Manshi Agrawal, 2021, 9:4
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

Analysis of Screws under Different Types of Loading

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Abstract- Screw failures can have catastrophic consequences and significant financial losses. Typically, screw failure modes are failures due to axially applied loads, may result from torsional loads or a combination of both loads. Insufficient design considerations, material problems, insufficient pre-loading and overloading can all contribute to screw failure. This study investigates screw failure when subjected to different types of loads. In the first part, the exposure of the load to screw takes place axially. Two different types of material are used, ie plane carbon steel and AISI 1020, and the maximum tensile stress that the screw can withstand is calculated. After calculating the theoretical load, SOLIDWORKS analysis was performed for the confirmation of the calculations. In the second part it is subjected to torsional load and in the third part - to the combined axial and torsional load. The same process is performed in the next two parts. The simulation is performed and the results are obtained. It has been found that the results obtained in the calculations are quite close to the results obtained in simulations for all types of loads. Fatigue analysis is also performed at the end of all three types of loading.

Keywords- Screw, SOLIDWORKS, Axial Loading, Torsion Loading, Combined Loading.

I. INTRODUCTION

Screw play a fundamental role in engineering structures as a non-permanent bonding method for the aerospace, infrastructure, civil, automotive, energy production / distribution industries and many other industries. Screw failures can have catastrophic consequences and significant financial losses.

Common screw failure modes are failures due to the load being applied axially, a torsional load, or the combination of both loads may result. Insufficient design considerations, material problems, insufficient preload and excessive loads all can contribute to the failure of the screw.

In this study, the stress calculations of the screw are studied when it is subjected to different types of loading. The maximum stress that the screw can bear is calculated theoretically using the standard equations. In this chapter, the basic functions of screw, its advantages and disadvantages are Discussed in detail. Screw failures can have catastrophic consequences and significant financial losses. Common screw failure modes are failures due to the load being applied axially, a torsional load, or the combination of both loads may result. It is discussed why design of screw is important. The fundamentals of fracture the basic theory about stress concentration factor and fatigue is also discussed and the forces acting on the screw under different conditions, and the design process for a screw is studied.

II. LITERATURE REVIEW

Zhao, Jia et al. (2021) presented a new contact load model for ball screws configured with combined axial and radial loads in mind to study elastic deformation displacement and positioning accuracy. To obtain the effect of load conditions on the accurate stability of the ball screw, investigate the deviation and variation of axial elastic deformation due to dimensional errors of all balls.

Cui, Haipo et al. (2021) presented the bio mechanical differences between the three internal fixation configurations for the analysis of Powell's type II and type III femoral neck fractures.

Li, Jiantaoet al. (2020) evaluated the mechanical effect of various configurations formed by screws consisting of only partial screws (PTS) or PTS and full-thread screws (FTS) in the treatment of unstable fractures of the femoral neck

Grotmannet al. (2019) Presentation of a double-stain shredder consisting of a top part and a cutting section, a top part consisting of a corrosion-resistant material and a shaft component, and a cutting part consisting of a material which is hard to use, with a top part attached permanently to the cutting part in a shank portion field by means of an impact extrusion.

Basiaga et al. (2019) presenting a series of screw attachment connections designed to test cold-shaped steel moment attachment behavior. The research experiments contained hot-rolling parallel flange channels, cold-formed lip C-Channels and auto fastening boils. In this study we used two different C-Channels and several different screws.

Sønstabø et al. (2018) used models of finite elements with comprehensive solid element meshes to simulate the behavior of a flow-drill screw link under various quasi-static loadings. The numerical models have been developed using a model of isotropic hypo elastic-plastic material that is independent of the rate.

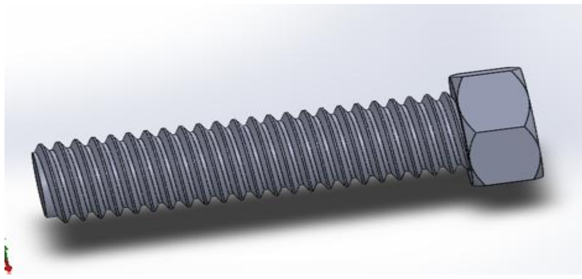
Peng et al. (2019) introduced dislocation movement that links atomic deformation events with crystalline metal microscope strength and ductility. The Burgers vector, of which the line is parallel, play a crucial role in the flow of plastics.

