Finite element analysis of hot roll-forming process of local thickened U-rib for bridge

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Finite element analysis of hot roll-forming process of local thickened U-rib for bridge

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Abstract. To solve the problems of small welding area and poor welding quality between traditional U-rib and bridge decks, a new type local thickened U-rib (LTU-rib) proposed by bridge experts. In this paper, the simulation software ABAQUS is used to simulate a hot roll-forming process of LTU-rib. Finite element model of hot roll-forming process was established. The influence of the pass design schemes and temperature parameters on the hot roll-forming process was analyzed and discussed. The simulation results show that first scheme is more suitable for hot roll-forming process. Although forming temperature can reduce the roll-forming force and improve the metal fluidity, excessive temperature will lead to redundant deformation. The simulation results provide a reference for the parameters design of actual hot roll-forming process.

1. Introduction
U-ribs for bridge are widely used in modern orthotropic steel deck due to their large torsional stiffness and bending stiffness [1-3]. However, in recent years, with the rapid growth of traffic vehicles and long-term overload of bridges, some steel bridges which had been built and used in China have different degrees of fatigue cracks in the welded joints of U-rib and bridge deck [4].The reason is that the U-rib can only be welded from the outside. The industry often uses 75%~85% partial penetration welding and the welding area is small. The unfused part itself forms a natural initial crack. Under repeated loading, it causes fatigue cracking at the weld of the bridge deck and U-rib, reducing the life of the entire bridge. Recent years, some bridge experts have put forward a viewpoint of local thickened U-rib [5], which can improve the quality of welded joints by increasing the weld area. In this paper, taking the new LTU-rib as an example, the finite element analysis of the hot roll-forming process is carried out by ABAQUS software. The influence of various parameters on simulation results is analyzed to guide the hot roll-forming process design of the LTU-rib.

2. Finite element model

2.1. Hot roll-forming process finite element modeling
The commonly specification 280×300×8mm U-rib is selected as the object of study. And its cross-sectional dimension is shown in figure 1. The focus of this paper is to simulate the hot roll-forming process of the LTU-rib. Therefore, the cold bending of U-rib is not considered. The traditional U-rib is selected as the preformed material, and the hot roll-forming is carried out after local induction heating in the deformation zone.

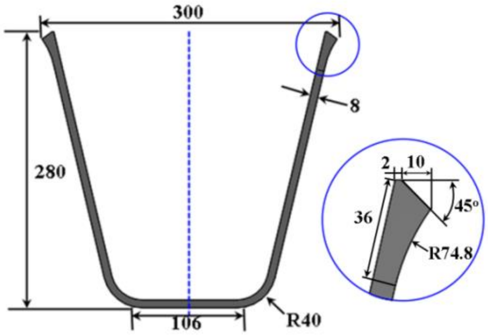

Figure 1. The section sizes of LTU-rib.

The simplified finite element model of hot roll-forming for LTU-rib is shown in figure 2. The two forming passes are selected. The first pass is mainly rough forming, consisting of upper roller and side rollers, and the second pass is finish forming, consisting of two side rollers. In the figure, the first group of flat rollers play a guiding role in order to ensure that the raw material enter the forming path steadily. Roller element types are selected as analytic rigid body. According to symmetry, 1/2 symmetry model is adopted. U-rib element is C3D8R. The mesh refinement at the forming end and the corner area at the bottom are refined appropriately. To ensure the U-rib bitten, bevel treatment is carried out at the feeding end. The friction coefficient between rollers and raw material is 0.35[6, 7]. And the forming speed is 6.0m/min.

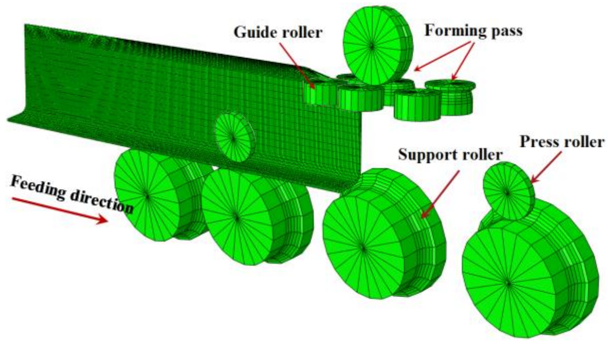

Figure 2. Finite element model of hot roll-forming process.

2.2. Material constitutive law

The investigated material，Q345qD，is a steel widely used in bridge engineering． Many research scholars [8-11]systematically studied the performance, high temperature thermal deformation constitutive model and dynamic recrystallization diagram. According to the production rate of U rib, the suitable deformation rate and temperature are selected.

