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Performance Analysis of Dual Hydroforming Process by Using the Finite Element Method and ANN

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***Abstract*—The hydroforming process for tubes has gained increasing attention in recent years.Coordination of internal pressurization and axial feed curves is essential in the pipe hydroforming process to generate successful parts without cracking or crumpling. The state of stress at any given time and place will vary depending on the history of the process and the design and control of loading routes. A parametric process include back pressure, is introduced to achieve a favourabletriaxial stress state during the deformation procedure this is known as dual hydroforming. The advantages offered by dual hydroforming will be characterized according to the amount of thinning of the wall, the limit of plastic instability and the final bulged configuration. A geometrical model is developed to analyse the state of stress and deformation in the tube during the dual hydroforming process. The effect of applying back pressure on the thin-walled tubes with a combination of internal pressure and independent axial load is considered. A parametric study was conducted to investigate the effectiveness of the conditions of the dual hydroforming process. Hydroforming Process under the application of internal pressure and axial load by the using of CATIA 5.1, ANSYS 2020 R1 and MATLAB R2016A. In this manner, finite element method analysis and artificial neural network analysis were performed. The results of ANSYS were used in MATLAB to generate the artificial neural network model for forecasting of the performance. It was found that the simulation of full Dual Hydroforming Process is too time consuming to be used in everyday engineering work. However, Equivalent Stress, Equivalent Elastic Strain, Penetration and Pressure can successfully be predicted with simplified models.**

Index Terms - Dual Hydroforming Process; Simulation; Finite Element Method; Artificial Neural Network; ANSYS; MATLAB.

I. INTRODUCTION

The back pressure supports the pipe material and therefore causes less thinning and a delayed onset of plastic instability. Conversely, a further expansion of the tube can be obtained. In addition, given part geometry, increased strength, and less malleable materials can be used. The hydroforming of tubes has been known since the 1950s. The hydroforming of tubeshas been called by many other names, such as liquid bulge formation, bulge formation tubes and hydrostatic pressure forming, depending on the time and the country in which it was used [1]. The tube hydroforming has developed in last decade into a practical method for the production of complex auto parts and an indispensable manufacturing technique. Hydroformed tube parts have improved strength and rigidity, lower tool costs, fewer secondary operations and tight dimensional tolerances compared to stamping processes, which lowers the overall manufacturing costs [1]. The success of the hydroforming process for tubes depends on a suitable combination of load curve (internal pressure and axial feed at the tube end), material properties and process conditions. One of the main concerns is to control the deformation process to maximize the expansion so that more complex shapes can be obtained. Similarly, a more resistant, less heavy, less conformable, or less expensive material can be used for a given shape.

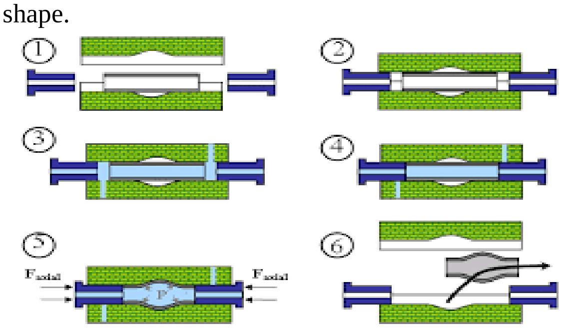

Figure 1.1: Tube hydroforming process

The operation process for a tube hydroforming is as followed as showed in Figure 1.1.

A. The hydroforming tube is placed between the attached dies. A clamper is used tclose the dies and apply sufficient force.
B. The tube is filled with hydraulic fluid to provide the required internal pressure. Axial punches are used for initial sealing to avoid pressure losses.
C. The fluid pressure in the tube increases after the nozzle is closed to create the necessary load while using an axial feed to force the material into the deformation load zone. The right combination of axial feed and internal pressure is applied during the hydroforming process to improve hydroforming capabilities. As soon as the tube touches the die, the calibration phase begins. No axial feed is required during the calibration phase. The tube is subjected to high pressures to form corner radii.
D. Finally, the hydroformed tube is removed from the matrix.