III. RESEARCH METHODOLOGY

The FORCE on the screw < the STRENGTH of the screwFig 3.1 shows a screw drew using SOLIDWORKS. The material of screw selected is plane carbon steel with elastic modulus 210000Mpa. An axial force of 6KN is applied on the head of the screw while its head is fixed and force applied on the left end of the screw. The nominal length is 4.5 cm, with a pitch of 0.2 cm. the major diameter is 7.6mm. The stress acting on the screw is calculated.

Table 1. Main geometry data for testing for case 1.

Elastic modulus	210000MPa
material of screw	plane carbon steel
nominal length	4.5mm
Pitch	0.2 mm
major diameter	7.6mm
Minor diameter	6mm



(a)

(b)

Fig 1. Geometric Model of screw with v threads and Mesh Modal.

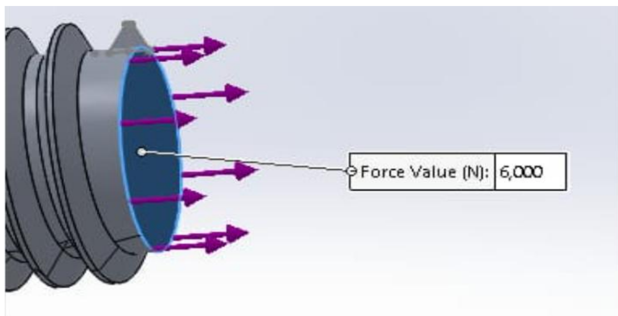


Fig 2. Screw subjected to force of 6000N.

IV. RESULTS AND CALCULATION

In this section, the stress calculations of the screw are studied when it is subjected to different types of loading. In the first part the screw is subjected to axial loading.

International Journal of Science, Engineering and Technology

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The two different types of material i.e. plane carbon steel and AISI 1020 are used and the maximum tensile stress that the screw can bear is calculated. In the second part, it is subjected to torsion loading and in the third part, it is subjected to combined axial and torsion loading.

1. Axial Loading:

Case 1: Material of screw =plain carbon steel

D=7.6mm, d=6mm, r=1mm, α=60°

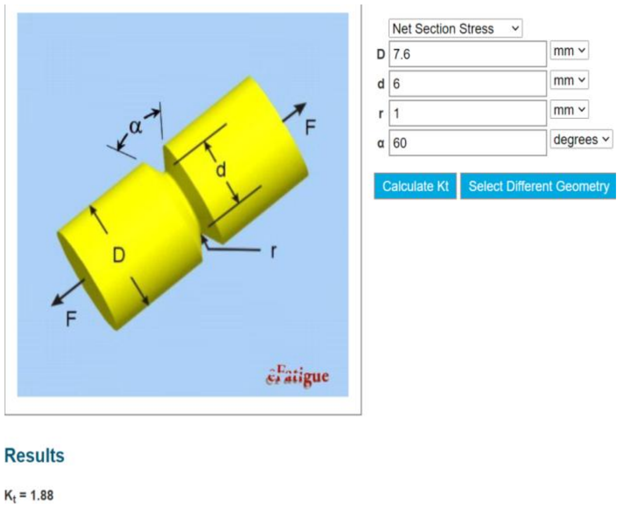

Fig 3. Stress concentration factor calculation.

From efatigue.com,

K_t = 1.88.

Yield strength of plane carbon steel, Yt=220.50

$$\boldsymbol{\sigma_{yt} = 220.50\ \mathrm{N/mm^2}}$$

Maximum force that screw can bear,

$$\boldsymbol{F_{yt} = 220.6 \times 28.3 = 6236\ N}$$

$$F_{yt} = 6.25\ KN \text{ (approx. 6KN)}$$

Now area of cross section of the screw with nominal diameter D is

$$\boldsymbol{A_D = \frac{\pi}{4} D^2} \quad \textbf{(1)}$$

A =45.36mm^2

So,

$$\boldsymbol{\sigma_D = \frac{F}{A_D} = 132.31\ N/mm^2} \quad \textbf{(2)}$$

Or,

$$\sigma_D = 1.32 \times 10^8\ N/m^2$$

$$\boldsymbol{A_d = \frac{\pi}{4} d^2} \quad \textbf{(3)}$$

A =28.27 mm^2

Now,

$$\boldsymbol{\sigma_{max} = \sigma_D \times k_t} \quad \textbf{(4)}$$

$$\sigma_{max} = 1.32 \times 1.89$$

$$\boldsymbol{\sigma_{max} = 248.60\ N/mm^2} \quad \textbf{(5)}$$

$$\boldsymbol{\sigma_{max} = 2.486 \times 10^8 N/m^2} \quad \textbf{(6)}$$

From SOLIDWORKS analysis, the maximum stress was found to be

$$\boldsymbol{\sigma = 2.57\ \times 10^8 N/m^2} \quad \textbf{(7)}$$

Summary

	Value	
Sum	5.176e+11	N/m^2
Avg	2.282e+08	N/m^2
Max	4.994e+08	N/m^2
Min	1.290e+08	N/m^2
RMS	2.323e+08	N/m^2

Fig 4. The average value of stress acting in unthreaded portion.