Combining with the true stress-strain curve given in the reference [8], the hyperbolic sinusoidal function Arrhenius model is selected to characterize the Q345 thermal deformation constitutive model, and the relevant parameters are obtained by curve fitting. The constitutive equation of flow stress, deformation rate and deformation temperature of Q345 steel during high-temperature deformation is as follows:

$$Z=\dot{\varepsilon}\exp\left(\frac{450.1\times10^{3}}{8.314T}\right)=5.7\times10^{15}\left[\sinh\left(0.015\sigma\right)\right]^{5.71} \quad (1)$$

3. Simulation results and discussion

3.1. Effect of pass design on hot rolling process

In the overall pass design, two kinds of pass design schemes are given. The first one is direct forming method, i.e. the cross-sectional shape of two pass is similar with cross-sectional size of LTU-rib product. The second scheme is upsetting to thick type firstly, and then precision forming. The upsetting deformation is more in line with the metal flow law, and it is not easy to appear unstable behavior. The specific pass design， metal flow law and LTU-rib section size are shown in figures3 to 6.

Figure 3 shows the pass design of the first scheme. It can be seen that there is a sloped surface between the roller and sheet material, which is also the reason for instability in figure 4. However, the LTU-rib obtained by this scheme is close to the ideal product. The disadvantage is that the fillet radius of corner position is larger than the ideal size. Considering the subsequent welding, this value has a small impact. The black line range in figure is the strain area. The first pass satisfies the radius of the bottom part, and the second pass determines the radius of the upper part. The whole solution can meet the roll-forming technology of LTU-rib.

Figure 5 shows the pass design of the second scheme. It can be seen that the roller is symmetrical and the upper end surface is plane, which also makes no instability phenomenon. The size obtained is ideal. But there is a significant difference in the second pass. On the lateral displacement of U1, the displacement value is changed from 3.74mm in first scheme to 5.36mm in second scheme, as shown in figure 6. It is clear that the ideal sharp angle can be obtained by the second scheme, but it is found that the downward flow distance of metal is insufficient, which ultimately leads to a great difference between the connecting arc and the ideal value.

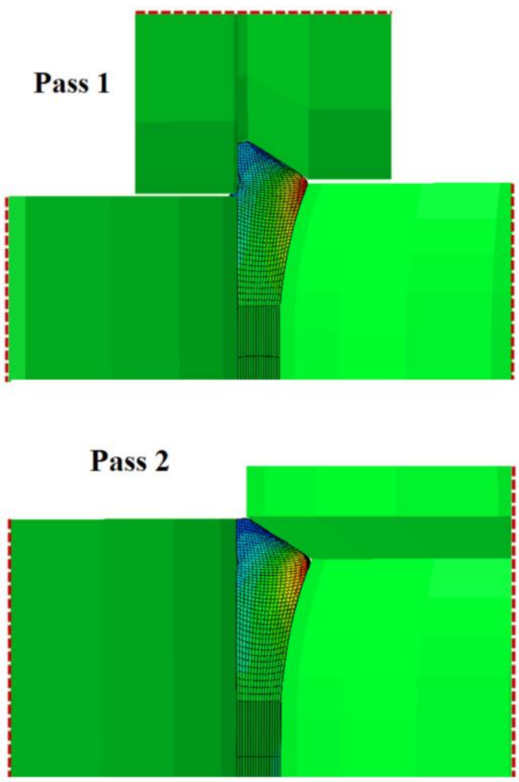

Figure 3. The pass design of the first scheme.

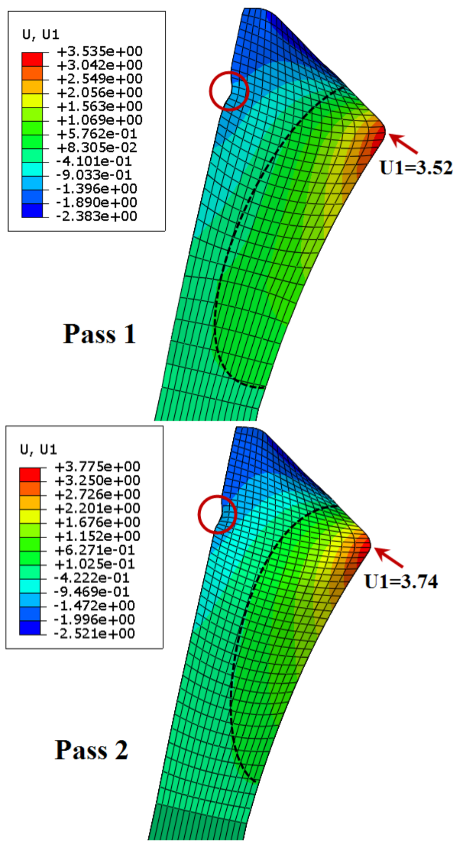

Figure 4. Metal flow at end of LTU-rib in first scheme.

