COMPUTER MODELLING AND FINITE ELEMENT ANALYSIS OF TUBE FORMING OPERATIONS

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INTRODUCTION:

Tubular sections can be converted into a variety of products. One or more forming processes can be used, including Tube Hydroforming, Tube pilgering, Tube bending etc. Finite Element Method (FEM) has been used for optimization of the above mentioned forming processes with a view to maximize deformation in order to aid in the formation of complex profiles. Designing with FEM can minimize costly experimentation and try-outs and reduce tool and material wastage thereby enabling to get the process right at the first try-out. Moreover the limits of formability and various process Kinematic relationships can be easily established which can lead to better productivity.

MECHANICS OF TUBE FORMING:

In the **Tube-forming** process, the tube is either closed at both ends by rigid plugs, or provided with floating pistons, which allow free axial contractions. The tube is assumed so large that plane transverse sections remain plane during the expansion. This means that the longitudinal strain ε_z is independent of the radius to the element. The internal and external radii of the tube is a and b and the tube is subjected to an internal pressure p and a Longitudinal force P. The stresses and strains sufficiently far from the ends do not vary along the length of the tube and the equations of equilibrium is :

$$\frac{\partial \sigma_r}{\partial r} = \frac{\sigma_\theta - \sigma_r}{r}$$

The z axis of the cylindrical co-ordinates(r,θ,z) is taken along the axis of the tube. When the tube is entirely elastic, the longitudinal stresses may be written from Hooke's law as :

$$\sigma_z = E\varepsilon_z + \nu(\sigma_\theta + \sigma_r)$$

Denoting the radial displacement by u, the radial strain ε_r and the circumferential strain ε_θ may be written as :

$$\varepsilon_r = \frac{\partial u}{\partial r} = -\nu\varepsilon_z + \frac{1+\nu}{E}[(1-\nu)\sigma_r - \nu\sigma_\theta]$$

$$\varepsilon_\theta = \frac{u}{r} = -\nu\varepsilon_z + \frac{1+\nu}{E}[(1-\nu)\sigma_\theta - \nu\sigma_r]$$

Since ε_z is independent of r, the following Compatibility Equation can be obtained:

$$\frac{\partial}{\partial r}(\sigma_r + \sigma_\theta) = 0$$

By analysis using **Lame's Solution** the stresses therefore become

$$\sigma_r = -p\left[\frac{\frac{b^2}{r^2} - 1}{\frac{b^2}{a^2} - 1}\right]$$

$$\sigma_\theta = -p\left[\frac{\frac{b^2}{r^2} + 1}{\frac{b^2}{a^2} - 1}\right]$$

If the resultant longitudinal load is denoted by P , then the axial stress is :

$$\sigma_z = \frac{P}{\pi(b^2 - a^2)}$$

FEM can be used for accurate estimation of the axial, radial and circumferential stresses and strains to accurately predict failure and distortion in the formed tube component at any location.

TUBE HYDROFORMING:

In the tube hydroforming process the tubular blank is preformed by bending and inserted into an axially or radially split die. Then the die is closed crushing the tube and the tube is sealed at each end. Finally, Hydraulic liquid fills the tube and hydraulic pressure is applied inside the tube whilst simultaneous axial loading is applied at the ends of the tube pushing it into the die. The tube wall is thus pressed and the internal contour of the die and part is formed. Thus the internal pressure and the axial loading are the two key parameters of the process. These two parameters have to be optimised for the successful operation of the process.

There are four types of failure modes of tube hydro formed components:

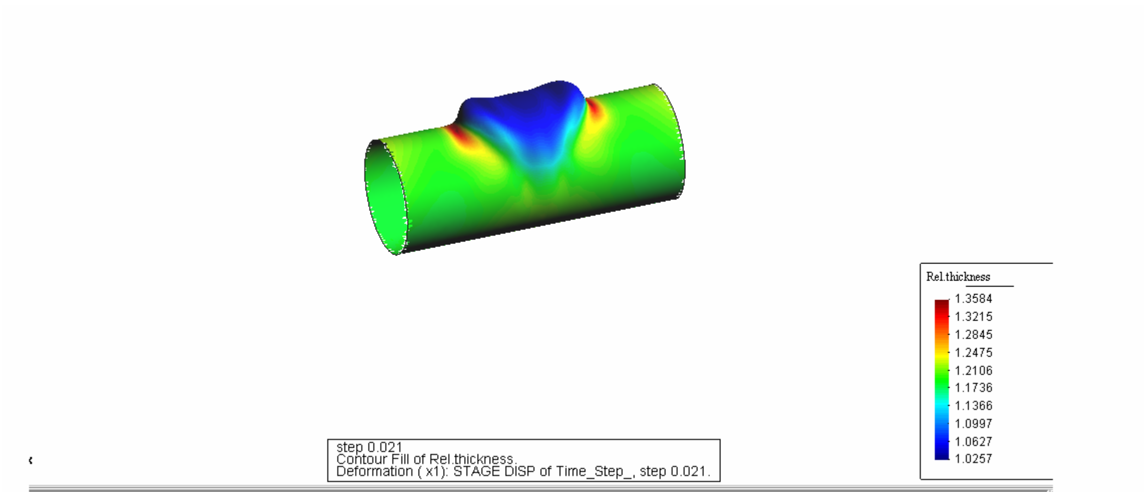
a) **Buckling**-This is caused due to excessive axial compressive deformation.

