# Review on Tube Hydroforming Process with Considerable Parametric Effect

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***Abstract - In this paper, an overall review of the different parameter affecting on tube hydroforming process is presented so that other researchers can concentrate on same to further critical investigations in this area. Tube hydro forming is one of the most acceptable unconventional metal forming processes which is widely used to form various tubular components. In this process, tubes are formed into different shapes using internal pressure and axial compressive loads simultaneously to force a tubular blank to conform the shape of a given die cavity. The main process parameters in hydroforming are the inner pressure and the material feeding, where a correct combination of these parameters is crucial for the success of the process. Finite Element simulations are powerful tools for estimating the process parameters in an automated procedure. Hyper works is software which is having applicability to simulate the appropriate section of the tube profile for in depth parametric analysis.***

***Keywords - Hydroforming, Tube hydroforming, Bulge test, Parametric Effect, Simulation***

## I. INTRODUCTION

There are many metal-forming processes which are well-established, among them the tube hydroforming is one of the best unconventional metal forming processes which is widely used in order to form complex shapes. Tube Hydroforming (THF) has been called by many other names such as bulge forming of tubes, liquid bulge forming and hydraulic pressure forming (HPF) depending on the time and country in which it was used. Establishment of process goes back to 1939 when Grey et al [1], investigated manufacturing of seamless copper fittings with T protrusions using a combination of internal pressure and axial load. The process involves forming a straight or a pre-bent tube into a die cavity using internal hydraulic pressure, which may be coupled with controlled axial feeding of the tube. Structural strength and stiffness can be improved and the tooling costs reduced because several components can be consolidated into one hydroformed part. The process is quite simple - a blank with a closed-form, such as a cylinder, is internally pressurized using fluid. The fluid is frequently water. The applied pressure is usually in the range 80-450 MPa. Its resultant plastic expansion is confined in a die of the desired shape. It is possible that some parts of the component thin excessively during hydroforming. This can sometimes be rectified, in the case of tube hydro-forming, by applying axial pressure to feed material into the bulges, thereby reducing bulging. Hydroforming is capable of producing parts within tight tolerances including aircraft tolerances where a common tolerance for sheet metal parts is within 0.76 mm. Then metal hydroforming also allows for a smoother finish as draw marks produced by the traditional method of pressing a male and female die together are eliminated. The 'T' junctions can be made without using any joining techniques, and the smooth profiles also help avoid stress concentrations. Tube hydroforming is a unique forming method since during deformation due to inner pressure it is possible to feed material axially by cylinders at the tube ends. If necessary, counter punches can also be used to control the tube expansion, as shown in below Figure1.Ref [2], in 2002 have analyzed necking & bursting effect in flange & tube hydroforming by considering influence of material & process parameter. Which were applied to illustrating for tube and flange hydro-forming, bulging tests and classical stamping with good agreement with experimental knowledge. Theoretical process window diagram (PWD) established & proposed by ref [4], in 2004, based on the mathematical formulations for predicting forming limits induced by buckling, wrinkling and bursting of free-expansion tube hydroforming & also validated against experimental results conducted for 6260-T4 60×2×320 (mm) aluminum tubes. Ref [3], in 2004 have used of the finite element method in conjunction with abductive network is presented to predict an acceptable product of which the minimum wall thickness and the protrusion height fulfill the industrial demand on the T-shape tube hydroforming process. T-shape part or tube using the designed adaptive system in combination with the finite element method is proposed by ref [6], in 2005 & found efficient way of process control & for the simulations ABAQUS/Explicit is used. In 2006 effects of the coefficient of friction, strain hardening exponent and fillet radius on the parameters, protrusion height, thickness distribution and clamping and axial forces on unequal T joints were simulated through a code ABAQUS/EXPLICIT 6.3-1 by ref [8], & found different loading path. The amounts of calibration pressures and axial feedings required to produce an acceptable product in FEM were compared to better agreement with result obtained through experimentally. Different process parameters like velocity and pressure profiles, and bucking system characteristics related to the finished product were studied by ref [17], in 2010 through copper T-shaped tube with FE simulation techniques with used codes such as LS- Dyna and ABAQUS. Bi-layered tubing which consists of two different metallic layers is recommended to use in complex working environments as it offers combined properties that single layer structure does not have so a ref [18], in 2011produced T-shape bi-layered components in which the bulge height and the wall thickness reduction of the bi-layered hydroformed parts are modelled as functions of the geometrical factors using the combination of the finite element modeling (FEM) and Response Surface Methodology (RSM) for design of experiments (DOE) & determined effects of the geometrical factors and their interactions on the responses. Similar formability and failures in bi-layered tube hydroforming were analyzed by ref [19], in 2011 using ANSYS LS-DYNA pre-processor and LS-DYNA solver in order to predict the most efficient and acceptable operating condition for certain material properties and initial blank geometry. Also with reference to take tabulated data [II] must be taken for T-Shape profile & which analyzed through a best simulation software (Hyper Works) & then to define the various parameter behavior with significant changes in the available model as corner fillet radius, thickness, internal pressure, material & many other parameters related with different effect.

