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Tube Hydroforming: Simulation on ANSYS and Validation

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Abstract

The objective of this paper is to validate THF process by using strength and mechanical properties of the material. The model is generated on SolidWorks and further imported to ANSYS for Analysis. The stress distribution during the THF process is also studied. Practical trial and error of the process is not advisable for processes like THF, thus there is need of some simulative experiments which can predict the performance of the process without any losses. Explicit Dynamics is used for Analysis and MISO plasticity model is used, considering the characteristics of the process and the end effects obtained from the process. The simulation results obtained using ANSYS were correlating with the experimental data, thus THF for a product can be validated using Explicit Dynamics.

Keywords: *THF, ANSYS, Explicit Dynamics, MISO, E34 4012A, Stress Distribution.*

1. Introduction

Recent growth in Hydroforming brings on several changes and advantages that the deep drawn product lacks. The light weight, complex geometry and efforts of assembling components, welding are looked upon in deep drawing but the light weight and complex geometry is better achieved in Hydroforming, also there is no welding and assembling needed as a part can be made as a whole, in Hydroforming. The recent development in Hydroforming process involves machines with number of intensifiers that allows quick process completion and more number of parts are producible in given time. Thus the production target is achieved before time. Complexities in Geometry are the most difficult part to obtain, but Hydroforming makes it simpler to achieve in less time compared to other forming processes. Hydroforming is already widely used - in the US, more than a million engine cradles a year are produced by hydroforming processes, and in Europe the technology is being used in sub-frames for models such as Ford's Mondeo and General Motor's Vectra. Some 2.8 million components a year for one of Chrysler's model are produced by hydroforming, too. However, as hydroforming - particularly high-pressure hydroforming - is at the frontier of modern steel technology, many designers and engineers still need convincing of its capabilities. No doubt Hydroforming has tremendous results, but those results could only be achieved if the designers and the engineers change their way of working and thinking throughout the production process. Due to its technical elegance it is even used in India, its robustness enhances its appearances in all the automotive industries. The main advantages of Hydroforming are complex geometry with contours, firm parts with light weight and enhanced strength, seamless bonding, Surface finish obtained is high quality, reduction in cost when compared to stamped parts or stamped and welded parts. Combination of spinning and hydroforming gives high quality products with cost effectiveness. The main purpose of this study is to validate the Tube Hydroforming process. The study is focused completely on the simulation results obtained on ANSYS 18.2, the analyzed process and the parameters are considered and user defined. Explicit Dynamics solver is used for analyzing the process. Multilinear Isotropic Hardening is used as Plasticity model in Explicit Dynamics. Different loading conditions are studied based on different metals used for Hydroforming. The pressure load and the axial load will definitely vary as we change the material. It is easy to simulate then produce rather produce and change. The results obtained experimentally can be validated on ANSYS 18.2 thus hydroforming can be used by any manufacturing industry which uses conventional forming process after simulating it on ANSYS. Analysis is of utmost important as all the material will require different parameters. Explicit Dynamics which uses the program code of LS-DYNA. Exclusive use of LS-DYNA can also be done for same results. The product that needs to survive through impacts or short-duration, high-pressure loadings, improvement in its design with ANSYS explicit dynamics is a quick solution. Specialized problems require advanced analysis tools to accurately predict the effect of design considerations on product or process behavior. Gaining insight into such complex reality is especially important when it is too expensive or impossible to perform physical testing. The ANSYS explicit dynamics suite enables to capture the physics of short-duration events for products that undergo highly nonlinear, transient dynamic forces. The specialized, accurate and easy-to-use tools have been designed to maximize user productivity. Prediction of complex responses, such as material deformations which is large and failure, body interactions, and fluids with rapidly changing surfaces. Explicit Dynamics is an extension of structural mechanical suite that deals for high strain rates and other complex problems which are otherwise impossible to solve using implicit suite which is a general purpose method used in ANSYS. The aim of this study is to analyze and validate the hydroforming of a tubular product using the software ANSYS 18.2, Explicit Dynamics.