b) **Wrinkling** - This is caused due to excessive axial loading or insufficient internal pressure.

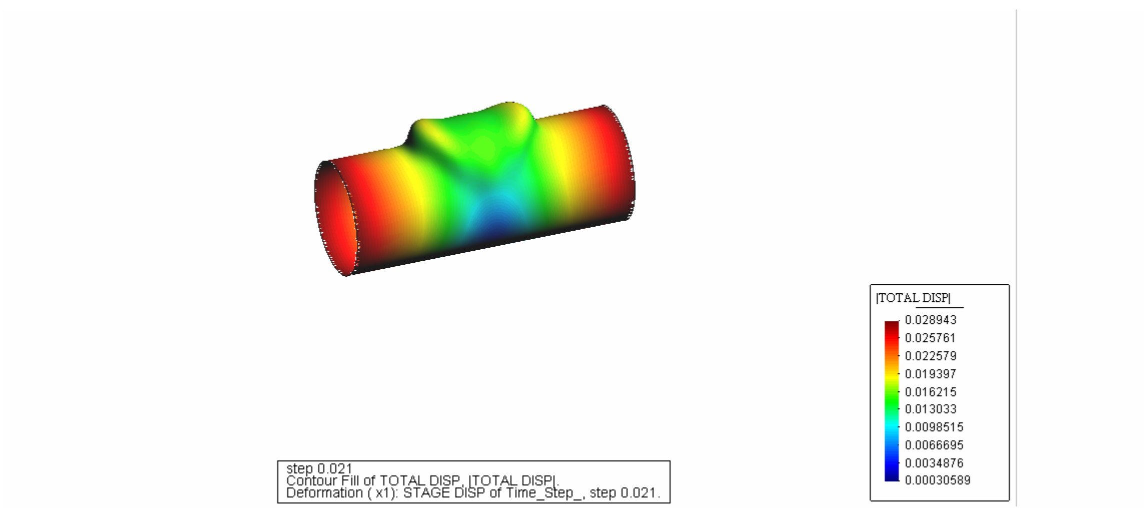
c) **Bursting** -This is caused due to the thickness of the tube blank being smaller than needed to sustain the hoop stresses or due to the axial loading being insufficient.

Thus it is observed that improper ratio of internal pressure and axial loading cause the failure of the tube blank by Buckling, Wrinkling or Bursting. Thus there is an urgent need to optimize the process through the use of the **Finite Element Method (FEM**). **FEM** can be used to optimize the pressure-time cycle needed for maximum and optimum deformation behaviour. The maximum deformation behaviour is related to the material properties like strain rate, temperature and grain size. The material has to be worked at ideal limits of strain rate, temperature etc to achieve maximum deformation without fracture. This is achieved through FEM simulations by varying the pressure -loading curve with time so that the material operates at its ideal possible limit. This obviates the need to conduct costly and tedious experimentation needed to optimize the pressure loading cycles. The axial loading imparted to the punch can also be optimised through the use of FEM and corrective measures can be recommended by observing the defects and failure mechanisms. FEM can also be used to establish the proper Kinematic relationships for the processes and prediction of limits of Formability and loads needed for optimizing the processes.

Fig (a)&(b) shows the hydro forming of tube simulated through STAMPACK-FEM based package.



Fig(a) :Relative thickness of tube after Hydroforming.



Fig(b): Total displacement of tube after hydro forming.

