The Finite Element Analysis of Profile Forming Assisted by Laser Heating

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Abstract. In this paper, by using the finite element analysis software ABAQUS, the high strength steel plate under the condition of the laser heating, was simulated by the method of the fixed mound and moving roll. The process adopts the way of coupled thermal-mechanical analysis completely, the finite element simulation was carried out on a portion of the car where using high strength steel material DP980. Through the simulation, we can obtain more complex forming law, roll forming force, and predict the spring back. By analyzing the temperature field, equivalent stress and strain fields, we can find the forming effect is good in the outside temperature about 600 ℃.

Introduction

Although the industry of the automobile is developing rapidly, but the traditional production of the industry of the automobile has a downward trend. In order to develop a new type of automobile industry, as well as the response to the market today is increasingly fierce competition, The production cost is low and to meet the needs of consumers of cars has becoming a problem urgently to be solved in the automotive industry. In addition, the current overall trend of the development of the automobile is security and comfort, further to consider the world's energy and environmental protection; it has become clear what a new development direction to the auto industry: reducing the consumption of fuel [1].

To achieve this development goal of reducing the consumption of fuel, it is an effective way to reduce the weight of the vehicle itself. its own gravity of Vehicles is reduced 100 kg, We can reduce the fuel consumption of 1.6 L in 100 km [2].But there is a big impact on the safety of the whole if we blindly reduce the weight of automobile ,so, The core aim of the current automobile industry is not only can research and development the manufacturing which it can reduce weight, but also can achieve safety standards; It can achieve these goals which use the high strength steel plate to reinforce body, it is one of the best ways to realize the auto lightweight and to improve safety performance[3-4]. The higher of the strength of high strength steel plate, the more difficult of the molding, especially when the strength of steel plate is high, it is almost impossible with traditional way of forming and molding process. And, sheet forming is through the roll of the lateral extrusion in existing roll forming equipment, and the diameter of the roll is very big, so it makes some metal von berg system will not be able to process which the size of cross section is small.

To solve above problems, it puts forward the method of exploratory roller bend forming of the Fixed Mould and Moving Roll is auxiliary heating by laser in this paper. The advantage of this method lies in: (1) it is can processing bearing parts of high strength forming components. ;(2) Because of the technology what is exploratory, So we can molding the mold only once which the cross section is more complex; (3) Under high temperature, the plastic of material and the performance of molding is good, It is not easy to damage the mould, and it can improve its service life; (4) it can basically eliminate the influence caused by the material spring back at high temperature, it can be Formed for the high precision and good quality; (5) It can increase the elongation of ultra high strength steel plate at high temperature, process and shape corners or bending parts which the radius

is very small[5]. Because of the numerical simulation can greatly reduce the development cost and development time, so it has become the effective means of equipment development. In this paper, the hot forming process of the high strength steel plate was simulated in ABAQUS software, and it analyzes the influence of temperature on the spring back amount and forming force, it laid a strong technical foundation for equipment development.

Classical theory of heat conduction temperature field analysis

The heat conduction can be defined as the exchange between two objects or an object within the different completely independent parts due to temperature difference between the induced internal energy. The transient temperature field for heat transfer basic equation is

$$\frac{\partial}{\partial x}\left(\lambda_x \frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda_y \frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda_z \frac{\partial T}{\partial z}\right)+q_l'' = \rho c \frac{\partial T}{\partial t} \tag{1}$$

From the formula(1), t on behalf of the time, ρ , c are the material density and specific heat, λ_x , λ_y , λ_z represent x , y , z three direction of thermal conductivity,for heat conduction of isotropic materials： $\lambda = \lambda_x = \lambda_y = \lambda_z$, q_l'' is the heat source density inside the material. For a single direction and without inner heat source of heat conduction ($q_l'' = 0$) in follow the Fourier law:

$$q'' = -k\frac{dT}{dx} \tag{2}$$

From the formula(2), q'' is Heat flow density(W/m²), k is coefficient of thermal conductivity (W/m-℃), minus sign said heat flow to the direction of the temperature decrease. In the process of sheet metal heat transfer analysis, temperature boundary conditions of mainly for sheet metal convection heat exchange with the outside world and sheet metal in the thermal radiation in the air.