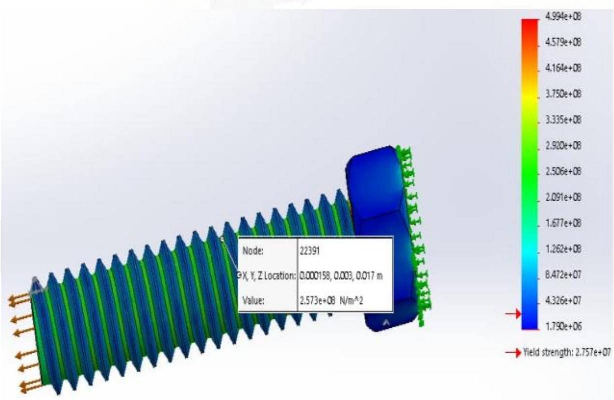

Fig 5. tensile loading for plane carbon steel screw with D= 7.6mm and d=6mm.

From Fig 4 and 5, it can be seen that The Results Obtained through calculations 2.486×10^8 is significantly close to the result obtained from simulation2.57 $\times 10^8$.

Comparing eq (6) and (7), we find that the simulation stress (SOLIDWORKS analysis) is significantly close with a quite less margin of error.

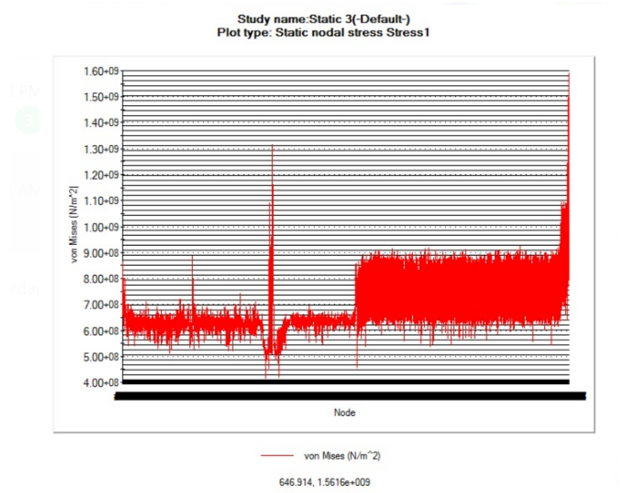

Fig 6. Graph showing stress distribution in threaded portion.

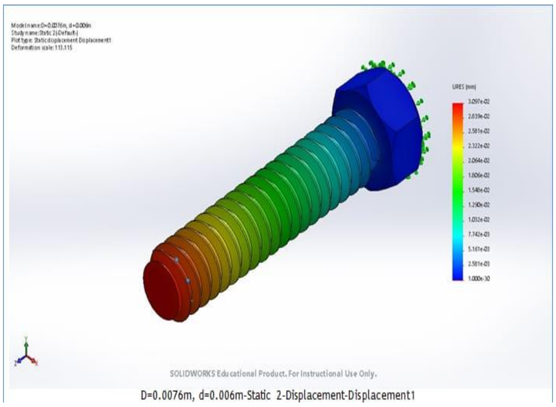

Fig 7. Displacement shown for axial loading.

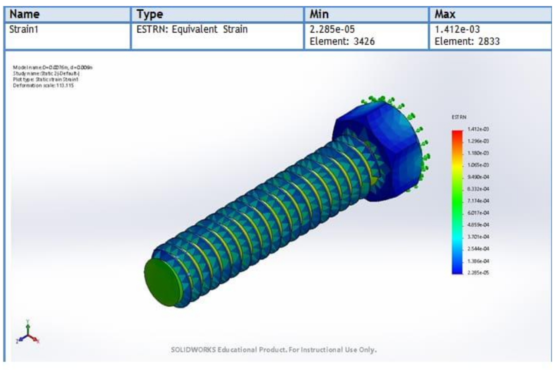

Fig 8. Strain for axial loading example.

The above Fig 7 shows the displacement of the screw as we can clearly see that the more displacement is appeared to be at the bottom end of the screw because the force is applied there so the maximum displacement is occurred at that end.

