Stress-strain analysis of NC bending and springback process for 21-6-9 stainless steel tube

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Abstract: In order to study the distribution of stress-strain of bending and springback process, based on the platform of ABAQUS code, a 3D elastic plastic model of the whole NC bending process of 21-6-9 (0Cr21Ni6Mn9N) stainless steel tube was established, and its reliability was validated. Then, the distribution and variation laws of the stress-strain for bent tube during NC bending and springback process were obtained by FE simulation. The results show that the outside of bent tube suffers tangential tension stress, and that of the inner is more complicated after bending. The stress unloading is not obvious after retracting mandrel, which indicates that the process of retracting mandrel has less effect on springback. The stress unloading is obvious, and a reverse loading phenomenon occurs after springback, while the strain of the bent tube is nearly not changed. The results can provide theoretical basis for springback control during tube NC bending process.

Introduction

Metallic bent tube parts have attracted increasing applications in many high-technological industries such as aviation, aerospace, automobile, and shipbuilding due to they satisfy the current needs for products with light weight, high strength and excellent mechanical properties from both materials and structure aspect. There are many tube bending approaches including compression bending, stretch bending, roll bending, laser bending, push bending and numerical control (NC) bending[1-3]. The NC bending can satisfy a demand for high precision, high efficiency, high flexibility, and low cost in tube bending forming process, which is the primary method for tube precision bending forming.

The inevitable springback phenomenon occurs after tube NC bending. Springback reduces both the shape and dimension accuracy of the bent tube parts, and thus affects the connection/sealing property of tubes with other components as well as the internal structure compact. In practice, established springback databases under the specific process parameters by using “trial and error” are the efficient solution method for springback. Then the springback compensation and control are carried out by using the databases [4,5]. This method will waste a lot of manpower, financial resources, and extend the production cycle, improve the production cost. Thus, analysis and research of tube NC bending springback are urgent needed to conduct. While the magnitude of springback is decided by the stress-strain state of tube internal after bending [6]. Thus, based on the platform of ABAQUS, a 3D elastic plastic FE model of whole process including bending tube, retracting mandrel and unloading of 21-6-9 stainless steel tube with the specifications of $\Phi 6.35\times$

*t*0.41 mm (tube diameter×wall thickness) in NC bending is established. And then the distribution and variation laws of the stress-strain are investigated during bending tube, retracting mandrel and unloading process. The achievement can provide theoretic foundation for the control of springback in tube NC bending.

FE model of the whole process of 21-6-9 stainless steel tube NC bending

The whole process of tube NC bending includes three processes: bending tube, retracting mandrel and unloading springback. Fang et al[7,8] established a 3D elastic plastic FE model of 21-6-9 stainless steel tube NC bending. Key technologies were analyzed involved in the modeling process, and the solution was given. On the above basis, the "odb" file of retracting mandrel was imported into ABAQUS/Standard, and boundary conditions were solved. Then, the springback FE model was established, as shown in Fig.1.

In order to validate the reliability of the FE model, the experiments were conducted by the NC tube bender SB-12×3A-2S without mandrel and wiper die. The experimental conditions are as follows: the bending speed is 0.4rad/s; the push assistant speed of pressure die is 8mm/s; the bending radius is 20mm; the bending angles are 30°, 60°, 90°, 120°, 150° and 180°, respectively, and the dry friction condition is used to the contact interfaces.

Fig.2 shows the comparison between simulation results and experimental results. It is founded that the variation law of the simulation results is agree with that of the experimental results, and the maximum relative error is 15.5%. Thus, the FE model is reliable.

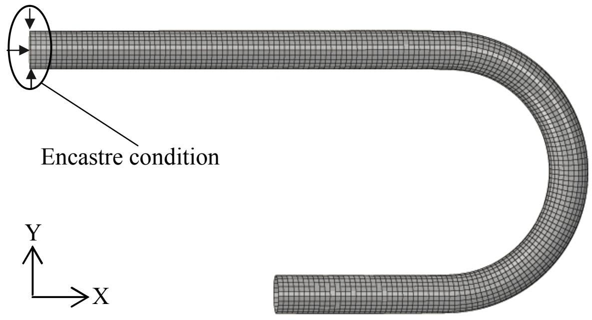

Fig.1 FE model of springback for 21-6-9 stainless steel bent tube

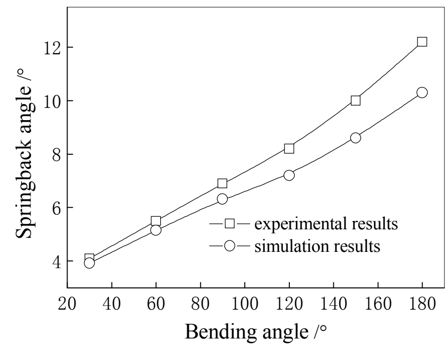

Fig.2 Comparison of simulation results and experimental results

Stress-strain analysis of the whole process of tube NC bending

The processes of tube bending and springback were mainly determined by tangential stress-strain of bent tube. Thus, the tangential stress-strain of bending portion of bent tube was studied.