II. LITERATURE REVIEW

In The geometry of the piece precludes the case of a counter strike. It is not possible todesign a counter-attack tool for a simple process of forming bumps with centerline symmetry. In addition, the kickback effect does not affect the entire part of the survey, but focuses on a localized area. Therefore, using a dual hydroforming system as shown in Figure 1.1 to increase the height of the protrusion is a logical alternative. Over the years, plastic instability for various manufacturing processes, including tube hydroforming, has been extensively studied. In his early work, Mellor presented an analytical solution that resulted in the unstable conditions of a thin-walled tube that was subjected to internal pressure and independent axial stress [22]. Hiller showed plastic instability of tension under complex tension [23]. He derived the instability criterion from the functional principle and applied it to thin pipes under internal pressure and independent axial load. He found that depending on the specification of freight rates, there could be more than one solution to a particular problem. For the thin-walled tube, he considered three load cases in which the proportional stress drop led to the same instability criterion as that of Mellor. Hiller presented a critical overview of apparently contradictory theories about the instability of tubes that were exposed to internal pressureand independent axial loads [24]. He showed that each theory is actually a solution to the problem, which is subject to different types of loading restrictions. Hiller presented the effect of pressure on the ductility of the metal that was exposed to certain sheet metal forming processes, such as the biaxial tension process, the expansion of the spherical housing and the crowning of the circular membrane [25]. In all the cases considered, it was found that the ductility was increased by the presence of liquid pressure on the surface of the film. Chakrabarty et al. presented a method for the precise determination of the instability stress for thick-walled cylinders using an expression of the pressure expansion relationship in closed form [26]. El-Sebaie et al. Calculation of the plastic instability conditions for deep drawing in a high-pressure environment [27]. They showed that the limit extraction ratio for the drawing process was increased from 2.19 to 3.44. Several parametric studies were carried out to analyze the influence of material properties on the hydroforming of tubes. Carleer et al., to get the most economical product with the best performance, it is important to choose the right material and process parameters [28]. The tests were carried out on various types of steel, ranging from high-strength to lowstrengthsteels. The investigated material parameters were the hardening exponent (s) and the anisotropic plastic parameter (r). They showed that the value of the anisotropy and the friction parameters have the greatest influence on the stress distribution. Manaber et al. examined the effects of process parameters, material properties and tool shape on the deformation process during tool formation. Previous research has focused on free bulge formation [29]. They used the explicit non-linear trade code FEM LS-DYNA3D to carry out a parametric study for various anisotropic values, hardening parameters, stress ratios and friction coefficients. It was concluded that plastic anisotropy is one of the most important material parameters for hydroforming tubes. Boudeau et al. developed a numerical approach that enables neck prediction from finite element results [30]. The properties of the steel and aluminum alloy material were used to demonstrate the influence of materials and process parameters. Koc saw the impact of material properties as a critical aspect of tube hydroforming technology. He examined the effects of the load path and fluctuations in material properties on the part quality specifications and capacity requirements of production plants [31]. Experiments were carried out to characterize the influence of the hardening exponent and anisotropy on tube formation. The load curve (variation of the internal pressure, the axial load and the counter pressure over time) defines the load profile and is influenced by the material, the thickness of the tube, the diameter of the tube and the relationship between the thickness of the shall and the diameter of the tube and the radius of formation [32-34]. Numerous researchers have presented theoretical and practical work on estimating stress parameters for hydroformedtubes using various techniques [35-37]. Asnafi et al. studied forming in free stroke for both theoretically and experimentally [35]. It derived the pressure and size of a hit at the elastic limit as well as during plastic deformation. Rimkuset al. describes the principles for creating load curves for the simulation [36]. They suggested that for the exact simulation of the forming process using the finite element method, the axial forcerequired to control the wall thickness development and the forming pressure required to press the tube into the tube must be calculated. and the calibration pressure required to form the (smallest) radii. Koc et al. presented analytical models for the prediction of bulks, creasing and cracking as well as for the calculation of the axial force, the internal pressure and the recoil force during the hydroforming of tubes on the basis of a force balance analysis [20].