TUBE PILGERING :

Tube reducing is the process of reducing the cross sectional area by rolling the tube over a tapered mandrel using semicircular dies with tapering grooves. These dies do not rotate, but rock back and forth. The mandrel and the tube are rotated between strokes & move forward at the same time. Experimental determination of metal deformations in the tube cold rolling process in Pilger mills poses a lot of technical problems. High speed of the rolling stand in the reciprocating motion makes immediate switching off in a precisely selected point of the rolling zone impossible. Compact and closed structure of the rolling mill, in particular of its working space, makes impossible to place sensors for measuring deformations, connecting measuring signals to the amplifying and recording equipment and protecting them against impact of high pressure rolling emulsion mist. Therefore ,the physical modeling method through **FEM** is applied in investigations of the deformation area in the cold tube Pilgering process. Through the use of FEM we can accurately estimate the deformations, stresses and damage at any point of interest in the deformation zone.

TUBE BENDING :

Tube bending requires internal support in the inner side of the tube bend. Mandrels are used in bending to prevent collapse of the tubing. The need for a mandrel depends on the tube and bend ratios. The tube ratio is D/t where D is the outer diameter and t is the wall thickness. The Bend ratio is R/D where R is the radius of the bend measured to the centreline. The wall thickness of the tubing affects the distribution of tensile and compressive stresses in the bending. A thick wall tube will usually bend more easily to a smaller radius than a thin wall tube. The four most common methods of bending tubing are Compression bending, stretch bending, draw bending and roll bending. The method selected for a particular application depends on the equipment available, the number of parts required ,the size and wall thickness of the tubing, the work metal, the bend radius, the number of bends in the workpiece. FEM can be used for estimating the optimum thickness needed for easy bending and for predicting the distribution of tensile and compressive stresses at any section of the bend.

FEM Simulation of TUBE BENDING:

In FEM based Tube bending we can determine Residual Stresses, Radial Stress & Strain distribution. Also we can simulate for spring back effect of the tube. Half symmetry is modeled by declaring the nodes in the symmetry plane as non-separable from the symmetry plane as shown in the figure ©.

<u>Process Parameters</u>

Tube temperature = 20 DEG C

Die speed = 1 radian/sec

Friction factor = 0.01

<u>Boundary conditions</u>

Bottom face of tube is fixed. Symmetry plane of tube is made non-separable with the symmetry plane