Stress analysis of the whole process. Fig.3 shows the distribution of tangential stress of bent tube crest line during bending and springback whole process. As can be seen from that the bent tube is subjected to tangential tension stress in outer crest line after bending. And the tangential tension stress is larger in the zone of bending plane, while that decreases gradually far from the bending plane. The tangential stress is more complex in inner crest line, and the tangential stress firstly increases and then decreases with the conducting of the bending process. When the angle between the measuring section and bending plane is about 42°, the tangential stress state is started to turn compression stress into tension stress, and the tension stress firstly increases and then decreases. When the angle between measuring section and bending plane is 80°, the value of tension stress reaches the maximum. The stress state is started to turn tension stress into compression stress when the angle between measuring section and bending plane is 160°. This is because that the compression unloading occurs with the conducting of bending process. Bending moment is passed to the bending tangent point through the forming zone by clamp die during tube NC bending process. The tractive force of clamp die on tube makes the compression stress of the inner forming zone decrease gradually until that is translated into the tension stress. And the tube in the zone plays a transfer bending force role.

After retracting mandrel, the tangential stress of the inner and outer sides of bent tube unloads as a result of the lack of constraint of the mandrel, but not significant. This is illustrated that retracting mandrel has less effect on the springback, thus the springback simulation calculation can not consider the retracting mandrel process, as shown in Fig.4. The results are different form that of literature [6], this is because that the literature [6] mainly aims at thin-walled tube bending forming with large diameter, and the effect of retracting mandrel on stress distribution is larger. Thus, the springback process must consider the retracting mandrel.

The tangential stress of inner and outer sides of bent tube unloads greatly during springback. After springback, the tangential stress distributes more uniform, and a reverse loading phenomenon occurs on the inner and outer sides of the bent tube. These results are different form the variation of tangential stress for 1Cr18Ni9Ti tubes before and after springback[6]. This may be that the 21-6-9 stainless steel tube has large strength coefficient and small hardening exponent, which lead to the larger springback occur, and make the stress on the inner and outer sides convert after springback.

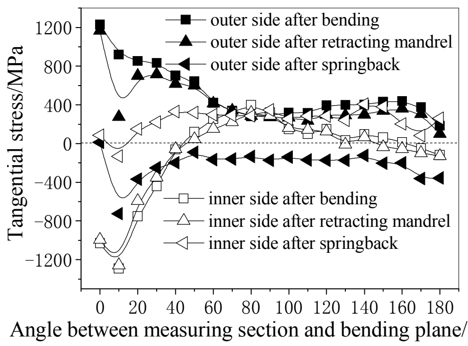

Fig.3 Distribution of tangential stress of the bending and springback whole process

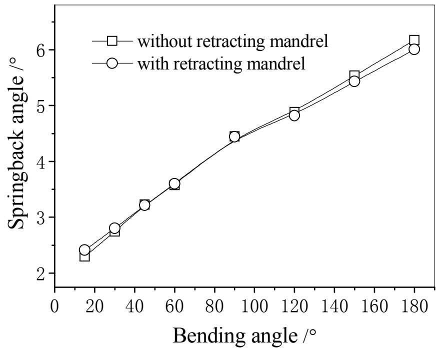

Fig.4 Variation of the springback angle with bending angles

Strain analysis of the whole process. Fig.5 shows the distribution of tangential strain of bent tube crest line during bending and springback whole process. As can be seen from that the outer side of bent tube is subjected to the tangential tension strain, and the inner side of bent tube is subjected to the tangential compression strain. The tangential strain of the bent tube changes a little at the end of bending tube, retracting mandrel and springback, only the tangential strain is slightly smaller nearby the initial bending plane after springback than that of bending and retracting mandrel. The reasons for this phenomenon are because that the measuring section of the bent tube occurs to change after springback relative to that after bending and retracting mandrel, which leads to the tangential strain change slightly nearby the initial bending plane. The inner and outer sides of the tangential strain is smaller nearby the bending plane and initial bending plane, while the tangential strain is larger in the middle portion, and the platform deforming characteristic occurs during bending process.

At the end of each forming stage, the slight variation of tangential strain of the bent tube is because that the strain of the bent tube is mostly plastic strain, while the proportion of elastic strain is very small in total strain. The elastic strain recovers after springback, but there have no obvious effect on the total strain of bent tube.

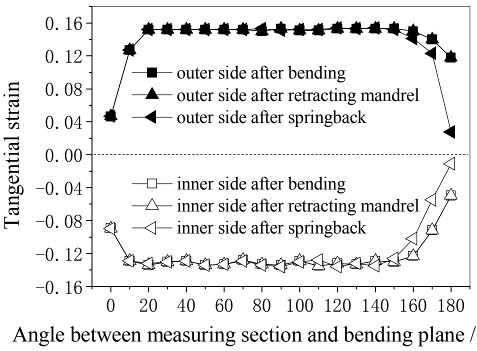

Fig.5 Distribution of tangential strain of the bending and springback whole process

Conclusions

(1) A FE model of the whole process of 21-6-9 stainless steel tube NC bending is established, and its reliability is validated by experiment.

(2) The outer side of bent tube suffers tangential tension stress and that of the inner side is more complicated after bending. The stress unloading is not obvious after retracting mandrel, which indicates that the process of retracting mandrel has less effect on springback. The stress unloading is obvious, and a reverse loading phenomenon occurs after springback.

(3) The tangential strain distributes uniformly and changes slightly at the end of the each forming stage. The outer side of bent tube is subjected to the tangential tension strain, and the inner side of bent tube is subjected to the tangential compression strain.

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