III. FUNCTION OF TUBE HYDROFORMING PROCESS

A. Functions of tube hydroforming

A typical hydroforming operation consists of applying proper combinations of internal pressure and axial feeding. There are many applications of tube hydroforming in the automotive industry and in household uses. This technology uses clamping devices such as mechanical presses, pressure intensifiers, hydraulic punches and control systems. There are various factors affecting the tube hydroforming process, such as, tube material and formability, friction, tube bending and pre-forming, and loading path (variation of internal pressure and axial feed with time). Tube Hydroforming prepared components have several advantages, like [37]:

1. Part consolidation.
2. Efficient section design
3. High structural strength.
4. Reduced tooling cost.
5. Requires lower secondary operations.
6. High dimensional tolerances.
7. Reduced scrap.

B. Applications of hydroforming

There are many applications of tube hydroforming in the automotive industry, and the aircraft industry [38]. Many companies in the automotive sector are experiencing great success with the process which can reduce weight, overall costs, and the number of parts per vehicle. Current automotive applications are listed below [39].

1. Roof Headers
2. Instrument Panel Supports
3. Radiator Supports
4. Engine Cradles
5. Roof Rails
6. Frame Rails.

Other automotive applications include engine sub-frame, rear axle and exhaust manifolds.

Current applications of hydroforming in the automotive industry are:

1. The Chrysler Minivan “S” body instrument panel beam was the first high volume application for Pressure Sequence Hydroforming [40].
2. A hydroformed instrument panel reinforcement replaced a proposed three piece stamped and welded assembly resulting in a 3 pound weight reduction in the Ford Aerostar Instrument Panel [40].
3. The Ford CDW platform was the first to utilize a hydroformed engine cradle perimeter tube [40].
4. The redesigned 1994 Dodge Ram pickup truck includes the use of a hydroformed radiator closure assembly. Dodge replaced the conventional stamped and welded closure with one using hydroformed tubes resulting in 28 % fewer parts and 24% less weight for Dodge Dakota [40].
5. The Opel Vectra is equipped with an engine cradle assembly which employs a tube formed using the Pressure Sequence Hydroforming processes [40].
6. The release of the redesigned Jeep Grand Cherokee saw the third introduction of a hydroformed radiator closure for DaimlerChrysler [40].
7. Tube hydroforming is also used for the manufacturing of bathroom faucet spouts, aluminium riflescopes and steel panic bars.

IV. ARTIFICIAL NEURAL NETWORK

A. Introduction

ANN is a machine type designed to generate the way as brain performs a specific task. To get a good performance, they use a massive combination of simple computer cells called "neurons" or "processing units". Therefore, a neural network can be taken as an adaptive machine which defines as a neural network, which have a parallel distributed processor made of simple processing units that has a tendency to store and share the parametric information. It looks like a brain in two ways:

1. The network acquires knowledge from the environment during the whole learning process.

2. Strengths of connection between neurons, called synaptic weights, is the storage of acquired knowledge.

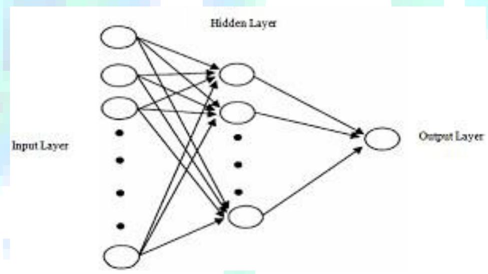

Figure 4.1: Feed Forward Network System

B. Uses of Neural Networks

The neural network offers the following useful properties and capabilities when uses:

- massive parallelism
- Distribution and computer representation
- learning ability
- Ability to generalize
- input-output mapping
- adaptability
- Uniform analysis and design
- damage resistance
- Inherent processing of context information
- VLSI implements the skill

4.3 Neuron Model System

Artificial neuron is a tool with large number of inputs and outputs. Each input is multiplied by a corresponding mass,

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analogous to the synaptic force, and all weighed inputs are summed up to determine the level of neuron activation. These weighted inputs.