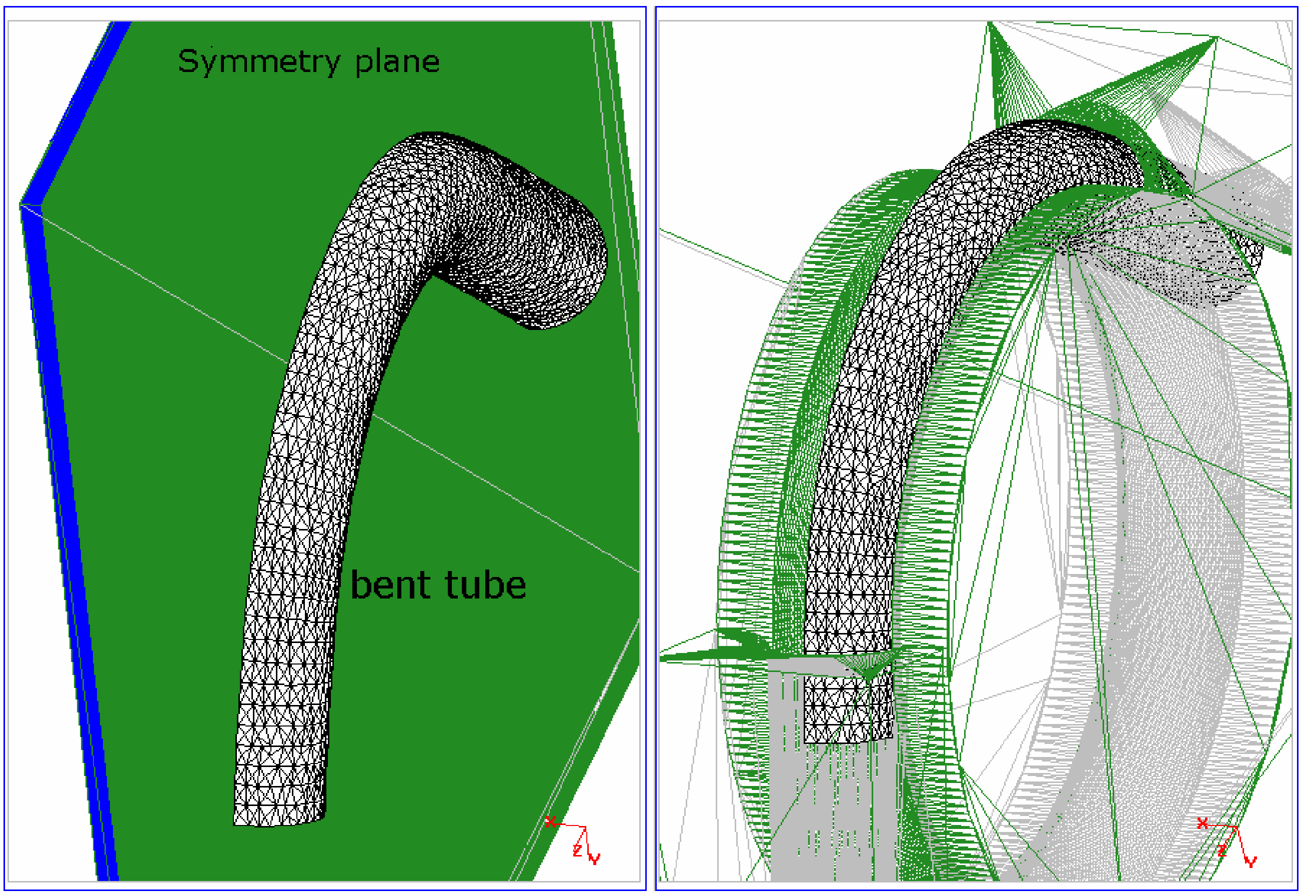


Fig © : Tube Bending die arrangement & FEM Mesh generated for Simulation.

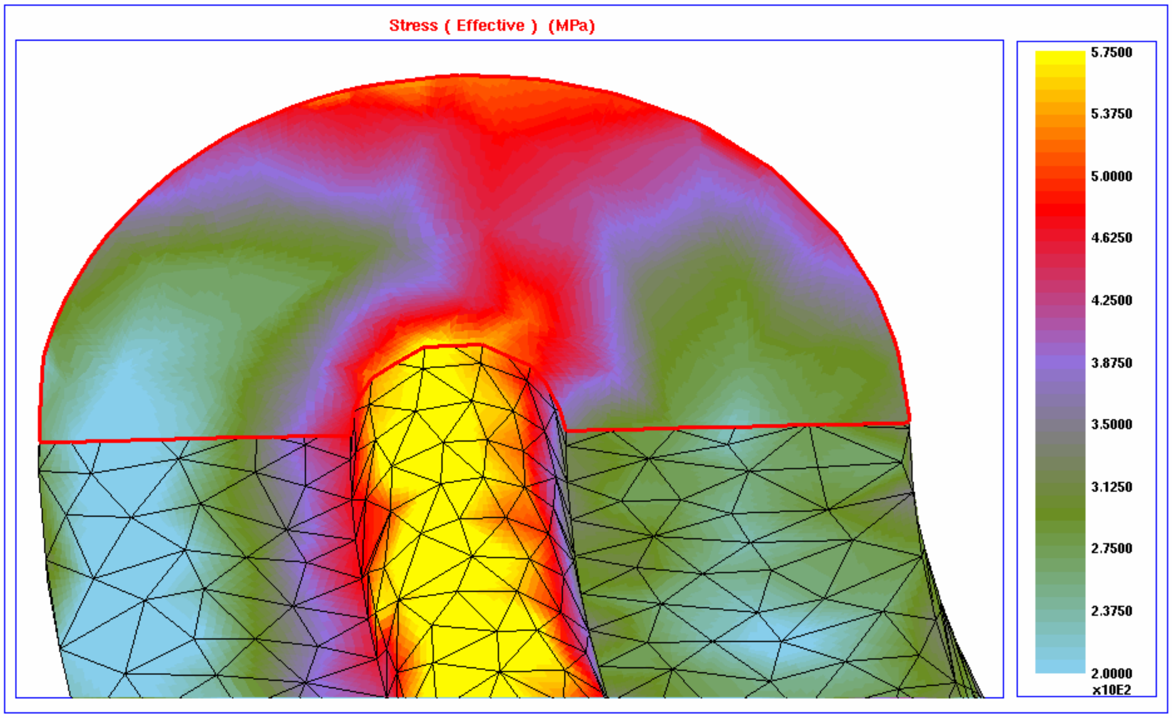


Fig (d): Effective Stress distribution in a tube bending operation.

TUBE SPINNING:

Tube spinning is a rotary –point method of extruding metal much like cone spinning. Spinning is one method of reducing the wall thickness of tubular shapes and increasing their strength, particularly for aircraft and aerospace applications. Producing specific shapes from tubing is a major function of tube spinning. For example, one or more flanges can be spun at selected areas on a tube, often at a savings in labor and material costs when compared with other processes such as machining. Fig (e) shows the mandrel , workpiece & roller arrangement. Fig (f) the spun tube at the end of the spinning process. This process can be modeled & simulated on FEM tool.

