Analysis of Socket and Spigot Cotter joint of 30C8 Steel

Minor Project
Soumyajyoti Roy
BME3-001811201154 (2018-2022)

Abstract

The aim is to study the stresses in socket and spigot cotter joint using analytical method. The socket and spigot cotter joint which is proposed to develop in the present study, is for an applied force of 100 kN. The material of the socket and spigot cotter joint is considered as mild steel of grade 30C8, in order to do the stress analysis. The 3D structure was drawn using SOLIDWORKS. Mesh was developed for the knuckle joint for further analysis. Afterwards, ANSYS software was run and the stress and displacement were obtained. Based on the ANSYS analysis it shows that the joint can withstand a load of 100 kN if we use particular factors of safety.

Cotter Joint: Definition

It is a joint used to connect two co-axial rods or a rod and a machine part (like crosshead) which are subjected to axial tensile or compressive forces.

Principle

A cotter is tightly fitted in the slot passing through the socket (provided at the end of a rod) and the spigot (provided at the end of another rod). The cotter inserted becomes tight due to wedge action.

Advantages

1. Assembly and dismantling of the parts of cotter joint is quick and simple.
2. Wedge action develops very high tightening force.
3. Joint is very simple to design and manufacture.

Disadvantages

1. Cotter joint does not allow angular misalignments.
2. Rectangular rods and dissimilar cylindrical rods cannot be connected.

Applications

Joint between piston rod and crosshead, foundation bolt, etc.

Classification

1. Socket and spigot cotter joint
2. Sleeve and cotter joint
3. Gib and cotter joint

Components of Spigot and Socket Cotter Joint

1. Spigot
2. Socket
3. Cotter

Calculation of Dimensions

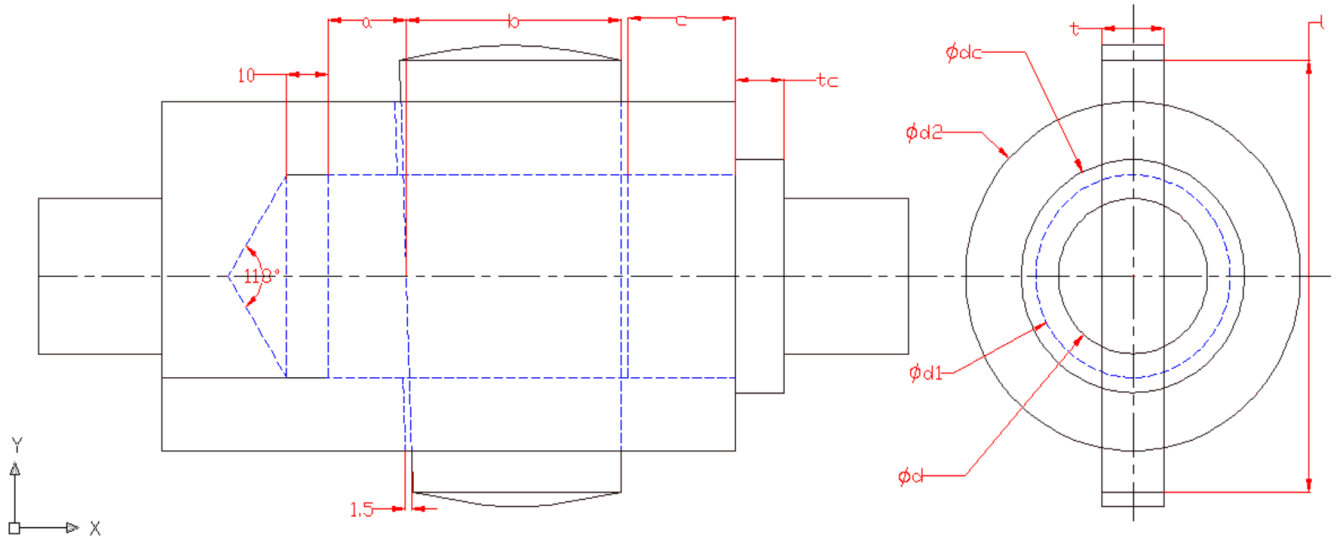
Selection of material

As the cotter joint is subjected to tensile, direct shear and bending stresses, so strength is the matter of concern for selecting a material. Thus we go for plain carbon steel of grade 30C8 (S_{yt} = 400 N/m^2).