Heat convection is refers to the solid surface contact between fluid, with its surroundings caused by the existence of temperature difference of heat exchange. Heat convection can be divided into two categories: natural and compulsory exchange. Thermal convection cooling by using Newton equation to describe:

Fluid is heated: $q'' = h(T_S - T_B)$ (3)

Fluid is cooled: $q'' = h(T_B - T_S)$ (4)

From the formula, h is film coefficient, T_S is the temperature of the solid surface, T_B is the temperature of the surrounding fluid [6] . Thermal radiation is to point to objects emit electromagnetic energy and is absorbed by other objects into hot heat exchange process. The higher the temperature of the object is, the more heat it radiates per unit of time. Heat conduction and thermal convection heat transfer must have medium, but thermal radiation without any medium. Blackbody radiation in unit time heat follows Stephen Boltzmann's law: $\Phi = A\sigma T^4$ from the formula, Φ is the heat flow that object itself radiation outward, rather than the radiation heat transfer, A is radiation surface area, σ is Stephen Boltzmann constant(Blackbody radiation constant),about $5.67\times10^{-8}\,\mathrm{W/(m^2\cdot K^4)}$, T is the thermodynamic temperature of blackbody [6-7] . In the engineering, usually need to consider the radiation between two or more than two objects, each object in the system radiate and absorb the heat at the same time. The net heat transfer between them can be developed by the above formula:

$$q = \varepsilon\sigma A_a F_{ab}\left(T_a^4 - T_b^4\right) \tag{5}$$

From the formula, q is the heat flow rate, ε is the emissivity(blackness), A_a is the radiation surface area of a , F_{ab} is the shape factor from radiation surface a to b , T_a is the absolute temperature of a radiation surface, and T_b is the absolute temperature of b radiation surface. It can be found out by the above formula: include thermal radiation thermal analysis is highly nonlinear [7].

Processing technology of the line and creating the model

Processing technology. The roll forming production line with fixed mound and moving roll of variable cross-section is a Mechatronics system. It includes uncoiled, leveler, punching and edge cutting machine, feeding machine, variable cross-section host, constant cross-section host, cutting-off machine and so on. It is shown in Fig 1. This article mainly aims at the numerical simulation of variable cross-section part of the production line. This variable cross-section includes five parts. The profile formation of steel sheet is driven by the movable machine rack. Laser is divided in on both sides of the frame movable body. Laser preheats along the outer contour of the upper and lower mound. At the same time of heating the plate, roll modeling was carried out on the steel plate processing. Therefore, forming trajectory and laser path are the outer contour of the mound. The contour of the mound is shown in Fig 2.

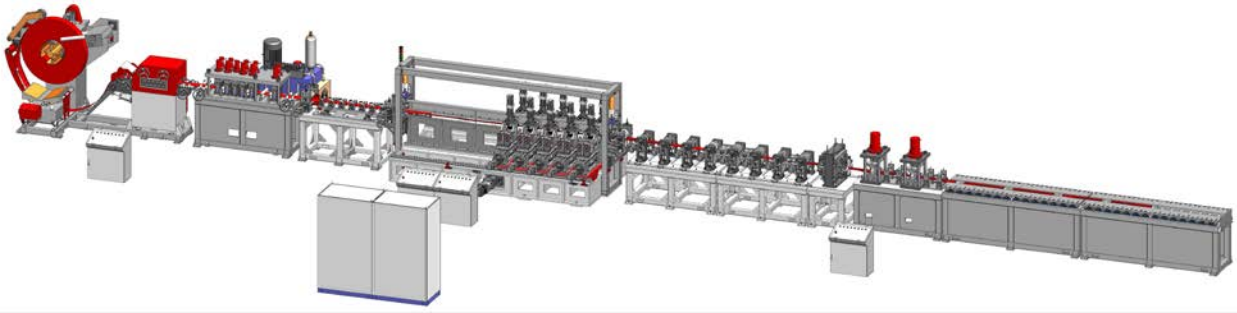


Figure1: The roll forming production line with fixed mound and moving roll of variable cross-section