### I.I TUBE HYDROFORMING PROCESS & THEIR DETAILED STEP FOR T-SHAPE PROFILE

The process can be divided into four phases as shown in below fig-2. Initially the tube is filled with a fluid, usually water. If preforming is considered during die closure, an inner pressure could be applied to prevent local buckling. After that in free forming stage a tube is expanding using a relatively low pressure. Generally, this is a phase where the die contact is limited and material feeding is possible. Then in Calibration stage a tube conforms to the shape of the die cavity. The pressure level is high, and due to material friction and tool geometry, minor feeding is possible and the axial stroke is used to prevent leakage. In final stage when the forming is completed, the pressure is released & then dies are opened and the produced part is extracted.

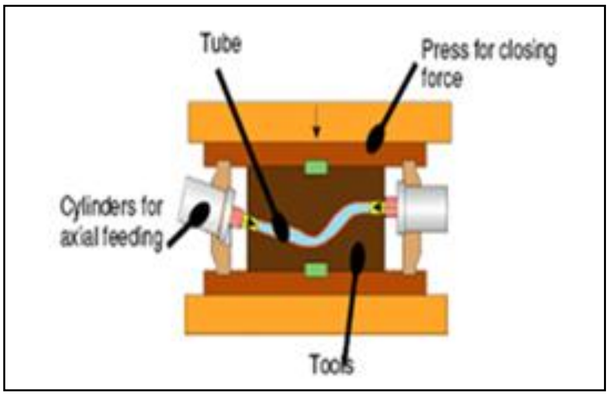


Fig. 1 : Tube Hydroforming

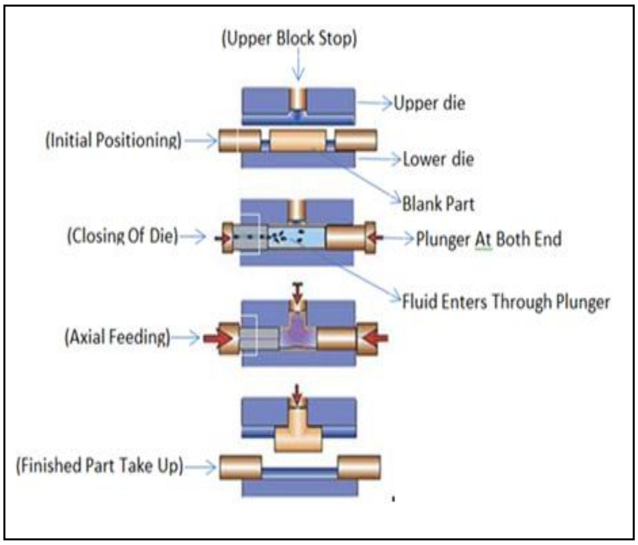


Fig. 2 : Tube Hydroforming sequence for T -shape

### I.II PROCESS ADVANTAGES

Hydroformed tubes can be used to develop cost effective lightweight components. It is possible to tailor the properties of the hydroformed tube by varying its initial wall thickness and cross section. The successive forming yields a product with properties similar to an assembly of parts, and for which the number of secondary operations such as welding or riveting thus are decreased. It is also possible to punch holes during the hydroforming process. Hydroforming produces products with high process repeatability due to tight dimensional tolerances and small spring back. The hydroforming process distributes the straining of the tubular blank and thus effectively utilizes the formability of the material.

### I.III Process Application

The main application of this method has been found in manufacturing of reflectors, household appliances as well as components in the hygiene, aerospace, automotive and aircraft industries. The process has become popular for the manufacture of aluminum bicycle frames.