Selection of factor of safety (FOS)

Based on the assumptions, high FOS are considered.

- For rod, spigot, socket, socket collar, let it be 4.
- For cotter, let it be 3.



Cotter is assigned low FOS so that failure (if occurs) always happen at cotter, keeping other components undamaged because cotter is the cheapest and easiest part to manufacture and there is no harm in replacing it.

Diagram

Fig 1. Socket and Spigot Cotter Joint

P = Tensile force acting on the rod
d = Diameter of rod
a = Distance from spigot end to end of cotter slot
d_1 = Diameter of spigot or inner diameter of socket
d_2 = Outer diameter of socket
d_c = Diameter of spigot collar
c = Distance from end of cotter slot to the socket end
b = Mean width of cotter
t_c = Thickness of spigot collar
l = Length of cotter
t = Thickness of cotter

Empirical design relations

$d_1 = 1.21d$
$d_2 = 1.75d$
$d_c = 1.5d$
t = (0.31 to 0.40) ×d
$t_c = 0.45d$
a = c = 0.75d
b = 1.6d
l = 4d

Data provided

P = 100 kN = 10^5 N
S_{yt} = 400 N/mm^2

Considering FOS 4,

The maximum allowable tensile stress, $\sigma_t = \frac{400}{4} = 100$ N/mm^2

The maximum allowable shear stress, $\sigma_s = 0.577\ \sigma_t = 57.7$ N/mm^2

The maximum allowable crushing stress, $\sigma_c = 2\ \sigma_t = 200$ N/mm^2

Considering FOS 3, for cotter,

$\sigma_s = \frac{0.577 S_{yt}}{3} = 76.93$ N/mm^2

$\sigma_t = \frac{400}{3} = 133.33$ N/mm^2

Design of Rod

Considering the tensile failure of rod, the resisting area = $\frac{\pi}{4}d^2$

P = $\frac{\pi}{4}d^2$ x σ_t

$\Rightarrow 10^5 = \frac{\pi}{4}d^2 \times 100$

$\Rightarrow d = \sqrt{\frac{4\times10^3}{\pi}} = 35.68\ mm \approx 36\ mm$

Spigot Design

Tensile failure

The resisting area = $\frac{\pi}{4}d_1^{\,2} - d_1 t$

From empirical design,

$P = (\frac{\pi}{4}d_1^{\,2} - d_1 t) \times \sigma_t$

$t = 0.4d = 0.4 \times 36 = 14.4\ mm \approx 15\ mm$

$\Rightarrow 10^5 = (\frac{\pi}{4}d_1^{\,2} - 15d_1) \times 100$

$\Rightarrow \frac{\pi}{4}d_1^{\,2} - 15d_1 - 1000 = 0$

$\Rightarrow d_1 = 46.5\ mm \approx 47\ mm$ [Negative value is not possible to consider]

Crushing failure

The resisting area = $d_1 t$

$P = d_1 t \times \sigma_c$

$\Rightarrow 10^5 = d_1 \times 15 \times 200$

$\Rightarrow d_1 = \frac{10^5}{3000} = 33.33\ mm \approx 34\ mm$

So we have got two values of d_1, i.e., 47 mm and 34 mm. For better safety, we go for the higher value, d_1 = 47 mm.

Shear failure

The resisting area = $2ad_1$

$P = 2ad_1 \times \sigma_s$

$\Rightarrow 10^5 = 2a \times 47 \times 57.7$

$\Rightarrow$ a = 18.437 mm $\approx$ 19 mm

Socket design

Tensile failure

The resisting area = $\frac{\pi}{4}\left(d_2^2 - d_1^2\right) - \left(d_2 - d_1\right)t$

$P = \{\frac{\pi}{4}\left(d_2^2 - d_1^2\right) - \left(d_2 - d_1\right)t\} \times \sigma_t$

$\Rightarrow 0.785d_2^2 - 15d_2 - 2029.945 = 0$

$\Rightarrow d_2 = 61.3mm \approx 62mm$ [Negative value is not possible to consider]

Crushing failure

The resisting area = $(d_2 - d_1) \times t$

$P = (d_2 - d_1) \times t \times c_u$

$\Rightarrow 10^5 = (d_2 - 47) \times 15 \times 200$

$\Rightarrow d_2 = 80.33 \approx 81\ mm$

So, we have got two values of d_2, i.e., 62 mm and 81 mm. For better safety, we go for the higher value, d_2 = 81 mm.

