Stress & strain character of tube hydroforming and its application in processing analysis

Hongyang Li*, Song Yu, Jianhui Li
Department of technology, Dongguan zhongfan new material technology Co., LTD, Dongguan, 523808, China

*Corresponding author e-mail: li_hyraise@hit.edu.cn

Abstract. The mechanical character for tube hydroforming stress state of is discussed in this paper and the special stress states was classed by those discussed characters. For the mechanical character of tube hydroforming, tube hydroforming stress state was discussed with different families. Tube hydroforming stress state discussion was important in process analysis of tube hydorforming, it can determine what kind of component we get. Mechanical stress state character discussed can be used in the optimization of tube hydroforming and achieve proper component. The essence of tube hydroforming technological parameter choosing is procedure of analysis and optimization of the stress state.

Keywords: mechanical stress state, tube hydroforming, processing optimization, stress optimization.

1. Introduction
Hydroforming is an attracting hydro flexible metal forming technologies and has developed for few decades. Now it is attracting attention in industrial field for the production of hollow complex component. Especially for modern industry and car industry, tube hydroforming developed rapidly in the past few years. Almost all researchers and workers in such field is paying more and more attention on tube hydroforming technology and using its advantage [1-3].

Flexible manufacturing developed rapidly in the past decades, such as hydrobulging and deep drawing, which also contribute many special component for industry, but for hollow tubular component, tube hydroforming is more feasible. By using tube, it reduced the cost and weight of components higherly, it is now being widely used in many factory, especially for automotive parts.

For more and more researchers is working on tube hydroforming, papers and journals on automotive published many topics on hydroforming in the past few years. In the word almost every year many congress on hydroforming was hold to give more opportunity for researchers on hydroforming to discuss their current works. And big automotive maker in the world have all adopt tube hydroforming as special technology for enhance component performance [2-6].

But as a rapid developing process, tube hydroforming also express some drawbacks and problems, which was also recognized by researchers, and many workers is working on solving them. To solving the problems which is blocking the process many different analyzing methods was used. Some researchers works by experiment and some use finite element simulation and so on. For manufacturing
proper hollow component, these method all make many contribution on the process optimization and analysis, promoted greatly for tube hydroforming [7-10].

So, with the above introduction, the author intended to analyze the mechanism of tube hydroforming by some new method in this paper, by discussing the mechanical stress state. We all know, for the deformation of a kind of meal, in fact which force the deformation is not the external loading, or we can said that it is the internal stress state force the deformation. When mechanical stress state push metal arrived at the point of deformed the metal start to deform.

From the mechanical stress state we can understanding the deformation mechanism of tube hydroforming properly. By studying the mechanical stress character of tube hydroforming, many interesting result can by drawn, which provide more method in discussing the optimization of tube hydroforming [11-14].

2. Tube hydroforming and the character of its stress state
As we know, for metal the internal stress state of specimen is applied by the external loading. In the analysis of the process, we can see that external loading conditions provide internal stress state that makes the blank deformed in different direction.

Fig1 gives the schematic diagram of the process of tube hydroforming, in which tube was forced to deform according the internal shape of the die by applying both compressive force and internal expending pressure. The loading condition with compressive stress and expending stress determines how the blank deformed under different stress state.

![Fig. 1 Schematic diagram of tube hydroforming](image)

The external compressive force F1 provide internal axial compressive stress and expanding pressure p provide circumferential tensile stress. With this kind of external force, the blank deforming with hydroforming was with the state of two compressive stress and one tensile stress, which was shown in Fig 2. With the change of the external compressive force and pressure, the stress state keep as two
compressive stress and one tensile stress forever during deforming. The difference was just the value of $\sigma_\rho$, $\sigma_\theta$ and $\sigma_t$.

![Stress state of tube hydroforming](image)

Fig. 2 Stress state of tube hydroforming

Formula (1), formula (2) both together gives how to calculate the axial compressive stress and circumferential tensile stress

$$\sigma_\rho = \frac{F}{S}$$

$$\sigma_\theta = \frac{pR}{t}$$

With tube hydroforming, there are axial compressive force and internal pressure, so $\sigma_\rho \leq 0$ and $\sigma_\theta \geq 0$, $\sigma_t < 0$ forever. With thin thickness of tube, we always omit compressive stress during analysis tube hydroforming process.

If fact, for tube hydroforming is a continuous process which can’t be finished during the deformation, the stress state of tube hydroforming will change remarkably especially at the final stage. But during the mostly stages it doesn’t change essentially. That means the load condition of the initial stages can represent the whole course of tube hydroforming in some degree.

As described above, stress of tube hydroforming have special values. For those special value region ($\sigma_\rho \leq 0, \sigma_\theta \geq 0, \sigma_t = 0$), the stress state of tube hydroforming can be discussed with different stage. The combination of the different stress values builds up the stress state family. The families have been shown in table 1. There are 4 different families of stress combination. They are $\sigma_\rho = 0$ $\sigma_\theta = 0$, $\sigma_\rho = 0$ $\sigma_\theta > 0$, $\sigma_\rho < 0$ and $\sigma_\rho > 0$. During tube hydroforming the stress state can only take on the 4 kinds of stress states.