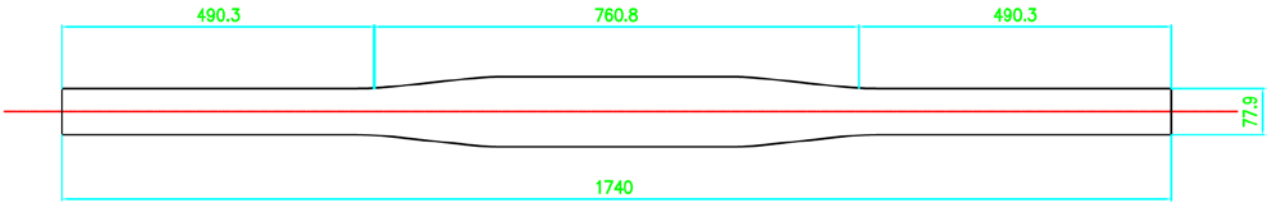


Figure2: The contour of the mound

Create the model

Sketch the model. Because the variable cross-section is very complicated and it has too many components and parts, this part will be appropriate and reasonable simplification. Finally select three groups of roll, up and down molds and deformation plate as the analysis object. Among them, the material of the deformation plate selected as DP980. The initial thickness of the plate is 1.0mm, and it total length is 1740mm. There are eight gaps around the plate. And it center has an oval positioning hole. In order to achieve the target shape, plate metal need three sets of work rolls. The forming Angle of each roll is 10°, 30°and50°. Every two roll center distance is 450mm. The assembly diagram after model simplified is shown in Fig 3.

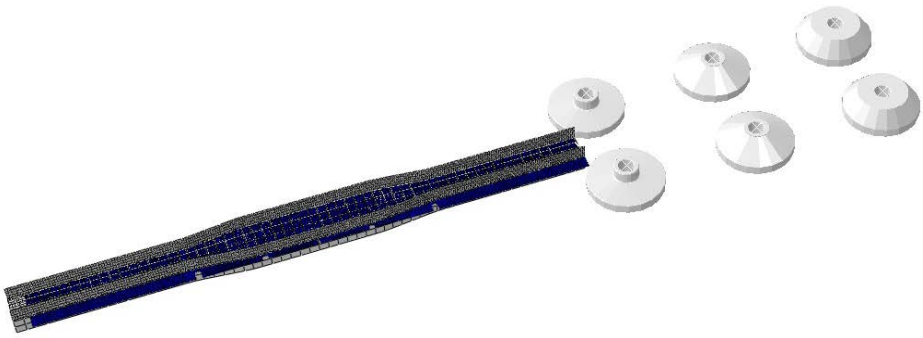


Figure 3: 3D assembly model

Because in the process of simulation in this paper not only have friction heat production, also have heat conduct, heat exchange, in this paper, the simulation of the process should use the method of the fully coupled thermal mechanical coupling analysis. In other words, the temperature and stress is

influence each other, rather than a single function. The whole emulation process adopts Dynamic-Explicit algorithm. The algorithm can effectively overcome the major flaws about convergence difficulties, long computing time and large storage space by using the Dynamic-Implicit algorithm and can improve the operation efficiency.

Element types and Material properties. The grid cell type of the deformation plate can be selected as displacement-temperature coupling unit. The initial thickness of the plate is 1.0mm, so we can extract the sheet of neutral layer instead of steel sheet entities to analyze. So the element type of the deformation plate can be selected as SC8RT. In the whole process of analysis, because up and down moulds only fixed and support the sheet metal, the grid cell type of the mounds can be selected as discrete rigid, the element type of the deformation plate is C3D8RT. In order to simplify the calculation, the grid cell type of three sets of rolls can be selected as analytical rigid. The whole simulation process adopts von-Mises Yield criterion and the model of the equivalent stress intensity. This procedure use the contact properties of Coulomb friction to narrate the contacts that between the moulds, rolls and the sheet metal.