Case 2: Material of screw= AISI 1020:

For which, Yt=351.5

D= 8.3mm, d=7mm, r = 1mm, α=60°

From efatigue.com, **K_t = 1.9**

$$\sigma_{yt} = 351.5N/mm^2$$
$$\boldsymbol{\sigma_{max} = 4.56 \times 10^8 N/m^2} \quad \textbf{(8)}$$

From SOLIDWORKS analysis,

$$\boldsymbol{\sigma = 4.637 \times 10^8 N/m^2} \quad \textbf{(9)}$$

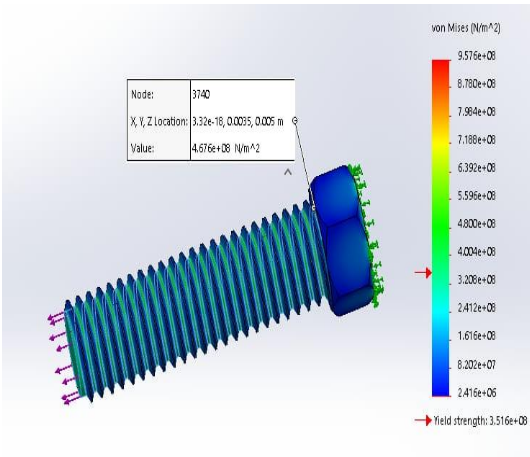

Fig 9. Tensile loading for AISI 1020 screw with D= 8.3mm and d=7mm.

From Fig 9, it can be seen that The Results Obtained through calculations4.58×10^8 is significantly close to the result obtained from simulation4.6×10^8. Comparing eq (12) and (13), we find that the simulation stress (SOLIDWORKS analysis) is significantly close with quite less margin of error.

2. Shear loading:

Case 1: Material of screw =plain carbon steel:

K_t = 1.31

Yield strength for plane carbon steel material,

Yt=220.5 N/mm^2

So the shear strength

$$\boldsymbol{\tau_{yt} = 110.5N/mm^2}$$

Maximum torque that can be applied on the screws is

$$\boldsymbol{M_{max} = \frac{110.5 \times \pi \times 7.6^3}{16}}$$

$$M_{max} = 9.5\ Nm$$

So taking M=9Nm for the calculations

$$\boldsymbol{\tau} = \frac{\mathbf{16M}}{\boldsymbol{\pi}(\mathbf{d_c})^3}$$

$$\tau = \frac{16 \times 8}{\pi(0.006)^3}$$

$$\tau = 2.1 \times 10^8 N/m^2$$

$$\tau_{max} = 2.1 \times 10^8 \times 1.31$$

$$\boldsymbol{\tau_{max} = 2.75 \times 10^8 N/m^2} \qquad \textbf{(10)}$$

Fig 27 shows result of application of torque on screw drawn using SOLIDWORKS. The torque of 9Nm is applied on the bottom end of the screw while its head is fixed. The maximum stress acting on the screw is calculated.

From SOLIDWORKS analysis,

$$\boldsymbol{\sigma_{max} = 2.52 \times 10^8 N/m^2} \qquad \textbf{(11)}$$

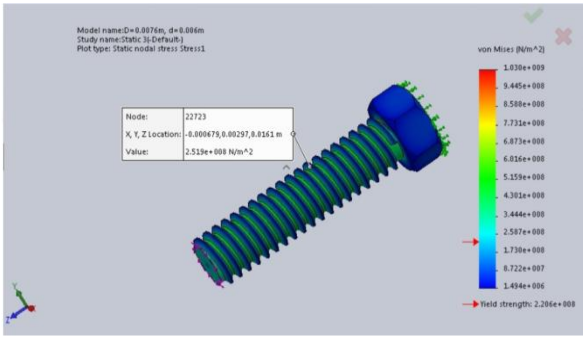

Fig 10. Torsion loading for plane carbon steel screw with D= 7.6mm and d=6mm.

From Fig 12, it can be seen that The Results Obtained through calculations 2.75×10^8 is significantly close to the result obtained from simulation 2.519×10^8. Comparing eq (14) and (15), we find that the simulation stress (SOLIDWORKS analysis) is approximately 8% lower than the calculated maximum theoretical stress.

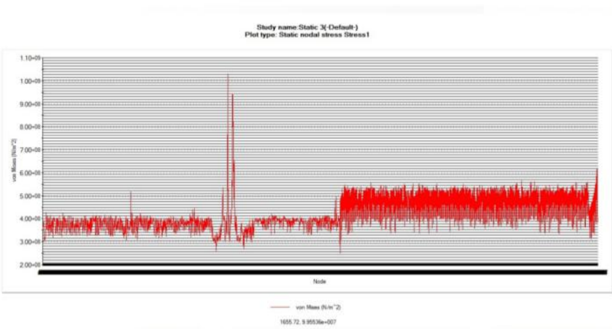

Fig 11. Graph showing stress distribution.