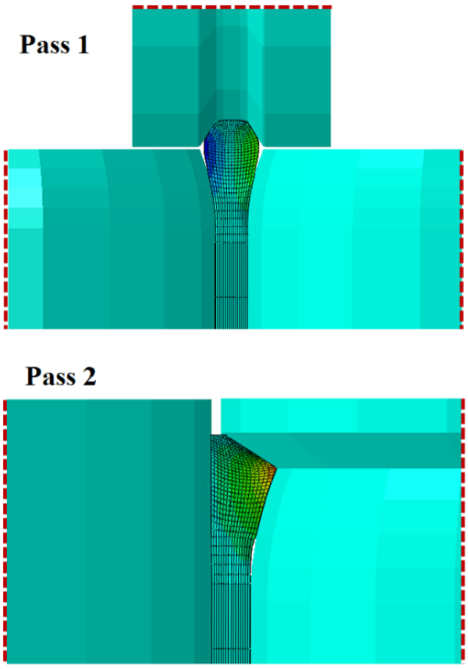

Figure 5. The pass design of the second scheme.

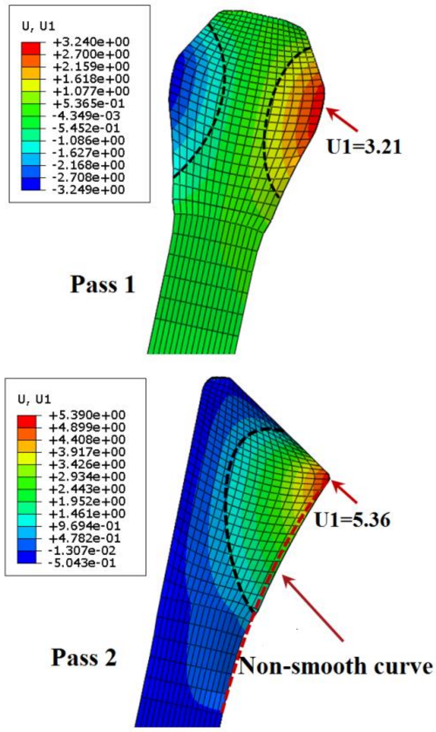

Figure 6. Metal flow at end of LTU-rib in second scheme.

In the above two design schemes, the rolling force and torque are similar because the same reduction amount is given at first pass. But the metal forming mechanism is different, which makes the stress of second pass different. Figure 7 shows the difference of the torque values of the secondary flat roller and profile roller. It can be seen that the values of flat roller and profile roller in second scheme are larger than those in first scheme. And the values of flat roller are larger than that of profile roller. This is because the large strain exists in second forming pass, while the flat roller and the profile roller in first scheme are similar in magnitude, about 508N•m.

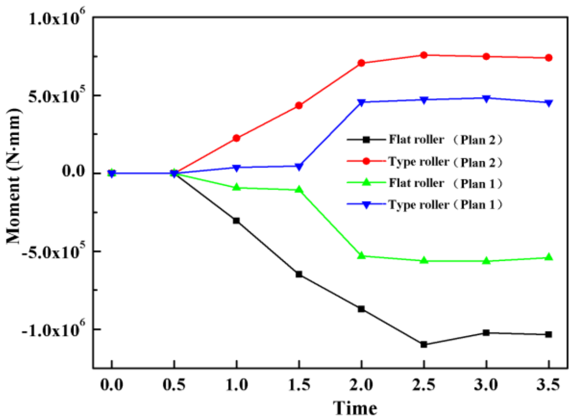

Figure 7. Roller torque of different process schemes.

3.2. Effect of temperature on hot rolling process

Temperature is one of the important technical parameters in hot roll-forming process, which is related to the forming equipment, rolling force and microstructure. According to critical transition temperature Ac1 and Ac3 of Q345qD sheet, forming temperatures of 700 ℃, 900 ℃ and 1000 ℃ are selected. And the forming at room temperature 25 ℃ is taken as a comparison.

The first scheme is selected as forming pass design. Figure 8 gives the changing of rolling force upper roller at different temperatures. As shown in the figure, the variation trend of rolling force at different temperatures is similar. In the biting zone, the rolling force increases rapidly. The rolling force decreases slightly and then stabilizes into the stable zone. However, the forming temperature has a significant effect on the rolling force. As temperatures rise, the rolling force decreases sharply. When forming at room temperature, the maximum rolling force is 282.9kN. The maximum rolling force is only 110.9kN at 1000 ℃. The roll forming force is reduced by nearly 61%, which means that temperature has a great influence on selection of forming power.