The whole simulation process adopts DP980 high strength steel plate as the research object, some important mechanical parameters of the steel plate can be described as: the density is 7.85E-009 tone/mm^3; the size of the yield strength and elastic modulus will decrease with the rise of temperature, the specific situation of them is shown in Fig 4; Poisson's ratio will slight increase with the rise of temperature, take the middle value 0.3 [8].

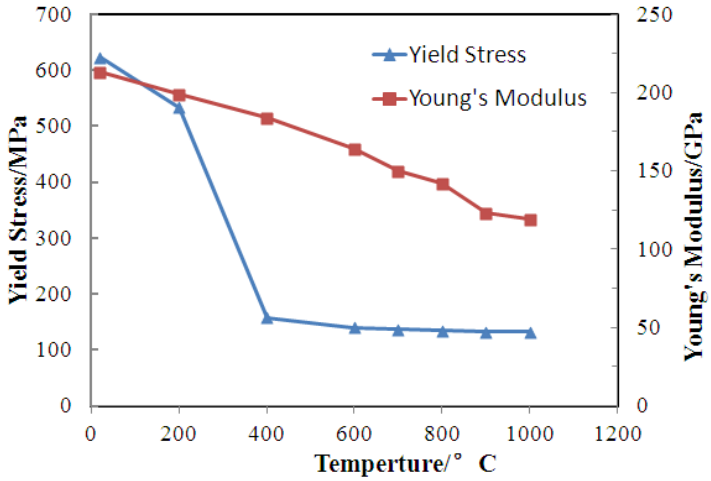


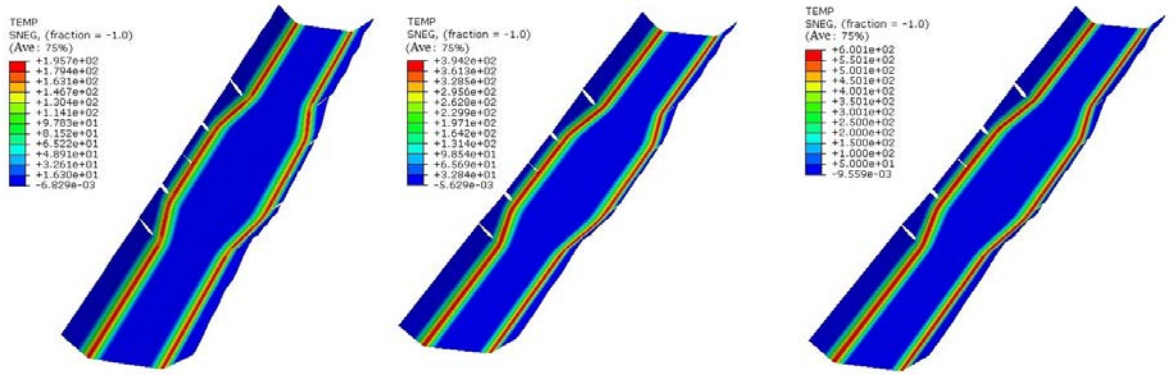
Figure 4: The yield stress and elastic modulus with temperature variation cross-section

Set the step the analysis step. In the simulation, due to plate bending in the pass, also, when the roll contacts to the steel plate, heating the plate on its bending area, setting up three analysis steps is reasonable. The first step is the first pass rolls move forward slowly, until the roll contacts to the steel plate, heating the plate on its bending area, and machining 100mm at this speed; the second step is the roll group machining of constant speed along the outer contour of the upper and lower mould; the third step is lifting the upper mould, finally, completing the whole process of simulation.Among them, the first two analysis steps adopt the type of “dynamic, temperature-displacement, explicit”, and the third one is “dynamic, explicit”. So we can use the fully coupled thermal-mechanical analysis method to analysis the model.