2. Review of Literature

Development of database for loading path, mainly Axial force for wide range of geometry of tubes. Based on geometrical configuration the parts are classified into families (Angshuman Ghosh, Karan Deshmukh & Gracious Ngaile, 2011). Friction is an important parameter when it comes to HPTH whereas in LPTH friction is not important factor (C. Nikhare, M. Weiss & P.D. Hodgson, 2009). Thickness distribution is mainly affected by the friction at the interface of die/material. The study also gives idea about limits of process capabilities (Hatem Orban & S. Jack Hu, 2007). Success or failure of THF process depends on the loading path imposed (J. Tirosh, S. Yosifon, R. Eshel & A. A. Betser, 2011). Behavior of Aluminum alloy on free Bulge Hydroforming and Die/Axial force Hydroforming is studied using LS-DYNA software (Jorge Paiva Abrantes, Carlos Eduardo C´elia de Lima & Gilmar Ferreira Batalha, 2006). Investigation of the optimization strategy for loading path due to which failure like wrinkles, bursting, buckling occurs. The study also states about how can "harmful wrinkles" be distinguished with useful wrinkles (Lihui Lang, Huili Li, Shijian Yuan, J. Danckert & K.B. Nielsen, 2009). Calculating friction co-efficient based on deformed geometry of tube and mechanical properties of material is possible without force measurements (M. Plancak, F. Vollertsen & J. Woitschig, 2005). Study of analytical and numerical forming limit predictions considering hydroforming as the FLD is basically based on deep drawing method which cannot be used for Hydroforming process (Mikael Jansson, Larsgunnar Nilsson & Kjell Simonsson, 2008). Thin and Thick tubes both are not desirable as extra thickness caused due to bending will cause wrinkles during THF process and thin tubes would undergo busting due to high internal pressure. Use of FEA to carry the results of bending and crushing in THF process is the best way to accomplish THF process without causing failures (Muammer Koc & Taylan Altan, 2002). Component and process design which includes finite element simulations must use FLC as an aid or instrument for design and analysis (Nader Asnafi & Anders Skogsgardh, 2000). There is influence of various materials and process parameters on loading path and forming results or limits in case of THF (Nader Asnafi, 1999). Optimization of the forming load path using fuzzy logic using LS-DYNA. Evaluated level of internal fluid pressure and axial plunge force always gives accurate results in case of THF process (P. Ray & B.J. Mac Donald, 2004). For smooth running of the process proper frictional conditions between the contact surface is must (Vijay. R. Parekh, Jay. Shah & B. C. Patel, 2012). The applied internal pressure must be high enough to avoid buckling but it should be in the range such that the tube does not burst, thus considering the ultimate strength of the material internal pressure must be applied in THF process (YANG Xiao-yu, 2012). Plastic flow pattern of circular tube is studied, the expansion and crushing of the circular tube into rectangular tube is studied using Finite Element Method (FEM) (Yeong-Maw Hwang & Taylan Altan, 2002). THF is tremendously growing and various conventional forming processes are replaced by THF process due to its effectiveness in reduction of weight, more complex geometry achieved in less time. The study of different loading conditions on the quality of product (Yi-Chun Chen, Chih-Yu Chuang & Ming-Fu Lee, 2014).

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2. Material and Methodology

2.1 Tensile test of E34 4012 A, CS tube

The tensile testing of the material E34 4012A was carried out. Results obtained from the same were in the form of load v/s deflection diagram, which was further converted to Stress- Strain Curve. The engineering stress strain curve is further converted to real stress curve using the following:

Up until twice the strain at which yielding occurs:

$\sigma = \sigma engg$ and $\varepsilon = \varepsilon engg$

Up until the point at which necking occurs:

$\sigma = \sigma engg\,(1+ \varepsilon engg)$ and $\varepsilon = \ln(1+ \varepsilon engg)$

Table 1Real Stress Strain Values

Strain	Stress (MPa)
0	0.0001
0.002033	404.95
0.0025001	430.34
0.0050204	445.29
0.0088981	455.6968
0.0140418	462.35693
0.0296573	476.1953214
0.0645694	499.9087675
0.1790898	570.7205616
0.2897601	643.1885006