V.PROBLEM FORMULATION

A. Objective

• According to the literature review, it is found that Artificial Neural Network Analysis and Finite Element Analysis (FEA) are useful for simulation of tool. By using FEM measure the Total Deformation, Equivalent Stress, Equivalent Elastic Strain, Equivalent Plastic Strain, Force Reaction, Penetration, Directional Deformation and Pressure. when axial force acts on the tube and by using the Artificial Neural Network Analysis approach we predict the performance of dual hydroforming process under different circumstances also we compare the results with previous FEM Study. The objective of present work is formulated and summary of these objectives are,

- To develop a Geometrical model with the help of CATIA 5.1 and Simulate the same model with the help of ANSYS 2020 R1.
- Finite Element Method Analysis with the help of ANSYS 2020 R1 to find the Total Deformation, Equivalent Stress, Equivalent Elastic Strain, Equivalent Plastic Strain, Force Reaction, Penetration, Directional Deformation and Pressure due to axial force.
- Developing an Artificial Neural Network Analysis Model with the help of MATLAB R2016A for finding the better prediction of performance of the Dual Hydroforming Process.

VI. MODELING& ANALYSIS OF THE DUAL HYDROFORMING PROCESS

The suite comprises of applications, each conveying a particular arrangementof capacities for a client part inside of item advancement. CATIA keeps running on Microsoft Windows and gives applications to 2D configuration, 3D CAD parametric component strong demonstrating, 3D immediate displaying, Finite Component Analysis and reproduction, schematic design, technical outlines, furthermore, survey and representation.

6.1 Modeling

Software used: CATIA 5.1 Tools used: Modelling, Assembly

6.2 Analysis in ANASYS Software

ANSYS is a broadly useful programming, used to mimic collaborations of all controls of physical science, basic, vibration, liquid flow, warmth exchange and electromagnetic for architects.

Therefore, ANSYS, which regenerates test or working conditions, allows you to test in virtual environments before collecting element models. In addition, 3D reproduction in virtual environments can design and improve impotent homes, determine life, and predict practical problems.

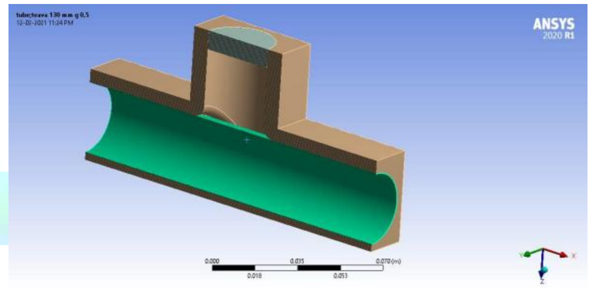

Figure 6.1: Dual Hydroforming Process after the modelling in CATIA software

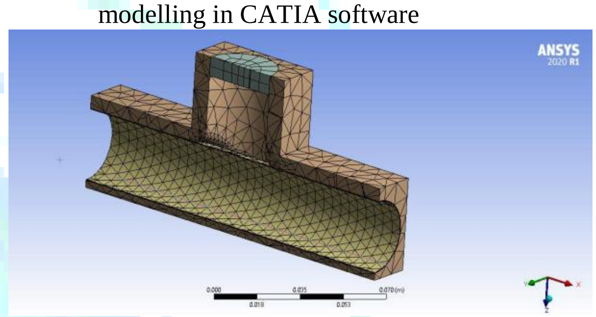

Figure 6.2: Triangular type of meshing is done in ANSYS software for Dual Hydroforming Process

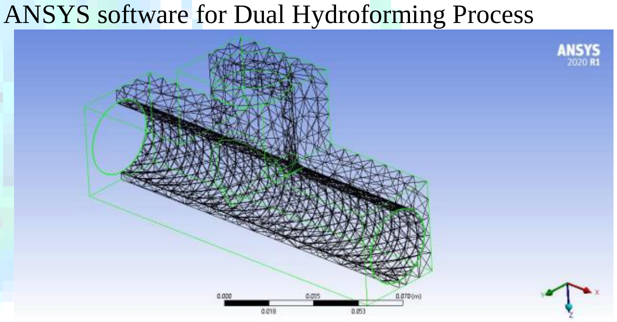

Figure 6.3: Wireframe View of triangular type of meshing is done in ANSYS software for Dual Hydroforming Process

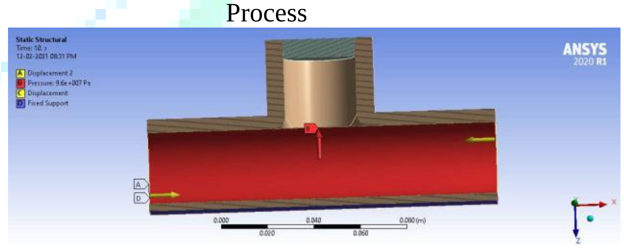

Figure 6.4: Applied Pressure Force and Hydroforming Tube Flow direction of the Dual Hydroforming Process