Shear failure

The resisting area = $2c \times (d_2 - d_1)$

$P = 2c \times (d_2 - d_1) \times \sigma_s$

$\Rightarrow 10^5 = 2c(81 - 47) \times 57.7$

$c = 25.487\ mm \approx 26\ mm$

Cotter

Shear failure

The resisting area = $2bt$

$P = 2bt \times \sigma_s$

$\Rightarrow 10^5 = 2b \times 15 \times 76.93$

$\Rightarrow b = 43.33\ mm \approx 44\ mm$

Bending of cotter

- Load is uniformly distributed over spigot area.
- Load is uniformly varying in the socket area; maximum at inner diameter and zero at the outer diameter.

The bending moment is maximum at the center. So, at the central section,

$$M_{max} = \frac{P}{2}\left\{\frac{d_1}{2} + \left(\frac{d_2 - d_1}{2}\right) \times \frac{1}{3}\right\} - \frac{P}{2} \times \frac{d_1}{4}$$
$$M_{max} = 870833.33 N\,mm$$

Now we know, $\sigma_b = \frac{M_{max}}{I} \times c$

$$\frac{\left(\frac{tb^3}{12}\right)}{\left(\frac{b}{2}\right)} = \frac{870833.33}{133.33}$$
$$\Rightarrow b = 51.11mm \approx 52mm$$

So, we have got two values of b, i.e., 44 mm and 52 mm. For better safety, we go for the higher value, b = 52 mm.

Length of cotter

Let us take length of cotter, l = 100 mm.

Taper of cotter = 1 in 32 = 1 mm taper for every 32 mm.

Spigot collar

Shear failure

The resisting area = $\pi d_1 t_C$

$P = \pi d_1 t_C \times \sigma_s$

$\Rightarrow 10^5 = \pi \times 47 \times t_C \times 57.7$

$\Rightarrow t_C = 11.74mm \approx 12mm$

Crushing failure

The resisting area = $\frac{\pi}{4}\left(d_c^2 - d_1^2\right)$

$P = \frac{\pi}{4}\left(d_c^2 - d_1^2\right) \times \sigma_c$

$\Rightarrow 10^5 = \frac{\pi}{4}\left(d_c^2 - 47^2\right) \times 200$

$\Rightarrow d_C = 53.34 \approx 54mm$

Assumptions

1. Rods are subjected to axial tensile force.
2. Effect of stress concentration due to slot is neglected.
3. Initial stresses due to tightening are neglected.

Clearance

- Let us take the clearance between cotter & socket and cotter and spigot as 1.5 mm.
- Let us take the clearance between spigot end and socket be 10 mm.