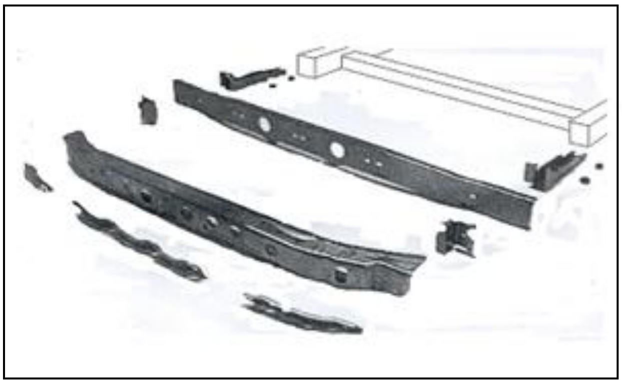

Fig. 3 : Original Sheet Metal

The earliest commercially manufactured one being that of the Revive bicycle first marketed in 2003.The technique is widely used in the manufacture of engine cradles. The first mass produced one was for the Ford Contour and Mystique in 1994.

As well as engine cradles, the main automotive applications for hydroforming are suspension, radiator supports and instrument-panel support beams. The first mass produced automotive component was in 1990 with the instrument panel support beam for the Chrysler minivan. Various vehicle bodies and body components, the earliest mass produced one being the 1997 Chevrolet Corvette. Also latest improvement in engine bumper system replaced ofsheet metal component shown in below fig.3

With hydroformed part as shown in below fig.4

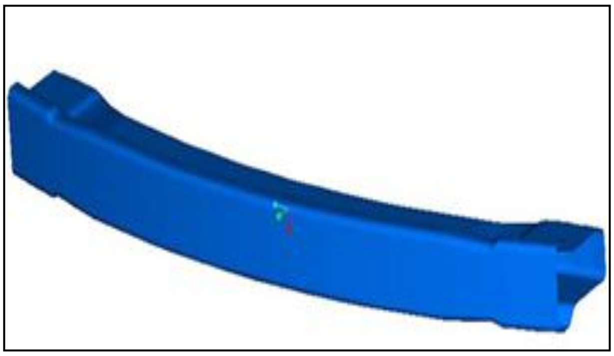

Fig. 4 : Hydroformed component

## II. Research Elaborations (Tabulated Form Of Authors Review)

| Ref | DISCUS-SED EFFECT | CONSIDE-RABLE PARAMETER | USED METHODS FOR ANALYSIS | RESULT & CONCLUSIO-N |
|---|---|---|---|---|
| [1] | Bursting & Necking | Material & Process Parameter | Bulge Test & Simulation Technique With & Without Considering A Counter Punch. | Both Effects Considered As Plastic Instability Phenomenon & Result Of Parameter Good Agreement With Experimental Study. |
| [2] | On Wall Thickn-ess & Protrus-ion Height Of T-Shap Tube | Process Parameter (Internal Pressure & Die Fillet Radius) | FEM In Conjunction With Abductive Network (AN) | A FE Based Code Is Utilized To Investigate The Material Flow Characteristics & The AN Is Then Applied To Synthesize The Data Sets Obtained From The Numerical Simulation. |
| [3] | Forming Limits Induced By Bukling, Wrinkling & Bursting | Internal Pressure & End Feeding | Mathematical Formulation | Proposed A Theoretical Process Window Diagram (PWD) |
| [4] | On Geome-tric Param-eter (tube length) | Process Parameter For Y-Shapes Tube (Pressure Levels, Axial Feed, And Initial Tube Length) | FEA simulations | The Tube Length Affects The Obtainable Protrusion Height; Because Of The Friction In The Guiding Zones. |