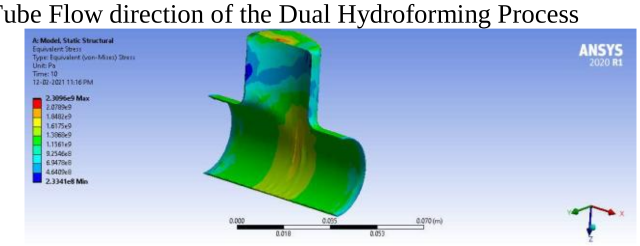

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Figure 6.5:Equivalent stress generated in Tube for Dual Hydroforming Process

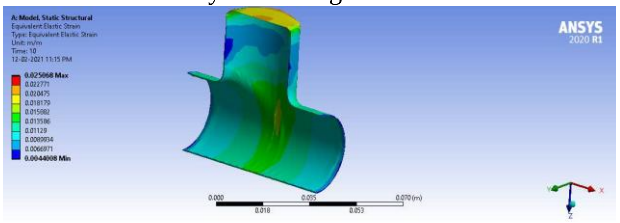


Figure 6.6: Equivalent elastic strain generated in Tube for Dual Hydroforming Process

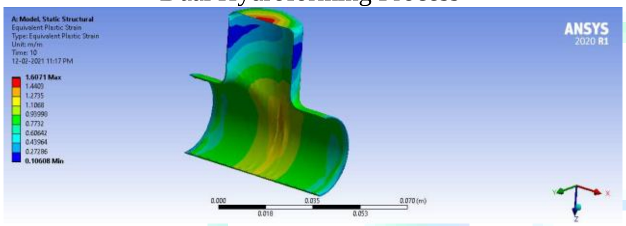


Figure 6.7:Equivalent Plastic Strain generated in Tube for Dual Hydroforming Process

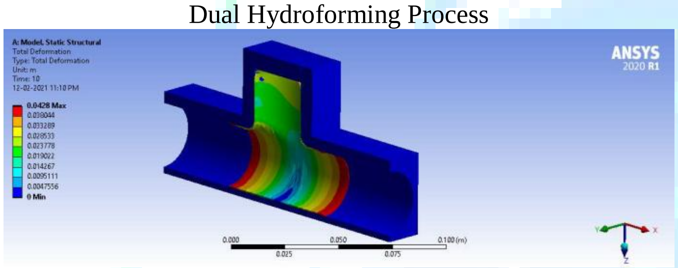


Figure 6.8: Total Deformation generated in Tube for Dual Hydroforming Process

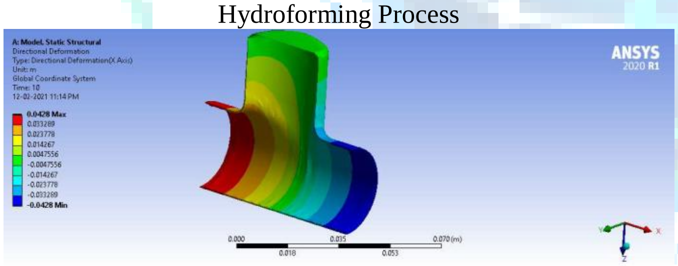


Figure 6.9: Directional Deformation generated in Tube for Dual Hydroforming Process