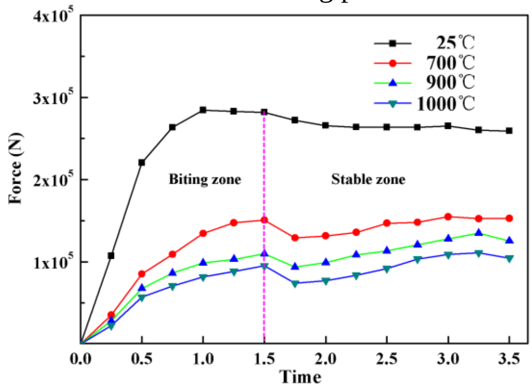

Figure 8. Rolling force at different temperatures.

Figure 9 is the section size and stress distribution of LTU-rib after roll-forming at room temperature. It can be seen that the cross-section size is different from the target product size. And the sharp corner is not formed, which will affect the welding penetration between U-rib and bridge deck, thereby affecting the welding quality. If the product size requirements are to be met, more forming passes and greater rolling force may be required. In addition, it is found that the residual stress of LTU-rib formed at room temperature is high, which will greatly increase the problem of cracking due to stress concentration after welding.

The simulation results show that the temperature not only reduces the forming force, but also improves the end metal fluidity. The end metal flows backwards due to the forming resistance. With the roll forming process, the metal accumulates gradually, as shown in figure 10 (a). The continuously accumulated metal is released at the trailing end, thereby forming the deformed tail shown in figure 10(b), which has a great influence on the yield of sheet, and increases the cutting process and cost.

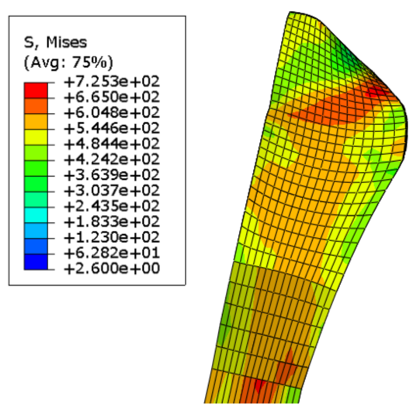

Figure 9. Stress distribution of LTU-rib after forming at room temperature.

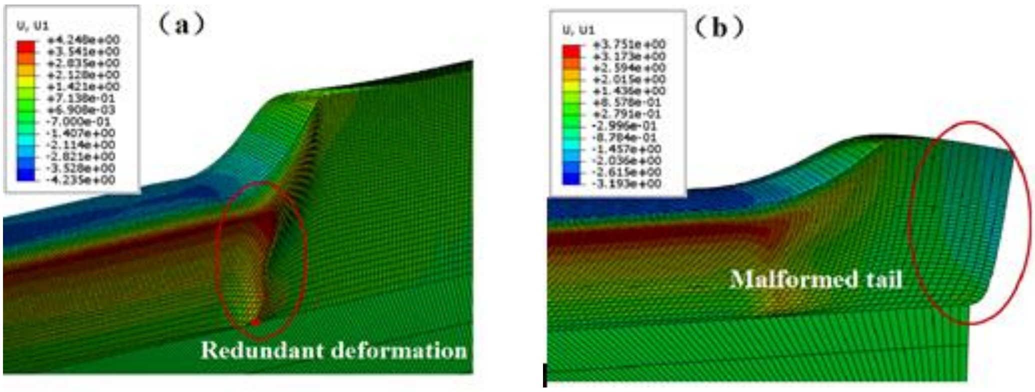

Figure 10. Redundant deformation of LTU-rib at 1000 ℃.

4. Conclusion

In the simulation process of LTU-rib, two kinds of passdesign schemes are given. The two schemes are compared from metal flow law, section size and roll force characteristics. In first scheme, there is slight instability, and the precision of corner is poor, but rolling torque is small at second pass. Although the ideal corner can be obtained in second scheme, the deformation is concentrated at the upper end and the deformation area is insufficient.

The forming temperature has a significant effect on the rolling force of the rollers. The maximum rolling force is only 110.9kN when the roll-forming temperature is 1000 ℃. And the rolling force decreases by nearly 61% compared with the value at room temperature. However, redundant deformation occurs if the forming temperature is too high.

Overall, the simulation results confirmed hot roll-forming process is more suitable for LTU-rib of bridge and provided a reference for the parameters design of actual hot roll-forming process.

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