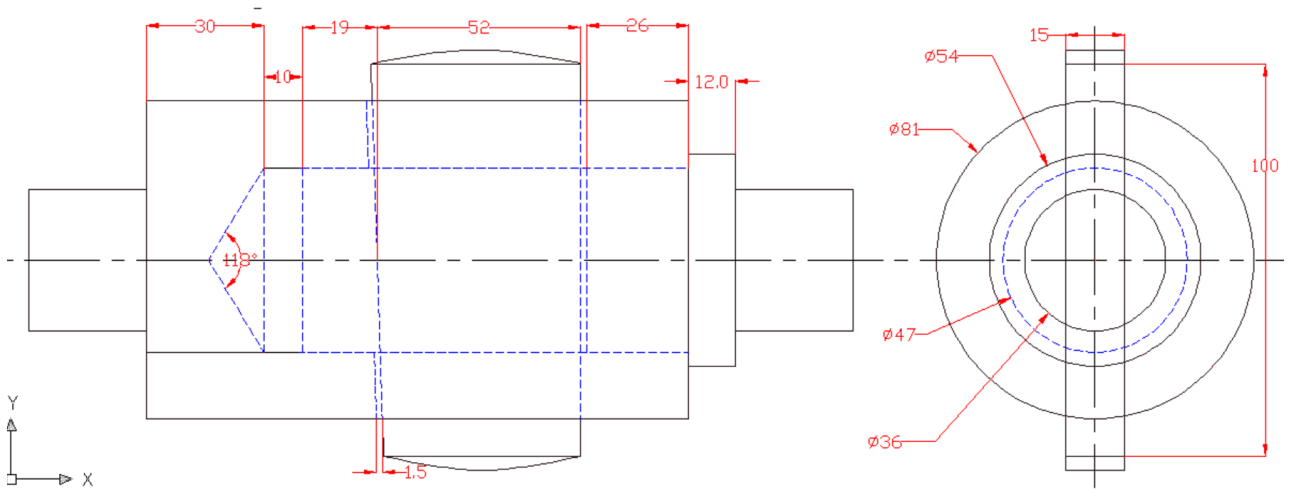


Fig 2. AutoCAD model of Socket and Spigot Cotter Joint

Model using ANSYS 2020 R1

The stress analysis and displacement diagram are obtained using ANSYS, a commercial FEA software. Initially, we have prepared the CAD model of cotter joint using SOLIDWORKS software as shown in Fig 3 and imported it to

ANSYS. While preparing the CAD model, we have assigned the proper dimensions and the material properties of the above mention parts. The material selected in the present investigation is plain carbon steel of grade 30C8. Following material properties have been considered for the FEM analysis:

1. Young's modulus: 2×10^5 MPa
2. Poisson's ratio : 0.3
3. Tensile Yield strength = 400 MPa

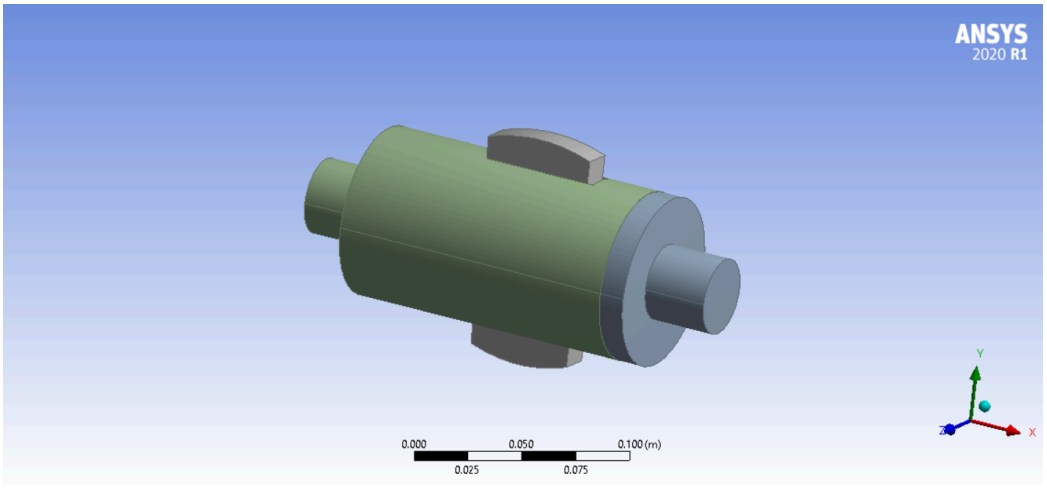


Fig 3. CAD model of Socket and Spigot Cotter Joint

Meshing and loading

The basic need for ANSYS analysis is to divide the whole section into many 4 nodded tetrahedral elements. This will enables us to analyze the stress and strain of the components and various points of the said components. In the present case number of nodes were 8450 and the numbers of elements were 4507. A typical drawing of the meshing of the cotter joint is shown in Figure 4.

The socket end is made fixed and an axial load of 100 kN has been applied at the spigot end of the joint.