| Ref | DISCUS-SED EFFECT | CONSIDE-RABLE PARAMETER | USED METHODS FOR ANALYSIS | RESULT & CONCLUSIO-N |
|---|---|---|---|---|
| [5] | Forming Limit (wrinkling And Bursting) | Process Control Parameter | Simulation Via A Fuzzy Knowledge Based Controller (FKBC) (ABAQUS/Explicit) | Validation Of The Method By Performing Parallel Experiments Still Needs To Be Done. |
| [6] | Wrinkling Behaviour | Formability & Thickness Distribution | Experiment & Simulation | Different Wrinkles Such As Useful Wrinkles, Dead Wrinkles, And Bursting Wrinkles & Study Of Their Effect. |
| [7] | Coefficient Of Friction, Strain Hardening Exponent And Fillet Radius (Unequal T-Shape) | Protrusion Height, Thickness Distribution And Clamping And Axial Forces | ABAQUS/EXPLICIT 6.3-1 | Estimation Of The Capacity For The Press & Loading Paths For Different Branch Diameters Have Been Determined. |
| [8] | On Branch Heights & Formed Product | Loading Paths And Thickness Distribution | Hydroforming Test Machine | Branch Heights Of The Formed Products With And Without The Counter Punch Are Compared |
| [9] | Bending Effects Include-d, Local Strain And Stress Distribution | Hydroformed Shape, Corner Fill, Wall Thinning, And Forming Pressure | Deformation Theory | Analytical Model For Planer Hydroforming Has Been Developed & Validated Using FEA |
| [10] | Different Lubrication Systems | Coefficient Of Friction At Different Forming Zones. | Numerical Simulation | The Model Is Implemented In A FE Code And Validated With A Pear-Shape Expansion Test. |
| [11] | On Seamless Tubular Components | Material Flow And The Stress Distribution In The Die Corner Region | Finite Element Simulation | New Die-Set Was Manufactured And Experiments Were Performed & Verified To Result Of Simulation. |
| [12] | Formability (AHSS) | Internal Hydraulic Pressure And End-Feed Rate | Optimization(HEED) Method Linked With FEM(Finite Element Code LS-DYNA) | Failure Limits Defined By The Forming Limit Diagram (FLD) & The Pressure And Feed Profiles Identified Through The Automated Optimization Procedures. |
| [13] | Loading Paths | Hydro-Formability Of Trapezoid-Sectional Parts | Numerical Simulations | Die Angles And Friction Coefficients & Thickness Variation were Analyzed. |
| [14] | Flow Stress Characteristic | Tabular Material | Uniaxial Test, Free Bulge Test | The Actual Free Bulge Test To Find The Practically Valuable Forming Limit Curve For The THF Process. |
| [15] | Die Closing Force | Low Pressure THF | Simplified Analytical Technique | The Analytical Solution Developed Was Compared With Experiment-al And Numerical Results. |

| Ref | DISCUS-SED EFFECT | CONSIDE-RABLE PARAMETER | USED METHODS FOR ANALYSIS | RESULT & CONCLUSIO-N |
|---|---|---|---|---|
| [16] | On Copper T-Shape Tube | Internal State Variable Model | Simulation & Parametric Finite Element Analysis (Tensile Test) | Study Provides In Depth Knowledge For The Variation Of Different Process Parameters |
| [17] | Geometrical Factors | T-Type Bi-Layered | Finite Element Modeling (FEM) And Response Surface Methodol-ogy (RSM) For Design Of Experimen-ts (DOE). | Bulge Height And The Wall Thickness Reduction Of The Bi-Layered Hydroforme-d Parts Are Modeled As Functions Of The Geometrical Factors Using. |
| [18] | Internal Pressure In Advance Of The Axial Pushing | Formability For The Process | Ansys Ls-Dyna Pre-Processor And Ls-Dyna Solver | The Resultant Bulge Height And Thickness Reduction Good Agreement With Experiment-al Evolution. |
| [19] | Internal Pressure And Axial Force Loading Paths | Axisymmetric Geometries Under A Failure Criterion | Simulated Annealing Optimization Method (Ansys/Ls-Dyna) | Less Thinning And Better Shape Conformati-on Is Attained Using The Optimized Parameters |
| [20] | Localized Thinning Mechanism | Stainless Steel Micro-Tubes | Integrated Crystal Plasticity Finite Element (CPFE) Modeling System. (ABAQUS/ Explict-FE Code) | Localized Thinning Observed In Hydro- forming Of Micro-Tubes Is Significantly Affected By The Microstruct-ure And Grain Orientations Of The Material. |

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Similar action for Y-shape hydroforming experiments were conducted by ref [5], in 2004 & estimated the process parameters pressure levels, axial feeds, and initial tube length , which ware optimized" through conducting FEA simulations and verified with hydroforming experiments.