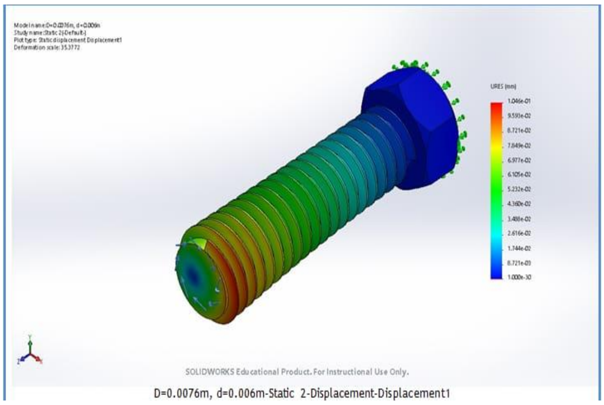

Fig 12 Displacement for torsion loading.

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	5.893e-06 Element: 7803	2.854e-03 Element: 2833

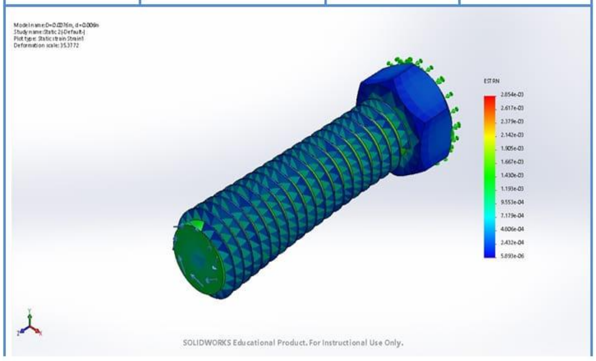

Fig 13. Strain in torsional loading.

Case2: Material of screw= AISI 1020:

$$\mathbf{K_t = 1.34}$$

Yt=351.57

$$\tau_{yt} = 175.8 \, N/mm^2$$

$$\boldsymbol{\tau_{max} = 3.75 \times 10^8 N/m^2} \qquad \textbf{(12)}$$

From SOLIDWORKS analysis,

$$\boldsymbol{\sigma_{max} = 3.44 \times 10^8 N/m^2} \qquad \textbf{(13)}$$

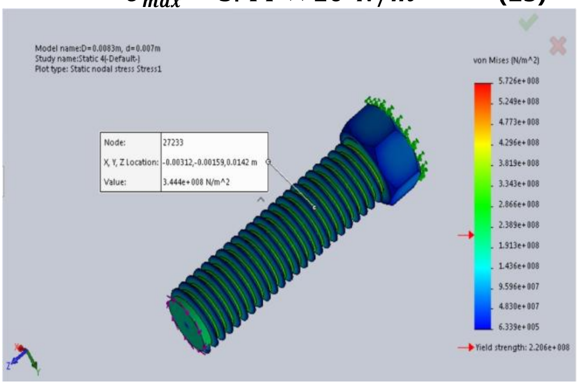

Fig 14. Torsion loading for plane carbon steel screw with D= 8.3mm and d=7mm.

From Fig 14, it can be seen that The Results Obtained through calculations$3.75 \times 10^8 N/m^2$ is significantly close to the result obtained from simulation3.444×10^8. Comparing eq (16) and (17), we find that the simulation stress (SOLIDWORKS analysis) is approximately 8% lower than the calculated maximum theoretical stress.

3. Combined Loading:

For Combined Loading both axial and torsional load is applied

Here, we have applied axial load,

$$\boldsymbol{\sigma_{max} = 2.48 \times 10^8 N/m^2}$$

And torsional load, $\tau_{max} = 2.75 \times 10^8 N/m^2$

The stresses are applied on the material plane carbo steel which is having the yield strength Yt=220.5 N/mm^2 and the material dimentions are as follows-
D= 7.6mm, d=6mm, r = 1mm, α=60