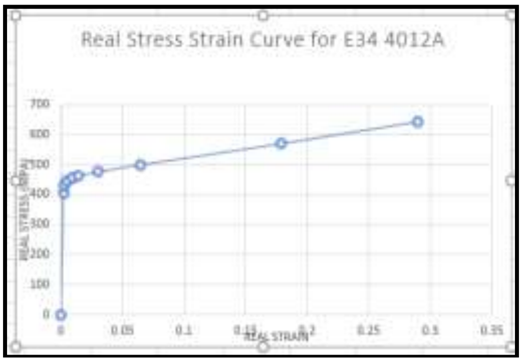

Figure 1 Real Stress Strain curve

Table 2 Chemical Properties

	C%	Mn %	S%	P%	Al %	Si%
E34 4012 A	0.060	0.631	0.004	0.009	NA	0.236

Table 3 Mechanical Properties

Tube size (mm)	117x.3.60
Condition	HRPO ASI Rolling
Strip Diameter (mm)	21.7
Strip Thickness (mm)	3.59
Area of Cross-Section (mm2)	77.9
O.G.L (mm)	49.86 / 24.93
UL (KN)	37.5
YL (KN)	34.5
F.G.L (mm)	66.5
Tensile Strength (MPa)	481.38
Yield Strength (MPa)	443
Elongation (%) min at 50 mml GL	33.4
Hardness (HRB)	79.00-80.00

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2.2 Explicit Dynamics Analysis

The structure which responds dynamically is easily analyzed in Explicit Dynamics. The Dynamic Response studied is due to Stress wave propagation, Impact or rapidly changing Load (Time- Dependent). Important aspects of this type of Analysis is Momentum Exchange between moving bodies. Explicit Dynamics can also be used to develop a mechanical model for phenomena which are highly non-linear in nature. Non-Linearity refers to Hyper elasticity, Plastic flows, failure when studied for material, when studied for contact it refers to Impact and High-Speed collisions and when studied for Geometric Deformation it refers to Buckling, Wrinkling and Collapse. Events with time duration less than 1 second (of the order 1 millisecond) can be considered using Explicit Dynamics.
The ANSYS explicit dynamics suite enables you to capture the physics of short-duration events for products that undergo highly nonlinear, transient dynamic forces. Our specialized, accurate and easy-to-use tools have been designed to maximize user productivity.

2.3 Geometry

Geometry is imported from SOLIDWORKS, which is assembly of lower die and a tube. The same can also be made in ANSYS geometry within the software. The geometry can also be edited in ANSYS geometry as per requirements. For the study 1/4th sectional assembly is considered to check the parameters.

