Research on forming effect of material with different thickness structure in continuous flexible rolling process

Shulin Liu¹ and Yi Li¹,*

¹ College of Mechanical Engineering, Jilin Engineering Normal University, Changchun 130052, China

*Corresponding author’s e-mail: lyi15@mails.jlu.edu.cn

E-mail address: lyi15@mails.jlu.edu.cn

Abstract. Continuous flexible rolling is a novel advanced manufacturing technology for vehicle body surface, the forming mechanism of this process is based on the uneven thickness reduction of rolled plate along the transversal direction. In the rolling forming process, working hardening is always an important factor for affecting thickness reduction of rolled plate. In this work, the method of decreasing working hardening was studied deeply in continuous flexible rolling process for 3D surface. By finite element analysis, the forming effect of metal plate with different thickness structure was studied in continuous flexible rolling process. The rolled plate consists of three piece of metal plate; in the comparing experiments, the total thickness of rolled plate is 3mm, from compression surface to tension surface, the thickness ratio of each layer metal plate is 1:1:1, 1:2:2, 2:1:2, 2:2:1 in order. The results show that: with the location of the thinnest metal plate moves down, plastic strain in the middle surface of rolled plate is increasing greatly, the thickness reduction is also improving significantly, and the thickness distribution is almost unchanged. Therefore, to optimize rationally the thickness structure is an effective method to decreasing working hardening, the forming precision of 3D surface can get improving in continuous flexible rolling process.

1. Introduction
Continuous flexible forming processes are commonly used for the body surface of vehicle [1]. In the years, as the small batch and diversification demands of vehicle surface, traditional forming processes can’t rapidly meet the market demands. At present, continuous flexible rolling process are still in the developing stage [2-4], and there are still many problems need to be solved. In the large thickness reduction forming process, work hardening is always a most important factor for affecting forming precision of forming 3D curved surface, the bending deformation precision of forming curved surface is greatly limited. In this work, for the purpose of decreasing working hardening effect on the forming effect, the forming effect of metal plate with different thickness structure will be studied in continuous flexible rolling process.

2. Forming process and mechanism
The forming experimental apparatus is presented in Fig. 1, the main parts in the forming system are a pair of up and down distributed flexible roll sets and a series of controlling units. The contour of each flexible roll set can be bent into a smooth and continuous arc by adjusting the vertical displacement of each controlling unit. When the contour curvature radius of the upper roll set is less than the one of lower roll set, the roll gap height is gradually increasing from inside to outside, and the shape of the
forming curved surface is convex, in this paper, take convex surface as examples. The forming process is shown in Fig. 2.

The forming effect of metal plate with different thickness structure in continuous flexible rolling process is studied. The width of rolled plate is 100mm, the length is 200mm, and the total thickness of rolled plate is 3mm, from compression surface to tension surface, the thickness ratio of each layer metal plate is 1:1:1, 1:2:2, 2:1:2, 2:2:1 in order. The rolled plate with different thickness structure is shown in Fig. 4, and the structures are presented in Table 1.
In the continuous flexible rolling, the upper surface of metal plate is formed as compressive surface, and the lower surface is formed as tensile surface, the surface between the upper and lower surface is the middle surface, its length is unchanged in the forming process. Fig 5 presents the plastic strain distribution of forming convex surface with different thickness structure. As can be seen from the plastic strain distribution, the plastic strain distribution of forming convex surface is gradually changing, the overall trend is that the transversal plastic strain in the middle of the convex surface is relatively largest, and it is decreasing from the middle to the both edges. The plastic strain distribution is related to the roll gap for forming convex surface. The minimum plastic strain in the middle surface of forming convex surface is the thickness structure with 1:1:1, it is 0.136; the maximum plastic strain in the middle surface of forming convex surface is the thickness structure with 2:2:1, it is 0.174. With the thinnest layer moves down, the plastic strain increases by 28%.