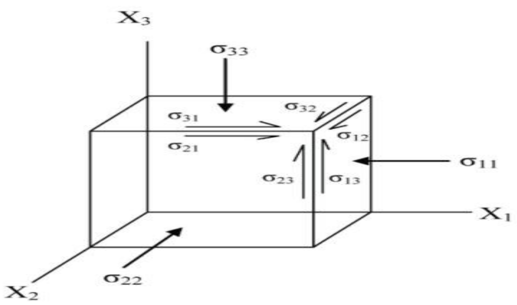

Fig 15. Stress on threaded part in different directions

$$\boldsymbol{\sigma_e = 5.3 \times 10^8 N/m^2} \qquad \textbf{(14)}$$

This is the manually obtained equivalent stress
From SOLIDWORKS analysis,

$$\boldsymbol{\sigma_{max} = 5.361 \times 10^8 N/m^2} \qquad \textbf{(15)}$$

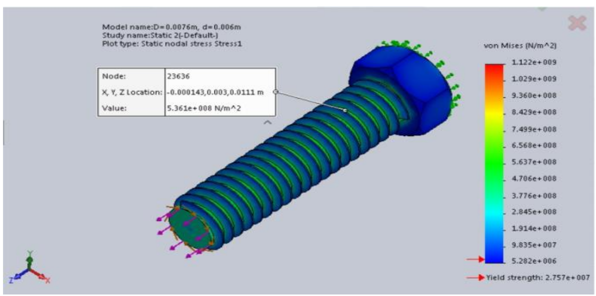

Fig 16. Combined loading for plane carbon steel screw with D= 7.6mm and d=6mm.

From Fig16, it can be seen that The Results Obtained through calculations$5.3 \times 10^8 N/m^2$ is significantly close to the result obtained from simulation$5.361 \times 10^8 N/m^2$. Comparing eq (18) and (19), we find that the simulation stress (SOLIDWORKS analysis) is same as calculated maximum theoretical stress.

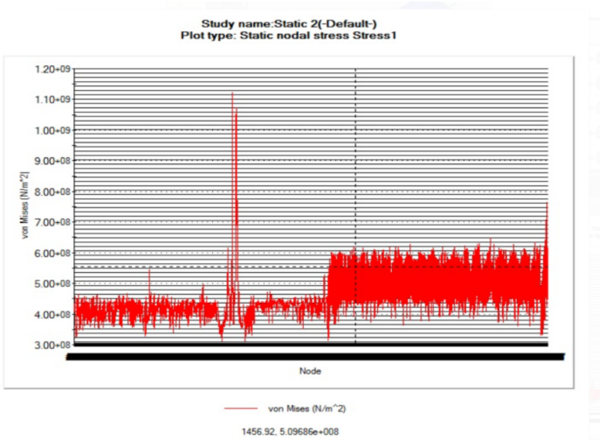

Fig 17. Graph showing stress variation.

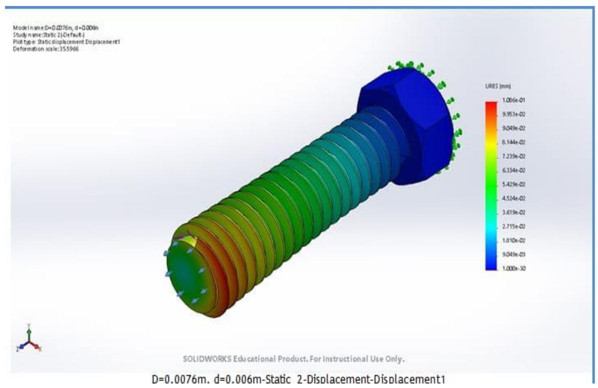

Fig 18. Displacement for combined loading.

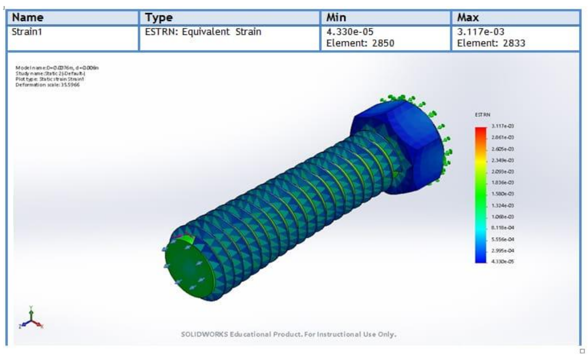

Fig 19. Strain combined loading.

For Case2,

We have applied both axial and torsional load. In this case, the force given is 13 KN and the moment applied is 19Nm. The material is changed to AISI steel 1020.

For this material, the yield strength Yt=351.57 N/mm^2 and the material dimensions are as follows-D= 8.3mm, d=7mm, r = 1mm, α=60 and from the axial loading example, $\sigma_{max} = 4.58 \times 10^8 N/m^2$ And maximum torsional load, $\tau_{max} = 3.75 \times 10^8 N/m^2$

The maximum equivalent stress is found as

$$\sigma_e = 7.6 \times 10^8 N/m^2 \quad (16)$$

From SOLIDWORKS analysis,

$$\sigma_{max} = 7.637 \times 10^8 N/m^2 \quad (17)$$

From Fig 20, it can be seen that The Results Obtained through $7.6 \times 10^8 N/m^2$ is significantly close to the result obtained from simulation$7.637 \times 10^8 N/m^2$. Comparing eq (20) and (21), we find that the simulation stress (SOLIDWORKS analysis) is approximately same as calculated maximum theoretical stress.