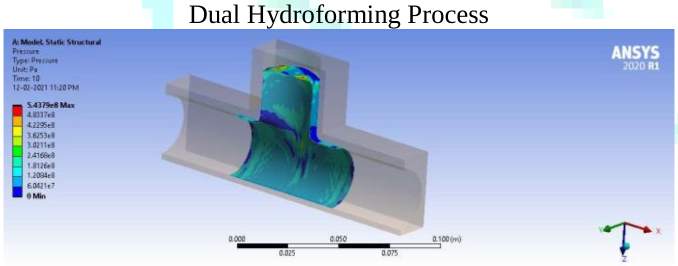


Figure 6.10: Total Pressure generated in Tube for Dual Hydroforming Process

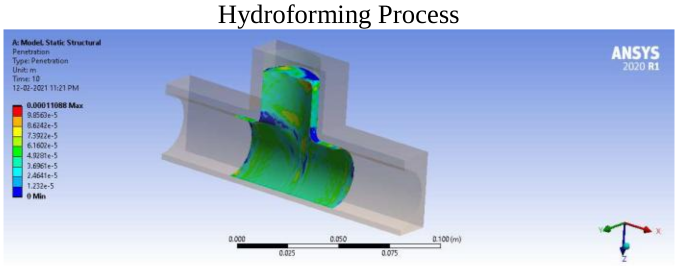


Figure 6.11: Total Penetration generated in Hydraulic Cylinder for Dual Hydroforming Process

VII. ANN ANALYSIS OF THE DUAL HYDROFORMING PROCESS

Detection Artificial Neural Network (ANN) is a system based on the operation of biological neuralbnetworks. System is a structure that receives an input, processes the data and provides an output. Once an input is presented to the neural network and a corresponding desired or target response is set as output, an error is composed from the difference of the desired response and the real system output. The error information is a feed back to the model which makes allnecessary adjustments to their parameters. This process is repeated until the desired output isacceptable.

A. Modeling

Software used: MATLAB Tools used: Artificial Neural Network.

B. Analysis in MATLAB Software

In neural network design the engineer or designers choose the network topology, the trigger or performance function, learning rule and the criteria for stopping the training phase. It is difficult in determining the size and parameters of the network as there is no rule or formula to do it. To have success with the design the best is to play with it. The problem with this method is to refine the solution when the system does not work properly. Despite this issue, ANN based solution is very efficient in terms of development, time and resources. The ANN provides real solutions that are difficult to get with other technologies.

C. Design of Neural Network for Performance of Dual Hydroforming Process

The present work was to develop an artificial neural network model that could predict theperformance of Dual Hydroforming Process. The main objective of the current work was to employ neural networks to model the Time, Total Penetration, Total applied Pressure, Total Deformation, Directional Deformation, Equivalent Stress, Equivalent Elastic Strain, &Equivalent Plastic Strain. Neural Network Toolbox of MATLAB (R2016a) was used to design the neural network. The basic steps adopted in the design are as follows: simulation and collection of data; analysis and pre-processing of data; design of the neural network; training and testing of the neural networks; simulation and prediction with the neural networks; analysis and post-processing of predicted result. ANN technique was used to predict the performance of Dual Hydroforming Process by the parameters; Time, Total Penetration, Total applied Pressure, Total Deformation, Directional Deformation, Equivalent Stress, Equivalent Elastic Strain, & Equivalent Plastic Strain.