Fig. 5. The plastic strain of forming convex surface with different thickness structure (a) 1:1:1 (b) 1:2:2 (c) 2:1:2 (d) 2:2:1

Fig. 6 presents the thickness reduction distribution. As the roll gap for forming convex surface, the thickness reduction presents a gradual decreasing trend from the middle to the both edges in the transverse direction; in the longitudinal, the thickness reduction changes monotonically near longitude both ends as end effect; when it is far away from the both ends, the thickness reduction distribution is almost stable. The minimum thickness reduction ratio in the stable area is the thickness structure with 1:1:1; the maximum thickness reduction ratio in the stable area is the thickness structure with 2:2:1.
Fig. 6. The thickness reduction distribution of forming convex surface with different thickness structure (a) 1:1:1 (b) 1:2:2 (c) 2:1:2 (d) 2:2:1

Fig. 7 presents the thickness distribution curve of forming convex surface with different thickness structure. With the thinnest layer moves down, at the same point in the transversal, the thickness is decreasing. In the longitude, the maximum thickness in the stable area is the thickness structure with ratio 1:1:1, it is 2.88mm; the minimum thickness in the stable area is the thickness structure with ratio 2:2:1, it is 2.85mm.

(a) The transversal thickness distribution

(b) The longitude thickness distribution

Fig. 7. The thickness distribution curve of forming convex surface with different thickness structure
Table 2 present the thickness reduction of each layer of forming convex surface with different thickness structure. As shown in the table, with the thinnest layer moves down, the thickness reduction ratio is increasing, and in a same forming curved surface, the thickness reduction in the lower layer is larger than the one in the upper layer.

Table 2. The each layer thickness reduction rate of forming convex surface with different thickness structure

| 1:1:1 | 1:2:2 | 2:1:2 | 2:2:1 |
|-------|-------|-------|-------|
| First layer thickness reduction rate | 3% | 3.33% | 4.17% | 4.17% |
| Second layer thickness reduction rate | 4% | 4.17% | 5% | 5% |
| Third layer thickness reduction rate | 5% | 5% | 5% | 6.67% |
| Total thickness reduction rate | 4% | 4.33% | 4.67% | 5% |

5. Discussion

In the rolling process, work hardening caused by thickness reduction is an important factor for affecting forming precision of 3D curved surface. In this work, the multi-layer metal plates are used. For forming large curvature curved surface, larger thickness reduction is needed. When the metal plate layer is one, with thickness reduction increases, it is harder to thin under the increasing work hardening; when the metal plate layer is multiple, as the multi-layer structure feature, the excessive thickness reduction of one layer metal plate is avoided, and it caused various degree of thickness reduction in the each layer of multi-layer metal plate, work hardening is obviously improving, so the thickness of multi-layer metal plate is obviously decreasing compared to one layer metal plate.

As the thinner metal plate is easier to be stretched. Based on the flexible rolling theory, when the thinner plate is used as tensile surface, the lower surface of metal plate is stretched longer, it also caused more thickness reduction, so the thinner layer is closer to the lower layer, the thickness reduction is increasing, and the total thickness reduction is also increasing.

6. Conclusion

In this work, the method of decreasing working hardening was studied deeply in continuous flexible rolling process for 3D surface. By finite element analysis, the forming effect of metal plate with different thickness structure was studied in continuous flexible rolling process.

1. When the metal plate layer is multiple, as the multi-layer structure feature, the excessive thickness reduction of one layer metal plate is avoided, and it caused various degree of thickness reduction in the each layer of multi-layer metal plate, work hardening is obviously decreasing, the thickness of multi-layer metal plate is obviously decreasing compared to one layer metal plate.

2. When the total thickness and layer are same, the thinner metal plate is easier to be stretched, with the thinnest layer moves down, the plastic strain increases, and the thickness reduction ratio is increasing, and in a same forming curved surface, the thickness reduction in the lower layer is larger than the one in the upper layer.

3. In conclusion, the thickness structure of rolled plate in the continuous flexible rolling is a novel study, it has great effect on forming precision of vehicle body surface, and it is effective to improve work hardening caused by larger thickness reduction. This work is still needed to improve, so it can be expected that further research results will be obtained.

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