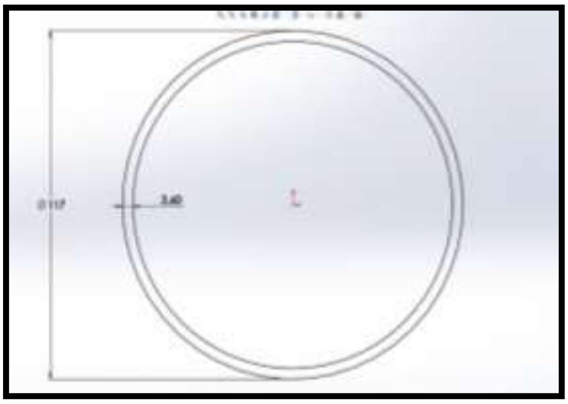

Figure 2 Cross-section of the tube

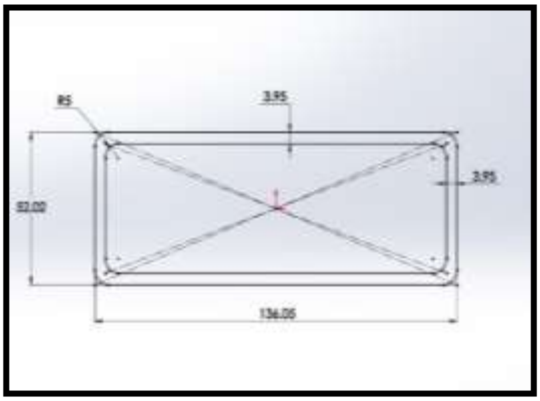

Figure 3Cross-section of the final rectangular product

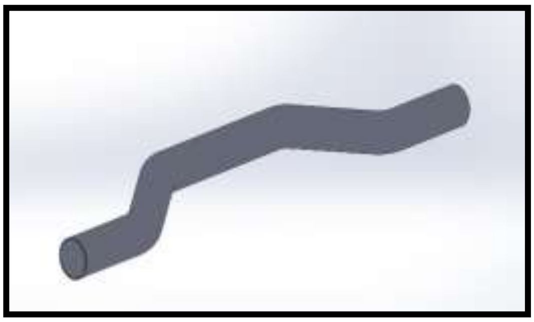

Figure 4Tube (before THF)

Figure 5 Tube (after THF), Final Rectangular Product

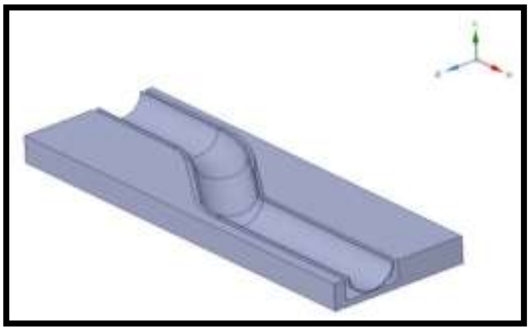

Figure 6 One-fourth geometry of tube and die assembly

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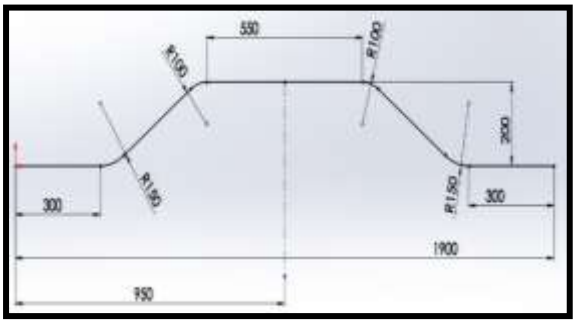

Figure 7 Tube and Die Axis

2.4 Modelling

The very first step of Analysis is Modelling. In case of Hydroforming wherein a metal is formed with the hydrostatic pressure, more specifically with the internal Hydroforming pressure in case of Tube Hydroforming. Forming needs, a proper geometric model in order to have genuine forming results which gives complete parametric knowledge after simulations. Using explicit finite elements code on ANSYS, the tube hydroforming process is simulated. For simplification one- fourth section of Tube and Lower Die is considered for Analysis. In Actual case there will be a complete tube overlapped by upper die same as the lower one. The diameter of the tube is 117 mm Thickness is 3.59 mm. The model assembly consisting the tube and the die is designed on SolidWorks software and then imported in ANSYS. The strength model used is Multilinear Isotropic Hardening.
Multilinear Isotopic Hardening, MISO is a plasticity model used for analyzing large strain analysis. The data required for this model is in the form of true stress and strain points. 10 stress strain points should be supplied. These points are user defined. In this model the yield surface deforms itself in the direction of load, whereas in the kinematic models the yield surface without deforming shifts in the direction of load.

- Global co-ordinate system is used for modelling.
- Symmetry Normal: X Axis
- Connection Type: Contact
- Body Interaction: Scoping Method is Geometry selection; all the geometries are considered.
- Type of contact is Frictional, Frictional co-efficient is 0.2

Depending on the mesh quality parameters and grid independent test the mesh is created. Mesh: Body sizing with element size of 150mm for die and Edge sizing no of divisions 3 per edge and no of edges 4 for tube

