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JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2015, 22(4): 279-287

Velocity Preset and Transitional Zone's Shape Optimization for Tailor Rolled Blank

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Abstract: Tailor rolled blank (TRB) is a type of emerging material to produce lightweight vehicle parts. Transitional zone's shape is an important parameter for tailor rolled blank. It not only affects mold design and the local carrying capacity of the stamping parts, but also determines the maximum value and variation characteristics of rolling force. How to get the best transitional zone's shape is a key problem for production of tailor rolled blank. A double power function is put forward using for transitional curve, which is continuous and smooth at all connection points independent of its parameters, so the sudden change of mechanical parameters during rolling and forming process can be avoided. At the same time, the velocity formula and restriction for arbitrary transitional curve are derived to preset vertical velocity of the roller and judge whether the curve can be rolled successfully or not. Then, the finite element method (FEM) is used to verify the precision of velocity formula and study the mechanical characteristics of different curves. Finally, a method to obtain the optimal curve equation is put forward and verified.

Key words: tailor rolled blank; transitional zone; double power function; velocity preset; shape optimization

As environmental pollution and global energy shortage continue to emerge, lightweight vehicle has become one of the main ways of energy conservation and improvement of combustion efficiency. Tailor blank (TB) is a type of promising material to produce lightweight vehicle parts. In general, the TB can be divided into four categories including tailor welded blank (TWB), patchwork blank, tailor rolled blank (TRB) and tailor heat-treated blank (THB). Among them, tailor rolled blank can be produced via a flexible rolling process with a continuous transitional zone and a better surface quality[1]. On October 25, 2013, the newest cold rolling mill to produce TRB in North America was opened. This flexible rolling mill in Florence is the third TRB production facility with an annual capacity of 80 kt in the world. And then the total global capacity increased to 240 kt[2]. With the ever increasing demand of automobile industry, the cold rolling mill for producing TRB should be built continuously in the future.

To satisfy the production requirement, the research on TRB's forming theory and process emerges continually. The rolling process and deep drawing tests of TRB with longitudinal and latitudinal transition were studied by Kopp et al. [3], and a concept of 3D-profiled-blank was put forward. Then the high pressure forming process and forming restrictions of TRB were studied by them[4]. The multidisciplinary design optimization was used by Chuang et al. to optimize the thickness distribution of the automotive parts[5]. The bending-rolling combination process to produce TRB was studied by Groche et al. [6]. The residual stress in TRB was studied by Kim et al. [7]. Numerical and experimental analyses to increase the TRB's drawing depth were carried by Meyer et al. [8]. Liu et al. put forward the formulas of deformation zone's length, neutral angle and for-

Foundation Item: Item Sponsored by National Science and Technology Support Program of China (2011BAF15B02); Natural Science Foundation of Hebei Province of China (E2012203108); Science and Technology Research Program of the Colleges and Universities in Hebei of China (ZD2014034); Independent Research Project of Yanshan University of China (14LGA003); Open Project of National Engineering Research Center for Equipment and Technology of Cold Rolling Strip of China (NECSR-201206)

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ward slip for TRB[9], and the springback behavior of TRB was studied by numerical simulation and experiment[10,11]. Recently, they have derived force balance differential equation and mass conservation equation for TRB, and the solving methods are being explored[12-16].

One problem of producing TRB is how to get the best transitional zone's shape, which not only affects mold design and the local carrying capacity of the stamping parts, but also determines the maximum value and variation characteristics of rolling force. The problem can be divided into three aspects: firstly, whether an arbitrary transitional zone's shape can be rolled successfully or not; secondly, if the transitional zone's shape can be rolled in theory, how to preset the roller's vertical velocity; finally, how to get the best transitional zone's shape. Up to now, the researches on the problem are rare. Du et al. take the roller's vertical velocity as a constant, and its value is optimized through orthogonal test and finite element method (FEM) to obtain ideal straight line transitional zone[17-19]. However, the rolling course of transitional zone is time-varying and nonlinear, so the roller's vertical velocity must be time-varying, too. Liu et al. presented four transitional zone's shapes which are straight line, double circular arc, concave arc and power function curve[20], but the common method was not given to preset roller's vertical velocity for an arbitrary transitional zone's shape. In this paper, the problem can be solved in detail. Firstly, a type of double power function was put forward using for transitional curve; at the same time, the preset formula of roller's vertical velocity and restriction for arbitrary transitional zone curve were derived. Then the FEM was used to verify the precision of velocity formula and to study the mechanical characteristics of different curves. Finally, a method to obtain the optimal curve equation was put forward and verified.

1 Basic Mathematical Equations

The rolling process of TRB can be divided into upward rolling process and downward rolling process. For simplicity, only the downward rolling process is studied in this paper, and the corresponding equations for upward rolling process can be easily obtained according to the same idea.

1.1 Transitional curve

The basic function of transitional curve is to realize continuous changing between thick zone and thin zone, so it must be a continuous curve. To avoid the sudden change of mechanical parameters, the transitional curve must be a smooth curve, which means the first-order derivative of transitional curve must also be continuous. At present, the commonly used transitional curve is straight line, whose first-order derivative is not continuous on the connection point of thick zone, transitional curve and thin zone. To solve this problem, a new type of transitional curve is put forward in this paper. As shown in Fig. 1, the respective thickness of thick zone and thin zone is h_1 and h_2, and the transitional zone's length is L. The original point of the local coordinate system ξ-η is the intersection of transitional zone and thick zone. The equations of the new transitional curve can be expressed by Eq. (1):

$$\eta=\begin{cases}\dfrac{\Delta h_{\max}/4}{(L/2)^n}\xi^n & (0\leqslant\xi\leqslant L/2)\\ \dfrac{\Delta h_{\max}}{2}-\dfrac{\Delta h_{\max}/4}{(L/2)^n}(L-\xi)^n & (L/2<\xi\leqslant L)\end{cases} \tag{1}$$

where, $\Delta h_{\max}$ is the difference between h_1 and h_2; ξ and η are the horizontal coordinate and vertical coordinate in the local coordinate system; and n is a real number higher than 1.

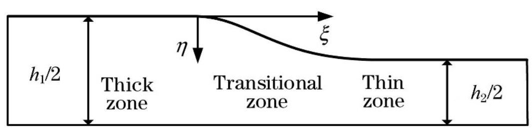

Fig. 1 Schematic diagram of local coordinate system

The curve can be named as double power function curve. The derivative of the curve at $\xi=L/2$ can be expressed by Eq. (2):

$$\lim_{\xi\to(L/2)-1}\frac{\partial\eta}{\partial\xi}=\lim_{\xi\to(L/2)+1}\frac{\partial\eta}{\partial\xi}=\frac{n\Delta h_{\max}}{2L} \tag{2}$$

When $n>1$, the derivatives of the curve at $\xi=0$ and $\xi=L$ are all zero, so it is continuous and smooth at all connection points independent of its parameters, and the sudden change of mechanical parameters during rolling and forming can be avoided. When $n=1$, Eq. (1) degenerates into a straight line expressed by Eq. (3):

$$\eta=\frac{\Delta h_{\max}}{2L}\xi \tag{3}$$

In this case, the derivatives of the curve at $\xi=0$ and $\xi=L$ are not zero, so the sudden change of mechanical parameters during rolling and forming cannot be avoided.

1.2 Velocity formula

As shown in Fig. 2, a global coordinate system