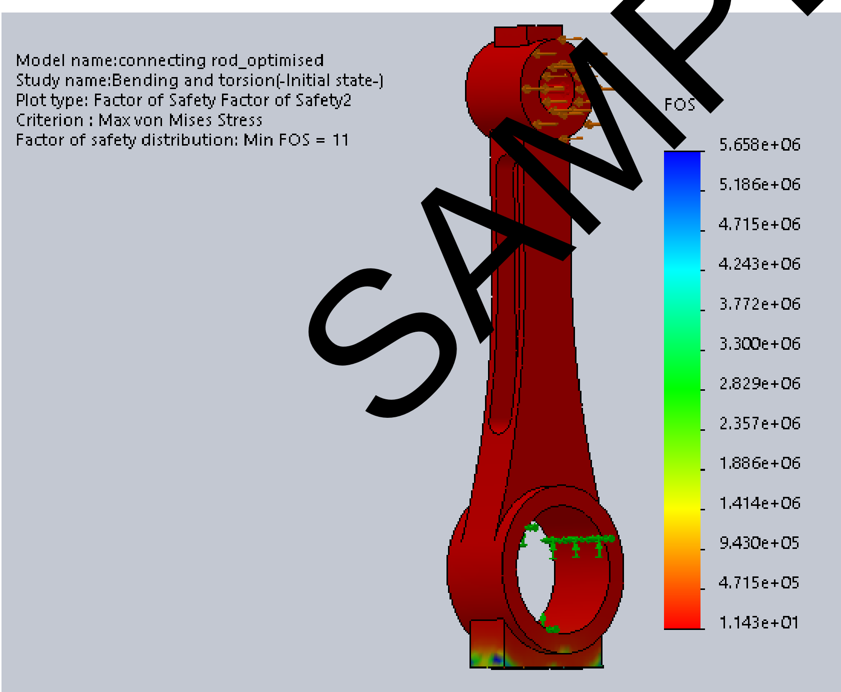
11.1.1 Stress plot:



11.1.2 Displacement plot:



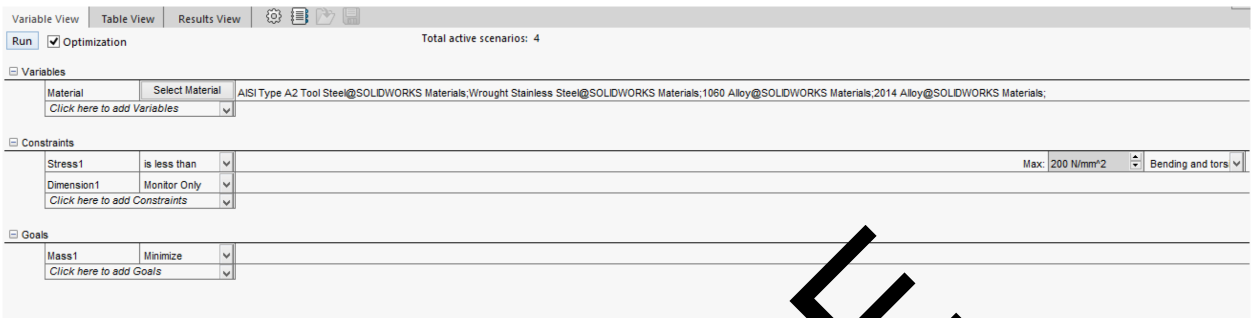
11.1.3 Factor of safety:

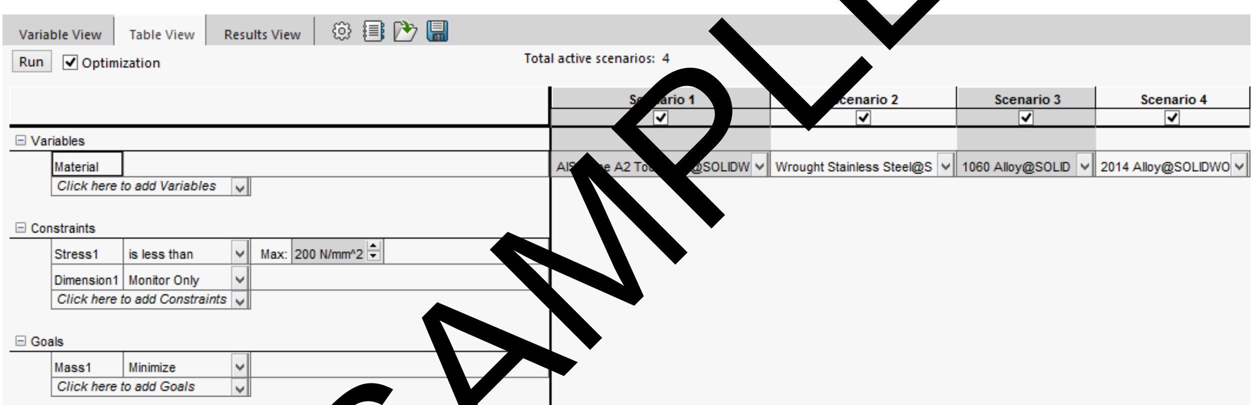


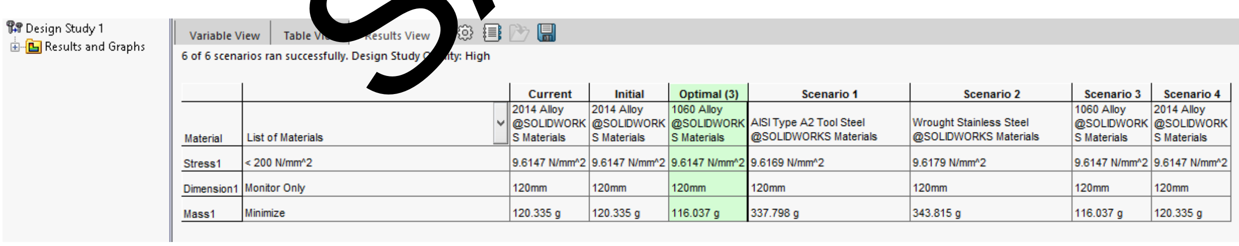
In the revised design of connecting rod weight reduction of 58gm is achieved at the expense of Factor of safety decrease from 23 to 11. Optimized design passes von-Mises stress criteria, hence it can withstand applied loading.

11.2 Material Optimization

Four materials are considered for this optimization approach, Al 2014 Alloy, AISI Type A2 tool steel, wrought stainless steel, Al 1060 Alloy. Constraint is to keep von-Mises stress in bending + torsion cases, below 200MPa and above four materials are selected as variable. Goal of this study is to minimize weight of connecting rod.







		Current	Initial	Optimal (3)	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Material	List of Materials	2014 Alloy @SOLIDWORKS Materials	2014 Alloy @SOLIDWORKS Materials	1060 Alloy @SOLIDWORKS Materials	AISI Type A2 Tool Steel @SOLIDWORKS Materials	Wrought Stainless Steel @SOLIDWORKS Materials	1060 Alloy @SOLIDWORKS Materials	2014 Alloy @SOLIDWORKS Materials
Stress1	< 200 N/mm^2	9.6147 N/mm^2	9.6147 N/mm^2	9.6147 N/mm^2	9.6169 N/mm^2	9.6179 N/mm^2	9.6147 N/mm^2	9.6147 N/mm^2
Dimension1	Monitor Only	120mm	120mm	120mm	120mm	120mm	120mm	120mm
Mass1	Minimize	120.335 g	120.335 g	116.037 g	337.798 g	343.815 g	116.037 g	120.335 g

12 List of Results and discussion:

Motion Analysis	**Max value**	**Units**
Linear Displacement (Max)	431.8	mm
Linear Velocity (Max)	236	mm/s
Linear Acceleration (Max)	3044	mm/sec2
Angular displacement (Max)	11	deg
Angular velocity (Max)	127	deg/sec
Angular acceleration (Max)	1603	deg/sec2

In motion analysis it is observed that linear displacement and angular displacement follow sinusoidal wave whereas acceleration is fluctuating continuously. During power stroke, change in velocity i.e. acceleration is observed to be maximum.