In 2006 ref [7], was conducted an experiment and simulation techniques for investigation the influence of wrinkling behavior on formability and thickness distribution in tube hydroforming process & found different types of wrinkles in which a useful wrinkle can meet both the stress condition and the geometrical condition during calibrating. Hydroforming test machine is designed and developed by ref [9], in 2007 for tube hydroforming processes & the effect with & without of counter punch on branch height of formed products analyzed & obtained the best result in the presence of the counter punch. In 2008 hydroformed shape, corner fill, wall thinning, and forming pressure were predicted by ref [10], used an analytical model for planar tube hydroforming based on deformation theory & also the model is validated through finite element analysis and tube hydroforming experiments on different hydroformed shapes. Lubricants are usually employed to increase the formability of the work piece so Ref [11], in 2008 have use different lubrication regimes and observed along the different forming zones which vary with the lubricant layer thickness, applied load and sliding velocity. The mechanism of improvement of die corner filling in a new hydroforming die for cylindrical stepped tubes was studied by the finite element simulation by ref [12], in 2009 & the contact region between the tube and die, the material flow and the stress distribution in the die corner region were examined & final result compared with result obtained experimentally. In 2009 an optimization method linked with the finite element method is presented by ref [13], for developing forming parameters of the tube hydroforming (THF) process for several advanced high-strength steel (AHSS) materials & for this investigation The optimization software HEEDS was used in combination with the nonlinear structural finite element code LS-DYNA. Ref [14], in 2009 experimentally investigated a tube with trapezoid-sectional die & studied the Effects of loading paths on the hydro-formability of trapezoid-sectional parts and the design principle for loading paths. The effects of die angles and friction coefficients on the hydroforming process and the final parts are explored through numerical simulations. In 2010 the free bulge test for the roll-formed tubular material are carried out by ref [15], can be concluded that the flow stress of the tubular material should be determined from the actual free bulge test to find the practically valuable forming limit curve for the THF process. Recently, low pressure tube hydroforming has emerged as a technology to reduce the weight of automotive body structures by allowing the implementation of advanced high strength steels and minimizing the number of process steps for that a simplified analytical model based on a rigid, perfectly plastic material model was developed to determine the die closing force needed to form a simple geometry using the low pressure hydroforming process by Ref [16], in 2010. Pressure and force loading optimization in tube hydroforming process were investigated by ref [20], in 2012 using application of simulated annealing techniques For analyzing the forming parameters the non-linear structural finite element code ANSYS/LS-DYNA were used & attained less thinning and better shape conformation. Experimental and numerical investigation of localized thinning in hydroforming of micro-tubes by ref [21], in 2012 through developing an integrated crystal plasticity finite element (CPFE) modeling system & finally analyzed that localized thinning observed in hydroforming of micro-tubes is significantly affected by the microstructure and grain orientations of the material with help of using ABAQUS/Explicit FE code. As per defined above ref table II a bulge test carried out by many researchers is to defined the maximum bulge height of the any given material under applied pressure, which denotes that up to that limit under which the material can deformed to get the desired shape of the die. With that data to form a model using FE method then simulated it by taking a quarter sectional part as for the symmetrical section. The different result can be obtained by considering different parameter with minor alteration as per previous availability of data & found the optimum value under which tube can deform ultimately best optimum way. Finally that data compared with the data obtained through experimentally. If it will be define great similarity then tube can be deformed in specified die sections.

## III. Results Of Literature Review

From different analytic & experimental study we have seen that when applied internal pressure from the fluid up to certain evaluated level with proper applying plunger force with axial feed we got the better output as per our required product. Here the material of the tabular blank & also a die material can develop greater effect of the final shape of the required product. Proper friction parameter related with two contacted surfaces as a die & blank surface can be utilized for the smooth operation condition. A multilayer tabular blank & bi layer tabular blank, which also have best possibilities to deformed in T & X section profile as a major acceptable product in many industries From the different prediction model, a suitable range of the process parameters for producing an acceptable T-shape tube that fulfills the industrial demand can be found. Two axial feeding punches, an internal pressure, and a counter punch was designed can provide proper loading path which can generate a sound product, was obtained.

## IV. Conclusion

Based on a number of research studies from different author of different university we conclude that , a detailed investigation on tube hydroforming process can be done by working on different parameters like tube material properties, the tube and die geometries, the process parameters and the frictional conditions .The application of finite element method in the tube hydroforming process analysis was introduced as it avoids the cost and limitations of compiling a database of real world parts, while guidelines for the successful application of the finite element modeling were proposed. Simulation technique adaption through latest software “HYPER WORKS” having facility to simulate different shape can be generated which may create extent to attain an optimum value of different parameter of similar result from different experimental & simulation techniques.

## V. References

[1] Grey JE, Devereaux AP, Parker WN. Ing for making wrought metal T’s. US Patent; 1939.

[2] N.Boudeau, A. Lejeune, J.C. Gelin, “Influence of material and process parameters on the Development of necking and bursting in flange and tube hydroforming”, Journal of Materials Processing Technology, vol. 125, pp. Feb 2002.

[3] F C.Lin, C.T.Kwan, ”Application of abductive network and FEM to predict an acceptable product on T-shape tube hydroforming process”, Computers and Structures, vol.82, pp. March 2004.