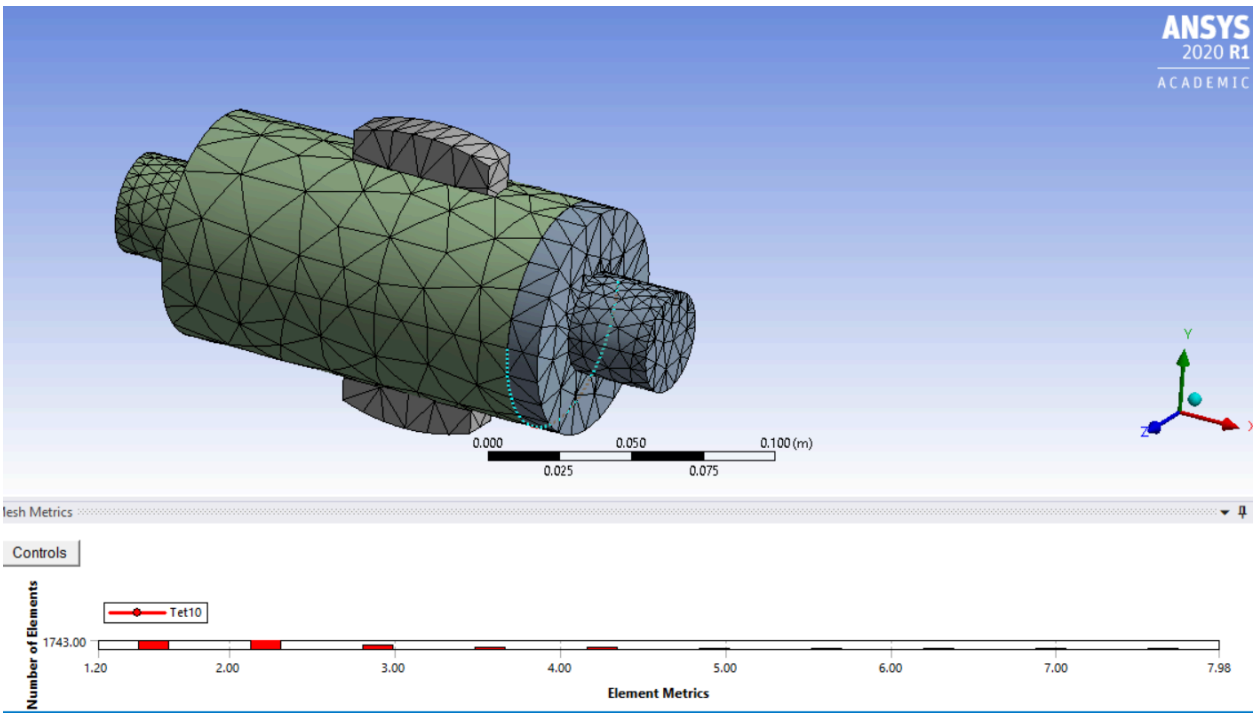


Fig 4. Meshing of Socket and Spigot Cotter Joint

Results and Discussion

Deformation

Fig. 5 shows a typical diagram depicting the elongation in each part of the cotter joint. It may be mentioned that maximum elongation is experienced at the spigot end of the joint and minimum elongation occurred at the socket

end. The above results show that the maximum deformation at the spigot end of the joint is around 6.0657×10^{-2} mm and the minimum elongation which is found at socket end is 6.7397×10^{-3} mm.