Piston Compression		
Stress Plot (Max)	3.23	MPa
Strain Plot (Max)	2.83E-05	
Displacement (Max)	1.39E+03	mm
FOS (Minimum)	8.5	

In piston compression simulation, maximum stress of 3.23MPa with factor of safety 8.5 against yield is observed. Maximum von-Mises theory is used to predict factor of safety. Considering given factor of safety piston clearly withstands applied loading without failure

Connecting rod compression		
Stress Plot (Max)	0.3395	MPa
Strain Plot (Max)	1.00E-06	
Displacement (Max)	[illegible].71E-0[illegible]	mm
FOS (Minimum)	64[illegible].8	
Connecting rod bending		
Stress Plot (Max)	4.086	MPa
Strain Plot (Max)	1.55E-05	
Displacement (Max)	1.04E-02	mm
FOS (Minimum)	54	
Connecting rod bending + torsion		
Stress Plot (Max)	9.617	MPa
Strain Plot (Max)	3.43E-05	
Displacement (Max)	2.78E-02	mm
FOS (Minimum)	23	

Connecting rod is analyzed for three cases such as compression, bending and bending + torsion. As expected least factor of safety is observed in the bending + torsion case which is 23. Von-Mises stress theory is used in all cases to predict factor of safety against yielding. Since FOS >>1, there is space for material and dimension optimization.

Connecting rod buckling		
Mode number	AMPRES	Load factor
Mode 1	7.96E-02	7286.2
Mode 2	7.49E-02	16651
Mode 3	5.55E-02	60586

Connecting rod is observed to withstand buckling load with load factor of 7286.2 which is huge. Connecting rod will not fail for applied buckling load. Critical buckling load is 100kPa*7286.2=7286.2MPa

Thermal Analysis			
	Max temp (K)	Min temp (K)	delta T (K)
Piston steady state heat transfer	1000	363.4	636.6
Piston transient state heat transfer	182.10	56.23	125.87

In thermal analysis of piston transient analysis process took more time than steady state analysis as expected. After 10sec, transient analysis, with same initial temperature as steady state analysis delta T of 125.87K is observed whereas same for steady state condition is 636.6K

Design Optimization	
Material	1050 Alloy (Aluminum)

Material optimization is performed to reduce weight of the connecting rod, constraining maximum von-Mises stress to 200MPa, it is observed that Aluminum 1050 Alloy is best material out of all selected for connecting rod.

13 Conclusion and recommendation:

According to the load cases considered, it is evident that minimum factor of safety is observed on piston compression test (8.5). Most critical simulation case for connecting rod is bending +torsion which means if connecting rod sustains this load case it can sustain other load cases comfortably. In material optimization, weight reduction of around 35% is observed (335gm to 116gm) without much change in strength of the connecting rod. Considering whole assembly, 219gm in each connecting rod makes it total of 876gm weight reduction in whole assembly.

For future work, it is recommended that, load case values must be taken from laboratory readings in order to make simulation more practical and realistic.

References:

- Thermal and Static Structural Analysis on Piston G.V.N. Kaushik International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8 Issue-7 May, 2019
- R. Munro, "Some diesel piston features in design analysis and experiment", SAE Paper 790858, 1979
- Srinadh M and RajasekharaBabu K 2015 Static and Thermal Analysis of Piston and Piston Rings, International Journal of Engineering Technology, Management and Applied Sciences 3(8) 51-58
- Singh P and Pramanik D 2015 Structural and thermal analysis of a C. I. engine piston of different materials using FEM technique, MR International Journal of Engineering and Technology 7(1) 41-48