TIME	Total Penetration	Total Pressure	TOTAL Force Reaction	Equivalent Plastic Strain	Equivalent Stress	Equivalent Elastic Strain,	Directional Deformation
2.45E-02	1.40E-06	1.68E+06	49.118	4.27E-03	2.78E+08	2.54E-03	2.49E-07
4.90E-02	2.00E-06	2.40E+06	460.81	1.12E-02	2.89E+08	2.65E-03	6.76E-07
8.58E-02	2.56E-06	3.07E+06	48.726	2.19E-02	3.03E+08	2.78E-03	2.61E-06
0.14087	3.05E-06	3.67E+06	165.14	3.83E-02	3.21E+08	2.95E-03	1.52E-06
0.196	3.44E-06	4.13E+06	322.11	5.49E-02	3.40E+08	3.13E-03	5.90E-07
0.22494	3.36E-06	4.04E+06	365.52	5.79E-02	3.44E+08	3.16E-03	2.20E-07
0.25388	3.34E-06	4.01E+06	365.76	6.00E-02	3.46E+08	3.18E-03	1.63E-07
0.29729	3.51E-06	4.22E+06	396.36	6.32E-02	3.50E+08	3.21E-03	1.86E-07
0.36241	3.88E-06	4.66E+06	433.4	6.80E-02	3.55E+08	3.27E-03	-4.06E-10
0.46008	4.44E-06	5.33E+06	533.72	7.53E-02	3.63E+08	3.34E-03	-2.04E-07
0.6066	5.26E-06	6.32E+06	820.64	8.64E-02	3.75E+08	3.46E-03	-3.27E-07
0.82636	6.45E-06	7.74E+06	1263.6	1.03E-01	3.94E+08	3.64E-03	-4.16E-06
1	7.46E-06	8.96E+06	1646.5	1.17E-01	4.09E+08	3.79E-03	-1.20E-05
1.2	8.31E-06	9.97E+06	1897.1	1.29E-01	4.22E+08	3.92E-03	-1.94E-05
1.4	8.63E-06	1.12E+07	2118.5	1.41E-01	4.36E+08	4.05E-03	-2.19E-05
1.7	9.95E-06	1.32E+07	2679.9	1.59E-01	4.56E+08	4.25E-03	-1.83E-05
2	1.02E-05	1.53E+07	3219.2	1.78E-01	4.77E+08	4.46E-03	-1.46E-05
2.2	1.06E-05	1.66E+07	3618.2	1.91E-01	4.91E+08	4.61E-03	-9.20E-06
2.4	1.17E-05	1.80E+07	3973.7	2.04E-01	5.06E+08	4.75E-03	-4.34E-06
2.7	1.05E-05	2.01E+07	4426.3	2.24E-01	5.29E+08	4.98E-03	1.52E-06
3	1.40E-05	2.18E+07	4726	2.44E-01	5.54E+08	5.22E-03	1.27E-05
3.2	1.27E-05	2.36E+07	4810.7	2.63E-01	5.76E+08	5.43E-03	1.16E-05
3.27	1.29E-05	2.40E+07	4900.2	2.69E-01	5.84E+08	5.51E-03	9.29E-06
3.34	1.40E-05	2.44E+07	4940.6	2.76E-01	5.92E+08	5.58E-03	7.08E-06

7.4 Proposed Model

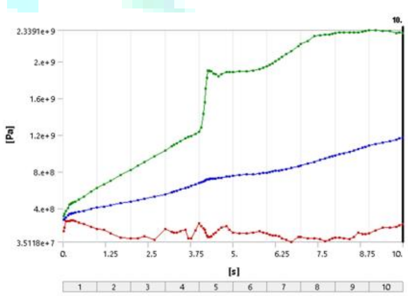
In this study, the artificial neural network based analytical model is proposed, in which Multi Layer Feed Forward Network is used.

Neural Network	MLP
Number of Input Variables	8
Number of Hidden Layer	2
Number of Hidden Neuron in First Hidden layer	10
Activation function used in first hidden layer	Straight line

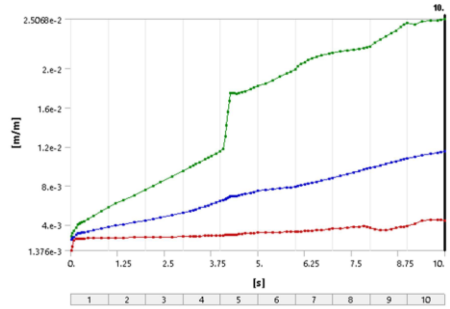
Table 7.2: Various elements of structure

VIII. RESULT & CONCLUSION

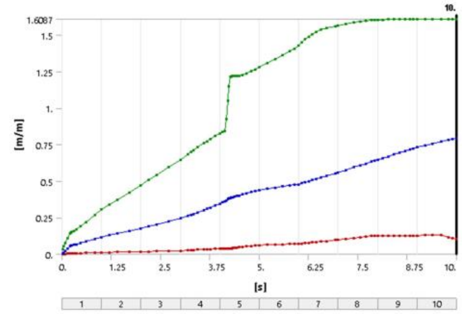
Results for The Finite Element Method Analysis The modelling of proposed design is done by using CATIA 5.1 software & static analysis isdone in ANSYS 2020 R1 software.