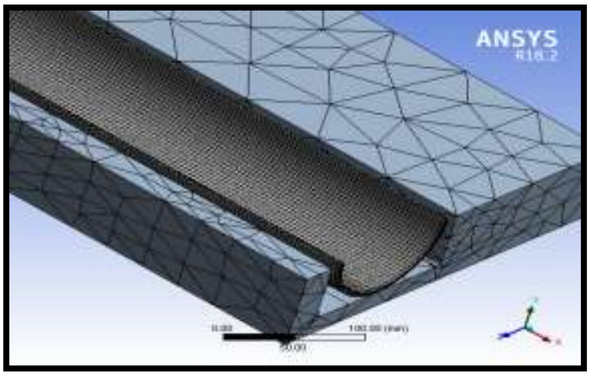

Figure 8 Mesh Generation

2.5 Boundary Conditions

The Die is kept Rigid and the tube is flexible for the contact pair, as we don't want the die to get deformed by the applied water pressure. The ductile behavior of the carbon steel can be analyzed only by keeping the tube flexible. The die is the fixed support. The Boundary conditions applied are the loads: Pressure of water and Force applied by the plunge on both the ends of the tube. The plunge force is compressive.
Solve command is given for obtaining various results once the boundary conditions are applied. Any changes in the Analysis settings or Boundary condition requires a solve command as the results would vary with every change of ANSYS settings and Boundary condition changes.

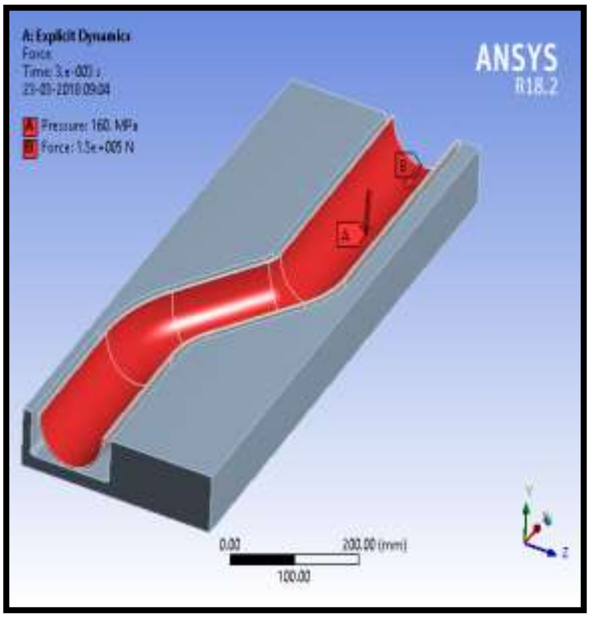

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Figure 9 . Rigid-to-flexible surface-to-surface contact pair

Table 4 Pressure and Plunge Force

Time (s)	Pressure (MPa)	X (N)	Y (N)	Z (N)
0	0	0	0	0
1.50E-03	80	-1.00E+05	0	0
3.00E-03	160	-1.50E+05	0	0

