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A Numerical Study on Conventional Tube Flaring Process

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Abstract. Tube flaring process involves a conical tool of a certain length which is displaced to get an end flared tube, which is utilized to form a tight seal between pipes or tubes. Tube flaring refers to a kind of forging which is often a cold working operation. The tube forming process is widely used in several industries to form condenser pipes, car seat structures, exhaust piping, etc. Thin-walled tubes were used in automobiles to reduce the total weight for better performance. A conical tool is used for tube end forming in which the tool is moved into the tube known as conventional tube flaring. In this work, a numerical study was directed using FEA software ANSYS/Implicit which is used to analyze the stress conditions involved in tube flaring. Here, the tool is considered rigid and displaced by using displacement control by 25 mm, and other parameters were studied at this displacement. Effects of different semi-cone angles were also considered for the study

Keywords. Tube flaring; Conical flaring; Thin-walled tube; End forming.

1. Introduction

Tube flaring is defined as the process of tube fabricating, or tube end forming, which is used to form a tight seal at the end of a pipe or tube. Tube flaring is a kind of forging which is often a cold working operation. Flaring is used to join two tubes having the same inner and outer diameters respectively. The tube flaring process is widely used in several industries to form condenser pipes, car seat structures, exhaust piping, etc. End flared tubes have a variety of applications in automobile, irrigation, shipbuilding, and aircraft industries. They are very good transporters of liquid, oil, refrigerant, etc. Hence, they have been used in the oil and pipeline industries.
Numerous researchers have already researched this topic in their studies. The Analytical expressions to know stress fields, strain fields and the force required for driving the expansion.[1] An analytical model to envisage the relationship among the punch stroke, flaring ratio, tube thickness, and flaring forming limit in the tube flaring process.[2] The axisymmetric tube flaring with conical tool Some factors that show a significant part in the tube flaring process like frictional resistance, temperature, and angle of the conical flaring tool. The impact of the frictional coefficient was demonstrated by adopting the modified Coulomb friction law on the tube flaring process. [3-4] also a combined study of tube flaring and tube spinning which gives an innovative method for creating a uniform thickness curved generatrix workpiece. The deformation features of tube flaring were studied by using ABAQUS/explicit software in 3D elastic-plastic FE simulation.[5] Rotary forming is one of the promising incremental processes. The comparison between

rotary forming and conventional flaring was investigated [6] a rotating tool on its flaring axis and performed experiments to analyze the expansion ratio, strain path, and failure limit. Several trials of tube end forming at varing rotational speeds and compared with other conventional flaring techniques. [7] Numerous studies have tried to execute numerical and FEA of the flaring process, a new process by using the Reuleaux triangle tool to perform the tube flaring into a square tube. The use of the Reuleaux triangle gives more formability than the conventional method which signifies the thinning aspect of the tube. [8] The tube deformation behavior using the incremental tube forming process. Deformation nature during grooving and end tube forming in single-stage and multiple increment strategies.[9]

In this present work, a numerical analysis of the tube flaring process was considered and, is validated with available literature for standardizing the FE code. The mesh sensitivity study for efficacy of finite element simulation was conducted and the effect of different semi-cone angles on a load-displacement curve and the impact on stress were analyzed.

2. Description of the Finite Element Model

The FEM has been known because of the most powerful method of study appreciation, its flexibility, and its accuracy. Initially, in this proposed flaring process the 4130-steel alloy was used and numerically simulated by using the FEA software ANSYS/implicit and validated with available literature to standardize the FE code and this standard code was applied to another material for further analysis. First, a 3D model is created for numerical simulation built on the given specification. The complete geometry of the tube was considered to recognize the shear of the element. The conical tool was kept rigid and the tube was set to deformable body. In this numerical analysis, the multizonal method of meshing with 20 nodes hexahedral ANSYS SOLID186 is used for meshing the tube. Numerous constraints affect the tube end-forming process. One of them is the geometry of the model which includes a tube and a conical tool. For the tool, the semi-cone tool angle (α) is 14^0 and the main dimensions of the tube can be found by three parameters as turned out in Figure 1.

The Mechanical Property of the tube material 4130 steel alloy is given in Table 1. and was used in this modelling for validation purposes and the Holloman-Ludwik equation mentioned as equation (1) was used to draw the true stress-strain plot along the longitudinal direction.

$$\sigma = K.\epsilon^n \qquad (1)$$

Table 1. The Mechanical property of tube (4130 steel alloy)[11]

Yield Stress (MPa)	Strength coefficient 'K' (MPa)	Strain hardening exponent 'n'
610	898	0.07

2.1. Boundary condition

In this model, boundary conditions include the contact type between tool and tube while flaring process. The contact in-between the outer and inner surface of conical tool and tube respectively as shown in figure 2 was considered fictional tangential type with a coefficient of friction value μ = 0.1 using Coulomb friction law and the tube length was set 50 mm to reduce the buckling of the tube due to axial forces.