[4] E Chu, Yu Xu,”Hydroforming of aluminum extrusion tubes for automotive applications. Part II: process window diagram”, International Journal of Mechanical Sciences, vol. 46, pp. Feb 2004.

[5] Suwat Jirathearanat, Christoph Hartl, Taylan Altan,” Hydroforming of Y-shapes—product and process design using FEA simulation and experiments”, Journal of Materials Processing Technology, vol. 146, pp. 2004.

[6] A. Aydemir , J.H.P. de Vree , W.A.M. Brekelmans , M.G.D. Geers ,W.H. Sillekens , R.J. Werkhoven ” An adaptive simulation approach designed for tube hydroforming processes”, Journal of Materials Processing Technology, vol. 159, pp. 2005.

[7] Shijian Yuan , Wenjian Yuan, Xiaosong Wang," Effect Of Wrinkling Behavior On Formability And Thickness Distribution In Tube Hydroforming", Journal Of Materials Processing Technology vol. 177 pp. 2006.

[8] Hossein Kashani Zadeh, Mahmoud Mosavi Mashhadi," Finite Element Simulation and Experiment in Tube Hydroforming of Unequal T Shapes", Journal of Materials Processing Technology, vol. 177, pp.2006.

[9] Y.M. Hwang , T.C. Lin, W.C. Chang, " Experiments on T-shape hydroforming with counter punch", Journal of Materials Processing Technology, vol. 192–193, pp. 2007.

[10] Chen Yang, Gracious Ngaile," Analytical model for planar tube hydroforming: Prediction of formed shape, corner fill, wall thinning, and forming pressure", International Journal of Mechanical Sciences, vol. 50, pp. May 2008.

[11] Mariela Luege, Bibiana M. Luccioni," Numerical simulation of the lubricant performance in tube hydroforming", journal of materials processing technology, vol.198, pp. July 2008.

[12] M. Elyasi, M. Bakhshi-Jooybari , A. Gorji," Technical Report Mechanism of improvement of die corner filling in a new hydroforming die for stepped tubes", Materials and Design, vol. 30, pp. March 2009.

[13] Nader Abedrabbo, Michael Worswick, Robert Mayer, Isadora van,"Optimization methods for the tube hydroforming process applied to advanced high-strength steels with experimental verification", journal of materials processing technology ,vol. 209, pp. Jan 2009.

[14] Xian he Cu, Weygand Zhang, ShuhuiLi, Zhongqin Lin ,"Study of tube hydroforming in a trapezoid-sectional die", Thin Walled Structures, vol. 47, pp. Dec 2009.

[15] Woo-JinSong, Seong-ChanHeo Tae-WanKu , JeongKim , Beom-SooKang, "Evaluation of effect of flow stress characteristics of tubular material on forming limit in tube hydroforming process", International Journal of Machine Tools & Manufacture, vol. 50 pp. May 2010.

[16] C. Nikhare, M. Weiss, P.D. Hodgson," Die closing force in low pressure tube hydroforming", Journal of Materials Processing Technology, vol. 210, pp. Aug 2010.

[17] J.Crapps, E.B.Marin, M.F.Horstemeyer R.Yassar, P.T.Wang, "Internal state variable plasticity-damage modeling of the copper tee-shaped tube hydroforming process", Journal of Materials Processing Technology, vol. 210 pp. June 2010.

[18] A. Alaswad, K.Y. Benyounis, A.G. Olabi Defining problem "Employment of finite element analysis and Response Surface Methodology to investigate the geometrical factors in T-type bi-layered tube hydroforming", Advances in Engineering Software, vol. 42 pp. July 2011

[19] A.G. Olabi, A. Alaswad, "Experimental and finite element investigation of formability and failures in bi-layered tube hydroforming process", Advances in Engineering Software, vol. 42 pp. May 2011.

[20] M.Mirzaali, S.M.H.Seyedkashi, G.H.Liaghatn, H.MoslemiNaeini, K.ShojaeeG. , Y.H.Moon" Application of simulated annealing method to pressure and force loading optimization in tube hydroforming process" , International Journal of Mechanical Sciences, vol. 55 pp. Dec 2012.

[21] W.Zhuang, S.Wang, J. Lin, D. Balint, Ch. Hartl "Experimental and numerical investigation of localized thinning in hydroforming of micro-tubes", European Journal of Mechanics A/Solids, vol. 31 pp. June 2012.

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