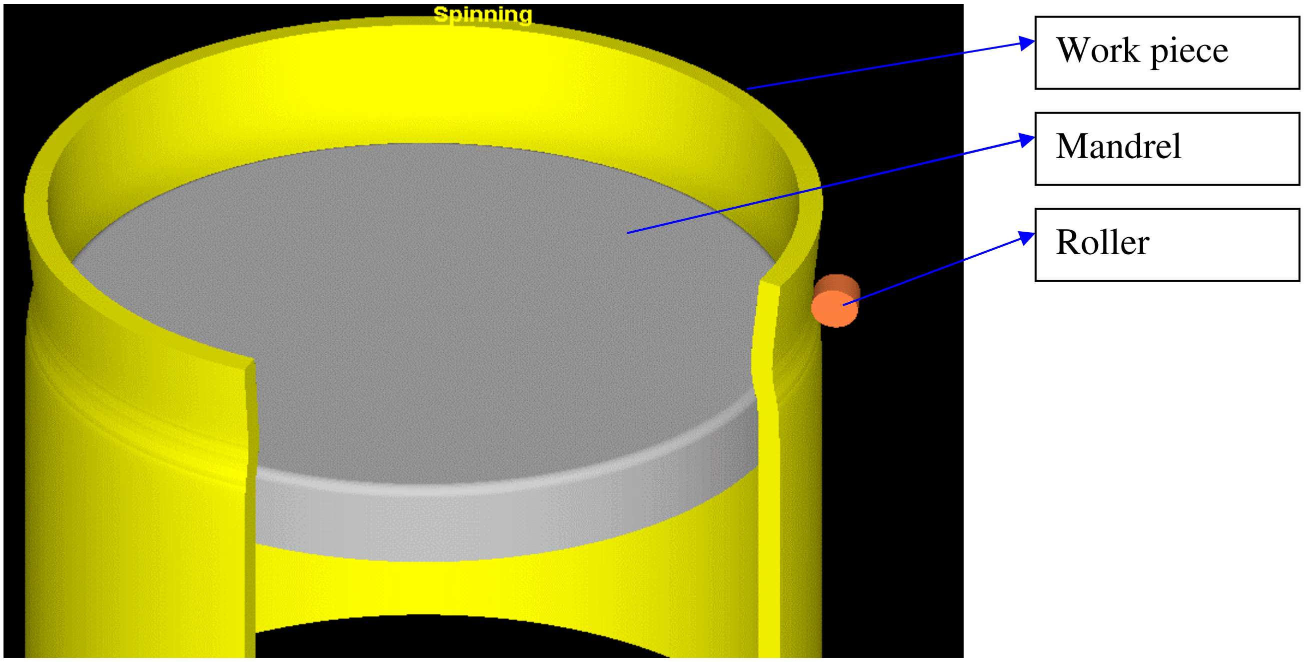


Fig (e): Tube spinning arrangement.