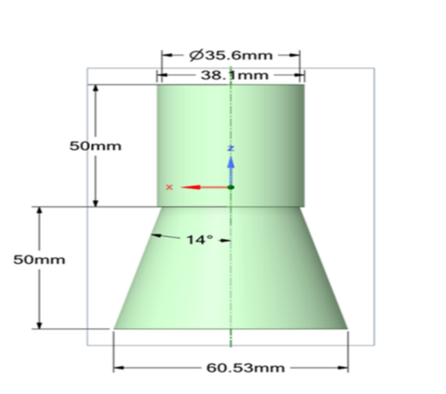

Figure 1. The geometric model

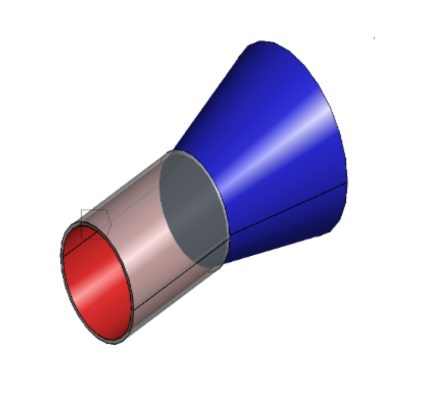

Figure 2. The contact interface

2.2. Validation

To regulate the FE simulation approach, the tube expansion processes have been modeled it is noticed that the FE predictions match well with the FE simulation result. In case of force-displacement nature, a small nonconformity is seen between the results of the present work and the available data from C.P. Nikhare (2018). [11] In the case of equivalent stress prediction, the results show good conformance with the available data, with minor deviation.

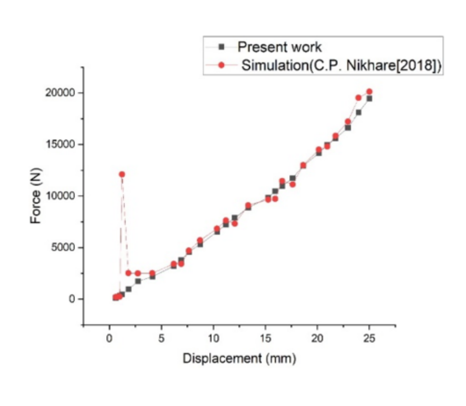

Figure 3. The Force- displacement curve

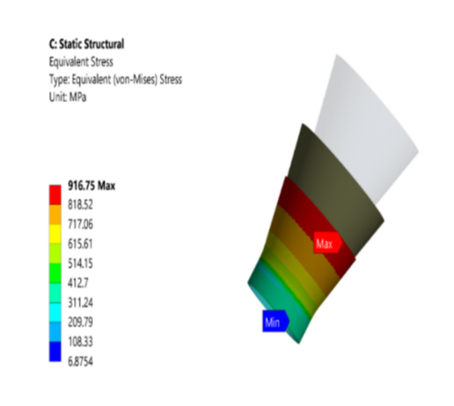

Figure 4. The Equivalent(von-Mises) stress distribution

2.3. Standardization of FE Model

After validating the FE Model with good accuracy, a similar approach for further analysis will be followed throughout the study. Same material model as used in C.P.

Nikhare (2018) was also implemented for stainless steel. Table 2 provides the properties of the tube material (SUS316L).

Table 2. The mechanical properties of the tube material (SUS316L) [10]

Yield Stress (MPa)	Strength coefficient 'K' (MPa)	Strain hardening exponent 'n'
287	1404.88	0.582

3. Result and discussions

In this section, mesh element size analysis of the tube has been conferred. The impacts of parameters on force progression and stress development have been discoursed. The effect of various parameters which is involved in the process was also discussed.

3.1. Mesh sensitivity study

To evaluate the appropriate mesh size for the present analysis, a wide-ranging mesh sensitivity analysis has been done for tubes in the tube expansion. For this purpose, a Load-displacement graph is generated at different mesh element sizes as revealed in figure 5. It can be realized that the graph with higher element size shows some irregularities in force evolution and the smaller size element shows almost the same inclinations in force evolution. Smaller mesh sizes (0.25) showed more computational time which will not suit this simulation. A larger mess size showed some irregularity in force evolution. In the case of mesh sizes, 0.5 mm, 0.75 mm, and 1 mm, the load evolution obtained is almost the same.