Exert boundary and constraint condition. In the process of the simulation, the main boundary conditions are two kinds: surface contact with the other surface and the surface heat exchange. In the process of contact, the position of roll group and the steel plate contact will change; using general contact form will increase the complexity of the simulation, so we can adopt the “set” and “surface” characteristic to simplify the calculation. In the process of creating the surface heat transfer boundary conditions, the variety of thermal conductivity and specific heat capacity is very large. In order to verify the initial temperature of the sheet metal can impact forming produce process, in the process of analysis, set the temperature of the laser heating at 200℃, 400℃ and 600℃. The initial temperature of the steel plate, the up and down molds and roll group were set up to room temperature.

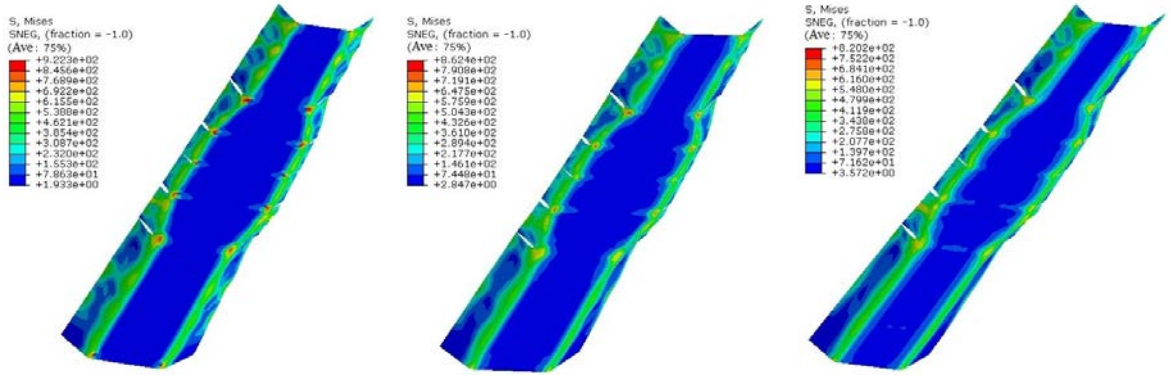
The results of simulation and analysis

Material temperature field distribution. Temperature field distribution of laser assisted heating roller bending plate obtained by simulation is shown in figure 5 below. From the figure, it can be got that the mainly bending deformation area is high temperature, and the heat flows in uniform radial way from the heating area to the surrounding at the effect of heat conduction and temperature gradient.But the temperature of non-forming area keeps unchanged at room temperature.Furthermore, the highest temperature of heated area agrees with the heating temperature basically. This suggests that the heat generated by the friction and plastic deformation is almost same with the heat conduction among the plate, roller and moulds. There is no much influence to the forming results.