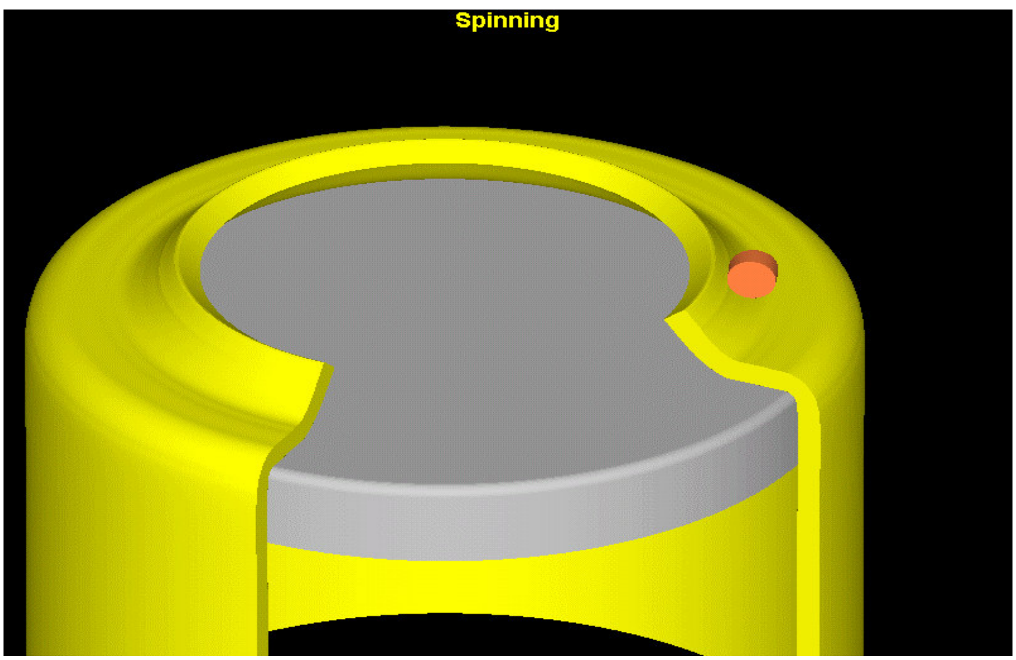
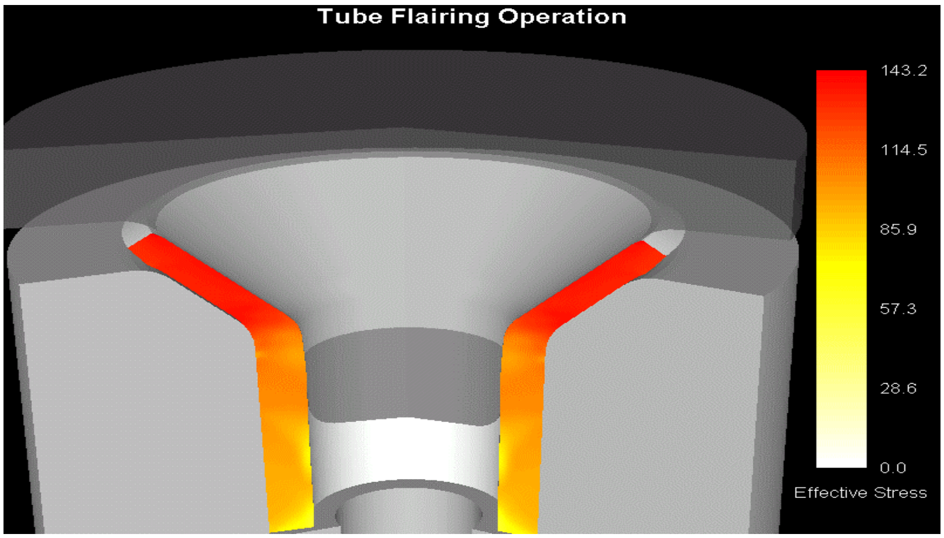


Fig (f) : End process of tube spinning.

TUBE FLAIRING :

Below fig shows the effective stress distribution during a tube flairing operation analyzed through FEM based simulation.
It also demonstrates deformation & die retraction. Contours of effective stress during deformation & after die retraction (residual stresses) are also obtained simulation Fig(g). There is spring back effect observed at the end of process Fig(h).



Fig(g) : Effective stress distribution in tube flairing operation obtained through simulation.

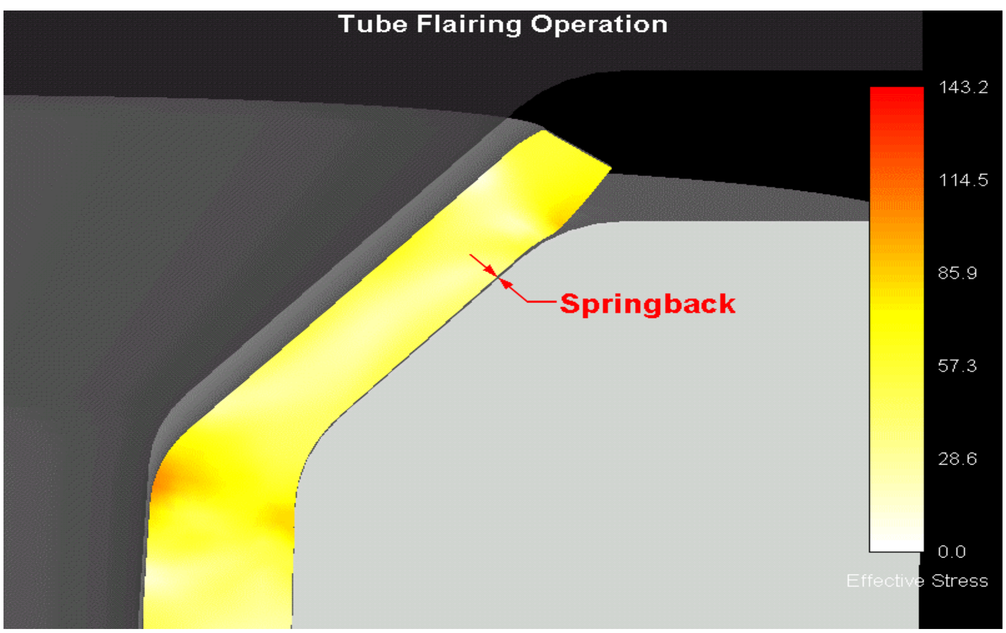


Fig (h): Spring effect in tube flairing operation.