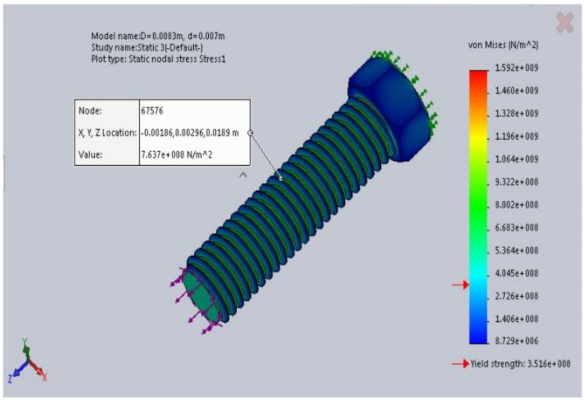

Fig 20. Combined loading for plane carbon steel screw with D= 8.3mm and d=7mm.

4. Axial loading fatigue analysis:

In this below example we have applied 6kN force on the bottom end where the head is fixed, here we have did the constant amplitude stress-life analysis using solid works and given the number of cycles as 1000 (as we can see that in the below simulation image), and we run the simulation and the results obtained are shown below.

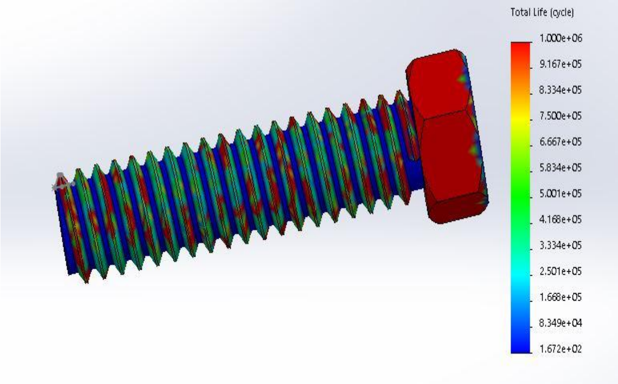

Fig 21. Life cycle for axial loading.

As we can see in fig 21, the region in red colour clear shows that it has lower life cycle when compared to blue part region, as that parts have more life.

The below Fig 48 shows the damage percentage when the screw is subjected to axial loading as we can clearly see that the total screw is appeared to be in blue that indicates it has subjected to less damage

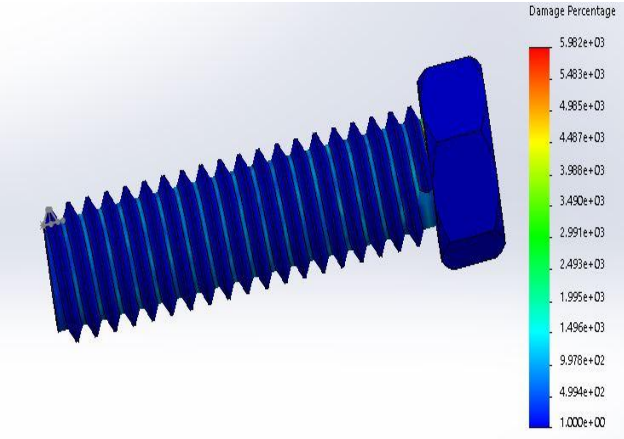

Fig 22. Damage percentage for axial loading.

5. Torsional loading fatigue analysis:

In this example torsional loading we have given plan carbon steel material and given 9NM moment because we have applied torque in this example it is given at the left end while the head is fixed and we have obtained the below simulation results, as we did the same process like the above.

Name	Type	Min	Max
Results1	Damage plot	1.000e-01 Node: 1	1.909e+01 Node: 14802

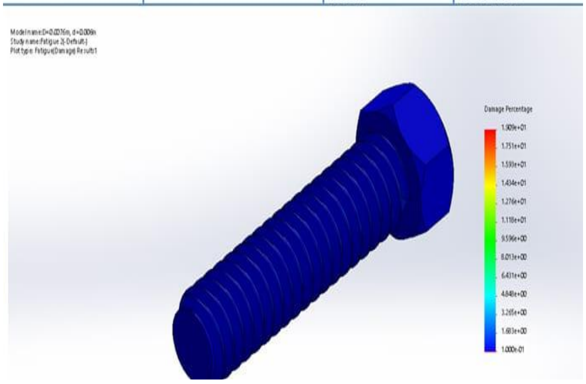

Fig 23. Damage percentage for torsion loading.