3 Results and Discussion

3.1 Total Deformation

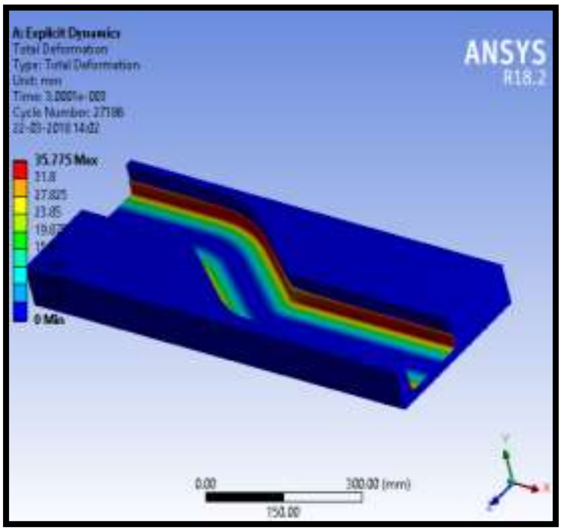

Figure 10 Total Deformation with max deformation = 35.775 mm

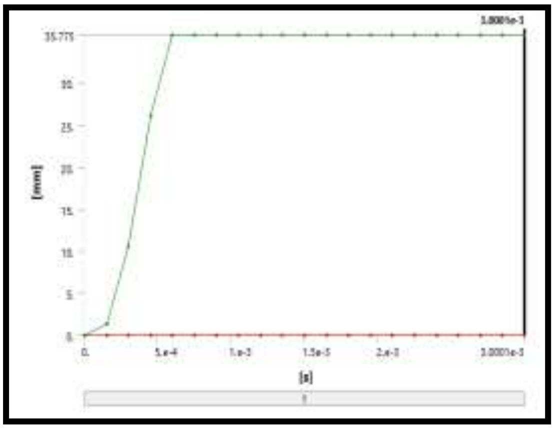

Figure 11 Deformation v/s Time

3.2 Equivalent Stress distribution

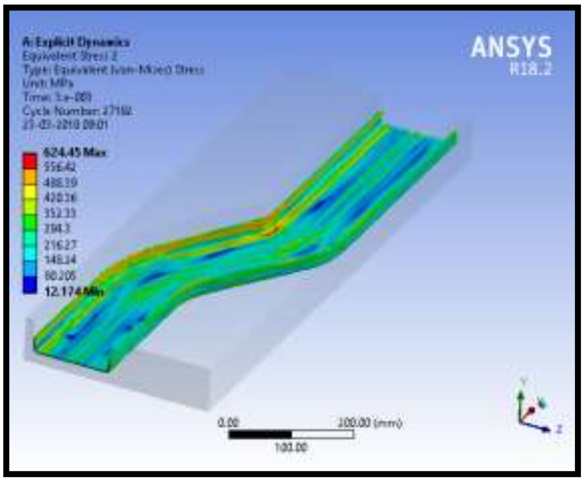

Figure 12. Equivalent stress distribution with max stress = 624.45MPa

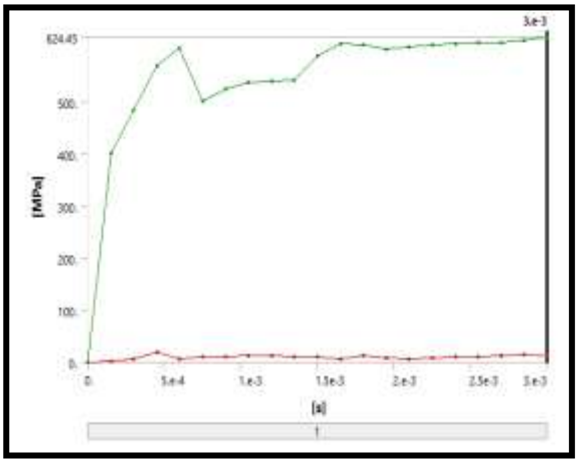

Figure 13. Stress v/s time

The Von- Mises Equivalent stress obtained is 624.45MPa, which is below the ultimate stress, 643.188MPa. Thus the Pressure and Plunge force can be used to produce these members without any further changes in these parameters.

4 Conclusion

The Von- Mises stress developed causes required deformation without causing failure. The maximum stress developed or equivalent Von- Mises stress is 624.45MPa and thus the deformation of the tube to a final product is achieved. The rectangular tube produced is end product which serves as side member of chassis and is automotive part and can be dealt as perfect side member as it forms within the given range of yield and ultimate strength of the material.

THF of any complex Automotive part is thus achievable by simulating the process on ANSYS, Explicit Dynamics. MISO serves as the best plasticity model for Analyzing THF process with ease. The parameters such as Pressure exerted by fluid, Plunge force on the ends of the tube are advised to be tested before actually performing THF.

Various Materials could be used for Hydroforming and following above steps equivalent stress generation and deformation of the material can be analyzed by simulations on Explicit dynamics using the same plasticity model MISO.

The above Analysis is done for validating THF process for the above product using the material CS E34 4012A. The validation was based on the parameters given by the manufacturer. Similar runs of simulations can be made to validate the process for different material and also for materials whose parameters are to be decided. The loading path could be determined using similar simulations. The range of allowable loading and parameters can be found using similar Explicit dynamics runs on ANSYS.

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