TUBE UPSETTING:

Tube upsetting can be simulated on DEFROM –A FEM tool to check the die design & based on the results we can optimize the die design. One such simulation example is given in Fig (i), which shows the fold in the tube at the final stages of tube upsetting. This defect can minimized by optimum die design.

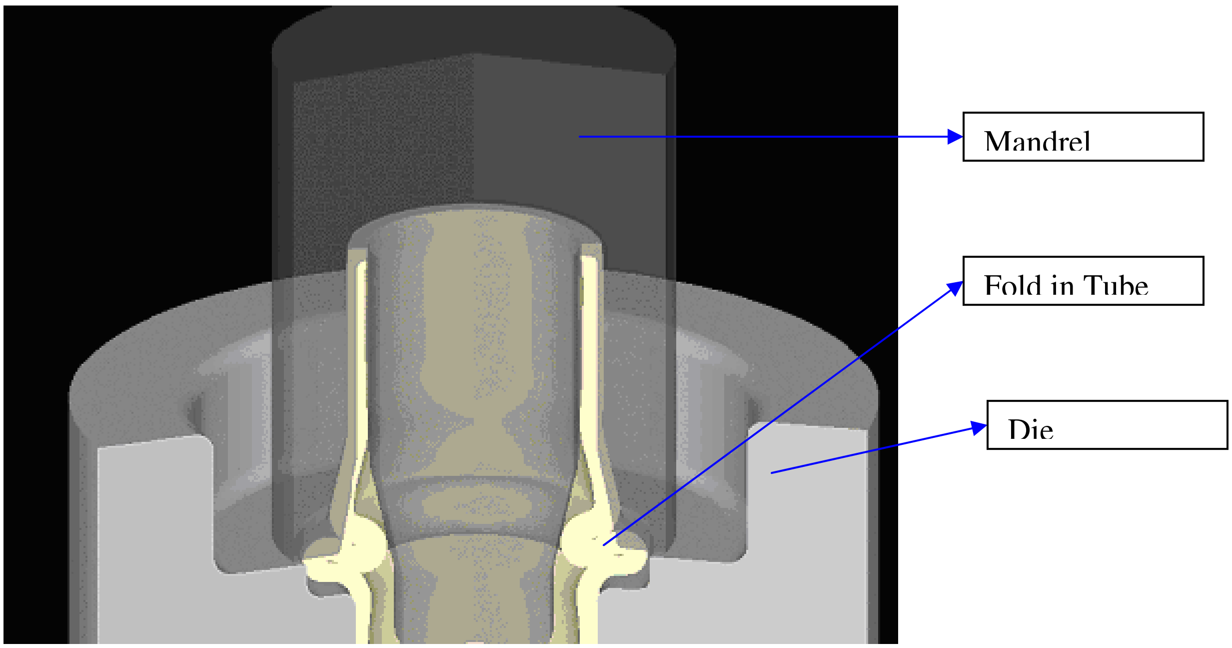


Fig (i) : Tube upsetting simulation result showing Fold in the tube.

TUBE SWAGING :

Tube swaging is a process for reducing the cross sectional area or otherwise changing the shape of the tubes by repeated radial blows with two or more dies. The work piece is elongated as the cross sectional area is reduced. The work piece is usually round or square or other wise symmetrical in cross section can swaged. Fig (j) shows one such set up of tool for tube swaging in which there are four dies arranged radially. The same tool set up is used in simulation. Another fig(k) will show the reduced cross section after swaging process.