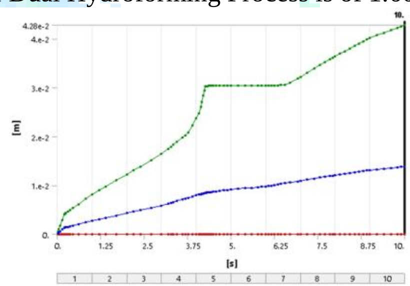
Graph 8.1: Equivalent Stress maximum generated in Tube of Dual Hydroforming Process is of 2339.1 MPa



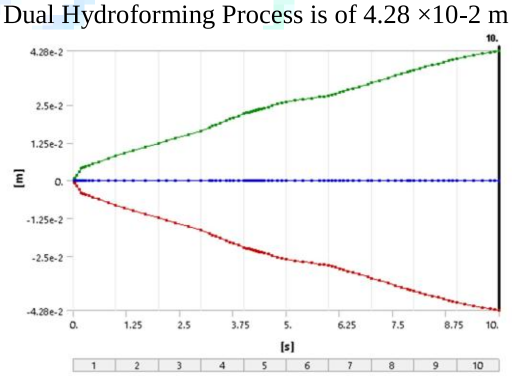
Graph 8.2: Equivalent Elastic Strain maximum generated in Tube of Dual Hydroforming Process is of 2.5068 ×10-2 m/m



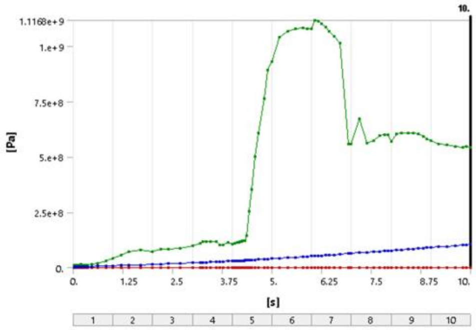
Graph 8.3: Equivalent Plastic Strain maximum generated in Tube of Dual Hydroforming Process is of 1.6087 m/m



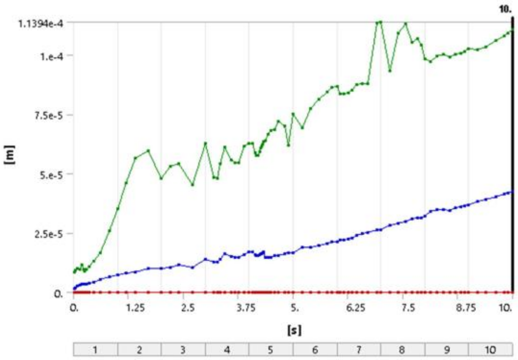
Graph 8.4: Total Deformation maximum generated in Tube of Dual Hydroforming Process is of 4.28 ×10-2 m



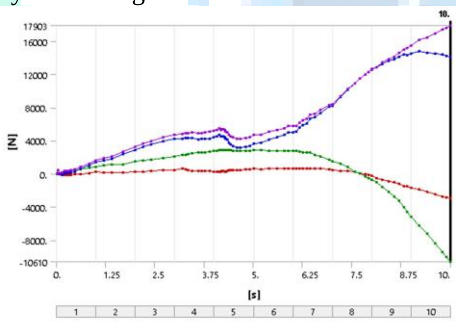
Graph 8.5: Directional Deformation maximum generated in Tube of Dual Hydroforming Process is of 4.28 ×10-2 m



Graph 8.6: Total Pressure maximum generated in Tube of Dual Hydroforming Process is of 1116.8 MPa



8.7: Total Penetration maximum generated in Tube of Dual Hydroforming Process is of 1.1394 ×10-4 m



Graph 8.8: Total Reaction Force maximum generated in Tube of Dual Hydroforming Process is of 17903 N.

IX. CONCLUSION AND FUTURE SCOPE

From the above tables and previous Chapter graphs, it is found that Time, Total Penetration, Total applied Pressure, Total Deformation, Directional Deformation, Equivalent Stress, Equivalent Elastic Strain, & Equivalent Plastic Strain for dual hydroforming process is well predicted by the Artificial Neural Network modal. Hence, Artificial Neural Network model is a good tool of MATLAB to predict the Different performance characteristic of any working mechanical model. On the basis of the current work, it is concluded that:

1. Any Performance parameter can be efficiently predicted by the Artificial Neural Network Analysis.

2. On the basis of Artificial Neural Network Analysis, as compare to applied force and internal pressure material properties are more responsible for proper dual hydroforming process.

3. Ansys is efficient Software to analyse the performance of Dual Hydroforming Process and results accuracy is totally depends upon the perfection of the boundary condition.

4. The prediction made using proposed model shows a high degree of accuracy for Total Deformation of Dual Hydroforming Process obtained through model 99.99%.

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