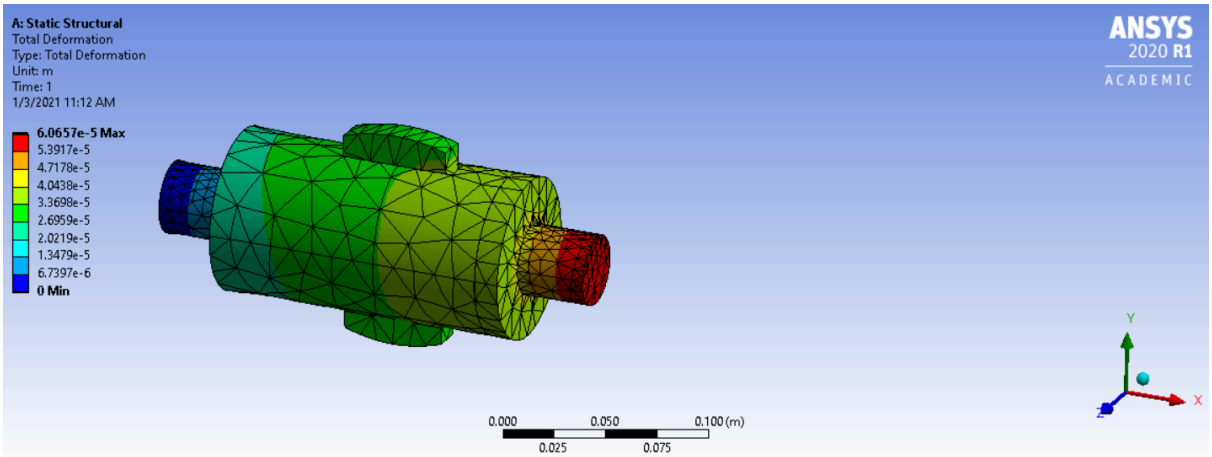


Fig 5. Total deformation analysis of Socket and Spigot Cotter Joint

Equivalent stress (Von-Misses)

When a load of 100 KN is applied in the system, the ANSYS analysis depicts that the maximum stress experience in the cotter is 145 MPa (Fig 6). It is known that 30C8 shows a maximum tensile yield strength of 400 MPa. This clearly states from the analysis that the cotter can sustain an applied load of 100 KN if we consider FOS of 3 for cotter and 4 for the other components.

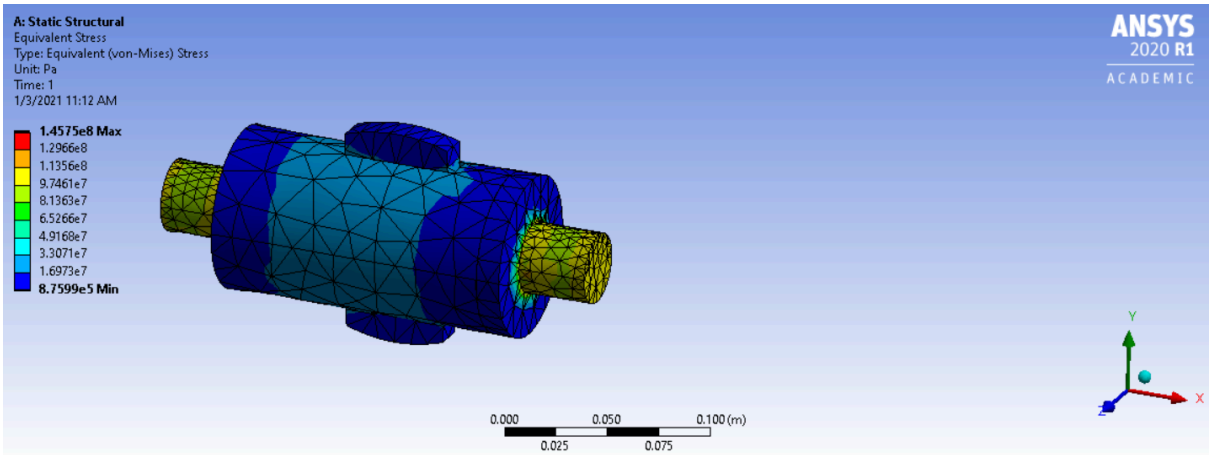


Fig 6. Equivalent stress analysis of Socket and Spigot Cotter Joint

Conclusion

1. The Socket and Spigot Cotter Joint required to develop in the present study is for an applied tensile force of 100 KN, made of 30C8 grade steel with a particular FOS.
2. Based on the above, a CAD model was developed using SOLIDWORKS.
3. In order to carry out the deformation and stress analysis, mesh was developed for the joint. The mesh consists of 8450 nodes and 4507 elements.
4. Based on the ANSYS analysis, it shows that the cotter can withstand a load of 100 kN if a factor of safety of 3 is used, while other components are assigned a FOS of 4.