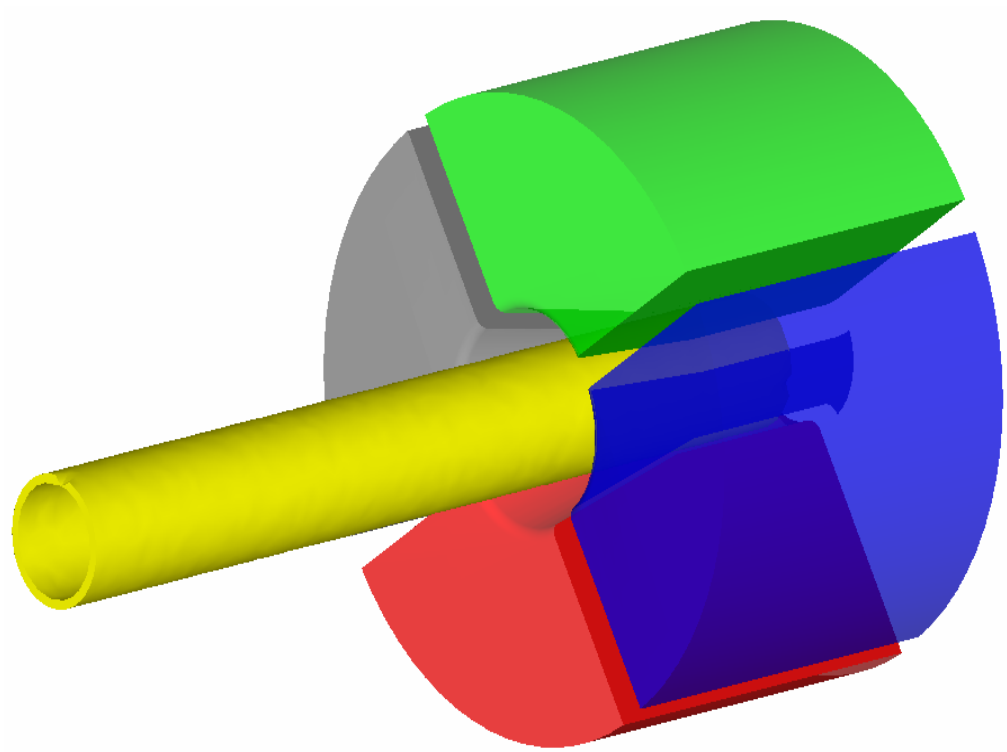


Fig (j): Tube swaging showing tool setup.

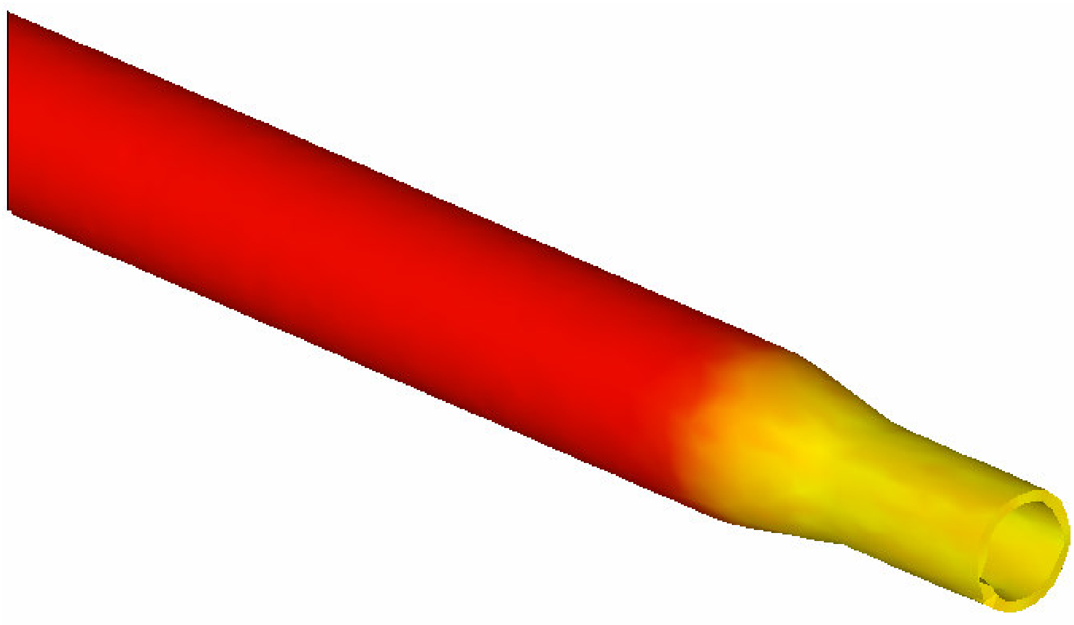


Fig (k) : Reduced cross sectional area after swaging operation ,simulated in DEFORM package.

CONCLUSION :

Based on the simulation results we can conclude that FEM is an important design tool which can be used for process optimization and design of tube forming processes. Innovative design modifications can be tested on the computer using FEM and the ideal process can be developed and got right at the first try-out in the shop floor thereby minimizing costly and tedious experimentation.

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