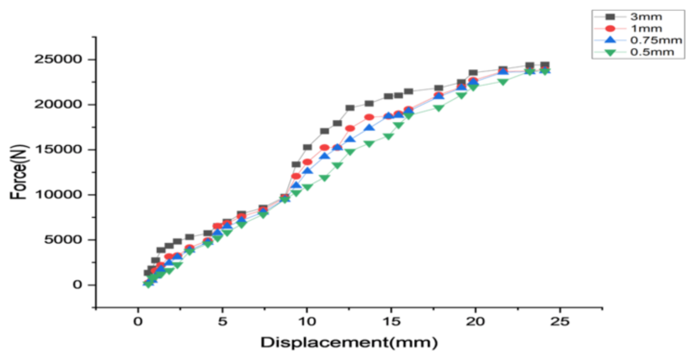

Figure 5. The force-displacement curve at different element size.

3.2. Impact of different semi-cone angle on tube flaring

In this section, the influence of the different cone angle on load-displacement, stress and strain behavior are considered. The objective of this section is to know the effect of parameters and also to recognize the successful tube flaring as per the criteria proposed. The effect of different tool angle on the force-displacement curve is revealed in Figure 6. It has been seen that, with increase in the semi-cone angle, the maximum force also increases. It is found that maximum load reflects to be approximately 35KN in case of tool with semi-cone angle 45-degree and least load was nearly 23.5 KN in case of 15-degree tool angle.

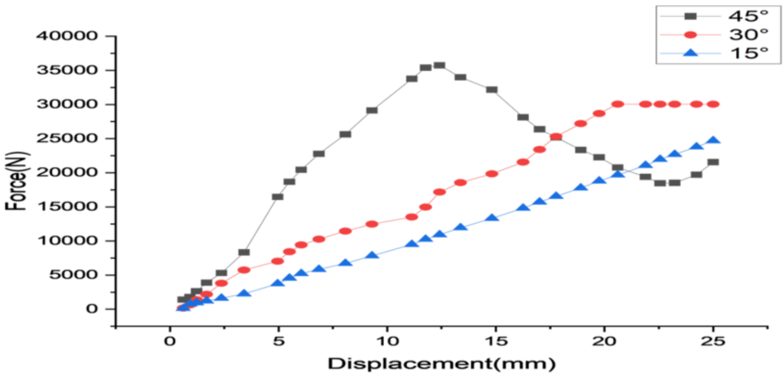

Figure 6. The force-displacement curve at a different semi-cone angle of tool

3.3. Influence of different semi-cone angles on stress behavior

Impact of tool angle on Stress distribution are shown in figure 7 which displays stress contour in MPa. The maximal stress increases with increasing tool semi-cone angles. The maximal stress 824.5 MPa, seems on the tool semi-cone angle of 45° at 25 mm displacement of tool, and at this displacement wrinkling and buckling of the tube were observed can be seen in figure 8. The maximal stress before buckling is 783.87 MPa at the tool with a 45° semi-cone angle as shown in figure 7. The minimal stress, 709.79 MPa, seems on the tool's semi-cone angle of 15°.

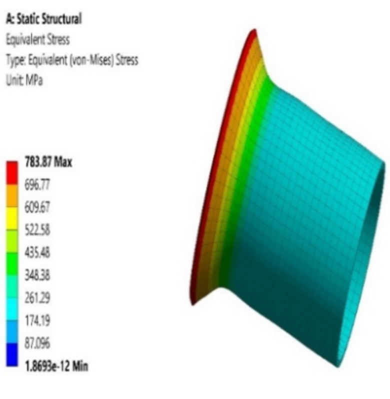

Figure 7. The equivalent (von-Mises) stress

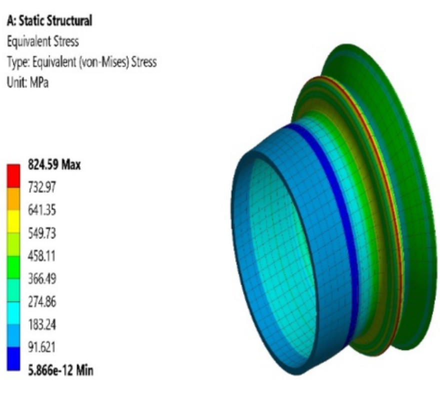

Figure 8. The equivalent(von-Mises) stress at full displacement

Conclusions

In this present work, the FE simulation of the tube flaring method was considered and analyzed. The key conclusions can be given as follows.

- Successful running of simulation for proposed process.
- Initial simulation is validated with available literature.
- It was observed that a larger semi-cone angle requires a large value of force for the same displacement.
- Larger mesh element size shows irregularity in results.
- Effects of the semi-cone angle of the tool on stress were also analyzed and maximum stress developed in the tube at a larger semi-cone angle.

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Endnotes

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