| $\sigma_\rho$ | $\sigma_\theta$ | $\sigma_t$ |
|--------------|----------------|----------|
| =0           | $\sigma_\rho = 0$ $\sigma_\theta = 0$ | $\sigma_\rho = 0$ $\sigma_\theta > 0$ |
| <0           | $\sigma_\rho < 0$ $\sigma_\theta = 0$ | $\sigma_\rho < 0$ $\sigma_\theta > 0$ |

According to the classification of table 1, to illustrate the relationship of the 4 families more clearly, the stress combination has also been drawn into a pie chart as Fig. 3.
The pie chart was divided into 4 parts by a horizontal line and a perpendicular line. The 4 parts present the 4 families of stress state respectively. Above the horizontal line $\sigma_\rho = 0$ and under the horizontal line $\sigma_\rho < 0$. On the left of the perpendicular line $\sigma_\theta > 0$, and on the right of the perpendicular line $\sigma_\theta = 0$. That means the families on the same side of the horizontal line have the same $\sigma_\rho$ and the families on the same side of perpendicular line have the same $\sigma_\theta$.

**Fig. 3 Stress combination of tube hydroforming**

### 3. Application of stress state character on processing analysis

For tube hydroforming, external loading with compressive force and pressure determined the mechanical stress state and mechanical stress state given the last component. For simple tube compressing without internal pressure, the higher compressive axial stress promote the tube to wrinkle. For tube bulging, without axial compressive force, the component just deformed with internal pressure so tempt to rupture. For tube hydroforming, because during the process there are both circumferential tensile stress and axial compressive stress, the component deformed with proper stress, so deform properly.

Tube deformed during hydroforming. As a kind of metal forming technology, higher external force make higher deformation. But in fact, the essence of the deformation is mechanical stress state of the tube. There are many factors effect the deformation of the tube, such as material property, outside radius, blank thickness, all the parameters should be considered. We must take external applied load, material property, geometrical parameter, together can we get the proper process. Stress state plays an important role for all the factors. With proper stress state point, then we can product acceptable component or the specimen will wrinkle or rupture. Fig. 4 is the component by application stress state character analysis on processing optimization.
So we can draw such a conclusion, that the work of technological parameter choosing is a searching process, which search for a special stress state which was proper for the process. It include how to determine the point for the tube deform from elasticity to plasticity and the speed for the point change along the curve.

4. Conclusion
The stress state analysis is a practical method in understanding the mechanism of of tube hydroforming. For the character of the promising process, the stress state of tube hydroforming can be discussed with different families. Stress state plays an important role during tube hydroforming, and all the factores such as materials property, geometrical parameter should be considered. The mechanism of tube hydroforming technological parameter choosing is the process of searching proper stress state.

Acknowledgements
This research was financially supported by the Dongguan Innovation and Entrepreneurship Leadership Program Funding.

References
[1] Z.R. Wang, Foundation of plasticity, Publishing company of national defence,1989:96-125.
[2] Dohman F., Hartl C. Hydroforming: Research and Practical Application. Proceedings of 2th International Conference on Innovations in Hydroforming Technology. 1997 (A):1-45.
[3] S.J. Yuan, Y. S. Zheng, and Z. R. Wang. The Integrally Hydro-Bugle Forming of Elliptical Shells. Proceedings of 5th International Conference on Plasticity of Technology. USA, 1994: 943-946.
[4] Yang, J.-B.; Jeon, B.-H.; Oh, S.-I.. The Tube Bending Technology of a Hydroforming Process for an Automotive Part, Journal of Materials Processing Technology, 2001,111(3):175-181.
[5] Hongyang Li, Shijian Yuan, Kun Dai, LiHui Lang, Xiaosong Wang, Zhubin He, Zhongren Wang. Effect of Loading paths on Hydorfoming Tubular Square Componetns. Materials Science & Technology, 2001,17(1):158.
[6] Dohman F. and Hartl C. Tube Hydroforming Research and Practical Application[J]. Journal of Materials Processing Technology, 1997:174-186.

Fig. 4 Hydroforming component with proper stress state character
[7] S.H. Zhang, Developments in hydroforming [J], Journal of Materials Processing Technology 91 (1999) 236–244.

[8] R. Zhu, I. Karaman. Phase constitutin effect on the ductility of low alloy multiphase transformation induced plasticity steels[J]. Materials Science & Engineering A, 2013, Vol.569: 137-143.

[9] W. J. D a n, Z. G. Hu, W. G. Zhang, Influences of Cyclic Loading on Martensite Transformation of TRIP Steels[J]. Met. Mater. Int. 2013, Vol. 19, No. 2:251-257.

[10] T B Hilditch, I B Timokhina, L T Robertson, et al. Cyclic Deformation of Advanced High-Strength Steels: Mechanical Behavior and Microstructural Analysis[J]. Metall. Mater. Trans. A, 2009, 40(2): 342-353.

[11] Marino Arroyo, Ted Belytschko. Continuum Mechanics Modeling and Simulation of Carbon Nanotubes[J]. Meccanica, 2005, Vol.40: 455-469.

[12] Paolo Maria Mariano, Furio Lorenzo Stazi. Computational aspects of the mechanics of complex materials[J]. Archives of Computational Methods in Engineering. 2005, Vol. 12, 4, 391-478.

[13] Richard Becker. Developments and trends in continuum plasticity[J]. Journal of Computer-Aided Materials Design, 2002, 9(2): 145-163.

[14] P. Haupt. On the mathematical modelling of material behavior in continuum mechanics[J]. Acta Mechanica, 1993, Vol. 100: 129-154.