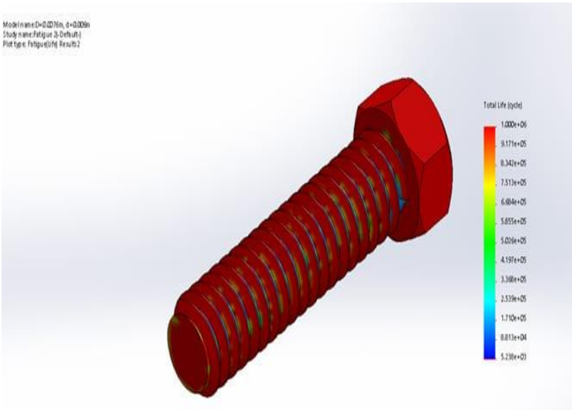

Fig 24. Life cycle for torsion.

5. Combined loading fatigue analysis:
In this example we have given both External loads, like force 6KN and Torque 9NM and we did the same fatigue analysis like we did for the above two examples and obtained the results as shown below.

As we see here same like the above description but when the screw is subjected to torsional and combined loading, we can see the red colour portion in the cases has less life compared to the other blue portions of the screw.

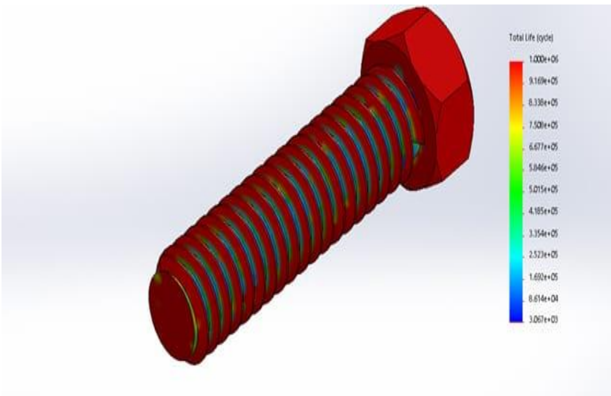

Fig 25. Combined loading life cycle in fatigue.

Name	Type	Min	Max
Results1	Damage plot	1.000e-01 Node: 1	3.261e+01 Node: 14411

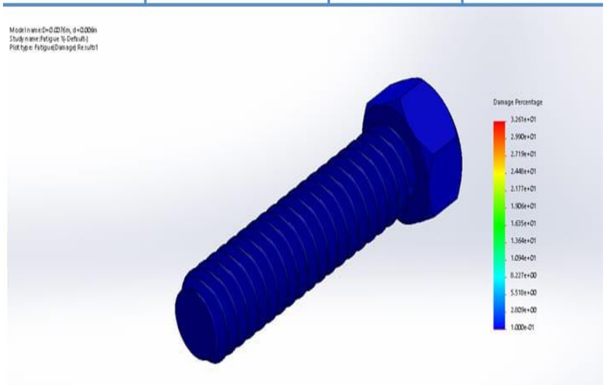

Fig 26. Combined loading damage cycle in fatigue.

V. CONCLUSION

In this study, the basic functions of screw, its advantages and disadvantages are discussed in detail. Screw failures can have catastrophic consequences and significant financial losses. Common screw failure modes are failures due to the load being applied axially, a torsional load, or the combination of both loads may result.

It is discussed why design of screw is important. The fundamentals of fracture the basic theory about stress concentration factor and fatigue is also discussed and the forces acting on the screw under different conditions, and the design process for a screw is studied.

The importance of screw connections and different types of screws are studied. Screw terminals are capable of making a tighter connection with the wires, which not only prevents the wires from coming loose; it also creates a better electrical connection. Screw terminals are typically used for attaching a chassis board, for example on a record player or surge protector. In the last, past work done on the similar topic is studied.

The stress calculations of the screw are done when it is subjected to different types of loading. In the first part the screw is subjected to axial loading. The two different types of material i.e. plane carbon steel and AISI 1020 are used and the maximum tensile stress that the screw can bear is calculated. In the second part, it is subjected to torsion loading and in the third part, it is subjected to combined axial and torsion loading. The calculation was compared to the results of solid works and it was found that results obtained from theoretical calculations were significantly close to the result obtained from simulation. After these loading the fatigue analysis was done and the effect of fatigue on damage and life cycle was studied.

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