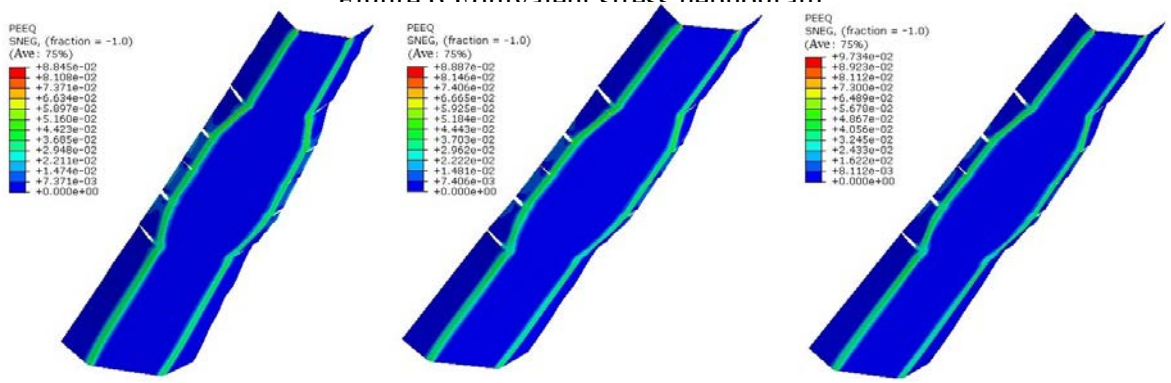
200℃ 400℃ 600℃

Figure 5 Temperature field distribution



200℃ 400℃ 600℃

Figure 6 Equivalent stress nephogram



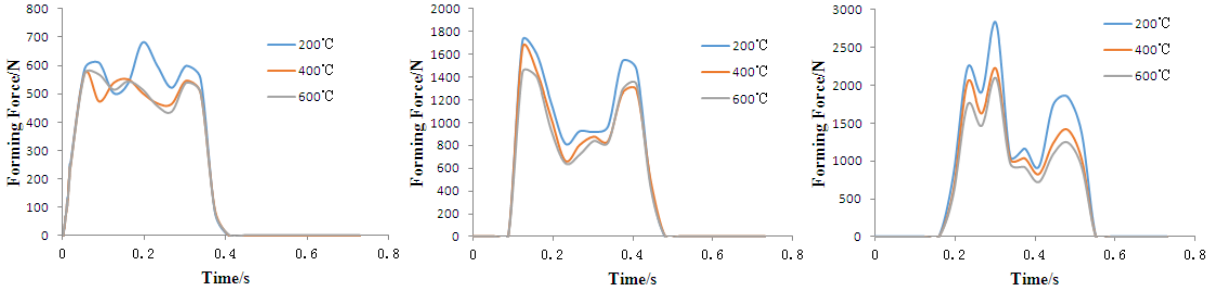
200℃ 400℃ 600℃

Figure 7 Equivalent plastic strain

The simulation results reprogram. After 3 passes process, Final plate forming of the equivalent stress and plastic strain reprogram in three groups of different temperature field simulation are shown in figure 6 and 7 below. From the figure, it can be got that material integral forming quality is better and no apparent edge wave in side forming area, slot opening with no impact on the material

forming, no molding defects produced like cornering or warp, etc. Otherwise, the equivalent stress concentration distributed in the molding area of bending parts, especially in the parts of sheet metal opening slot, same with the equivalent plastic strain. By compared the equivalent stress reprogram under different temperature conditions. Plates of the size of the internal stress are affected by the initial temperature. The higher the temperature, the smaller and the more uniform the internal stress. Through the analysis of the equivalent plastic strain, it can be found that the higher initial temperature of the sheet metal is beneficial to for

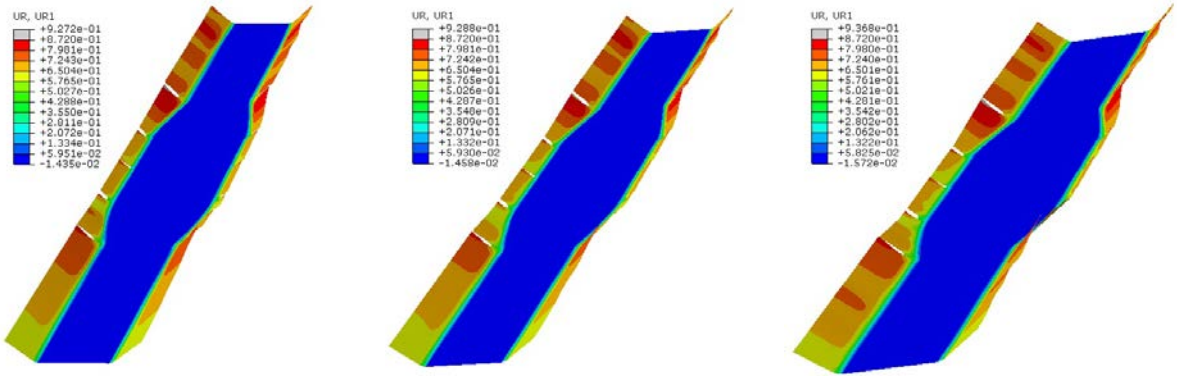
Roll forming force. The roll forming force under different temperature can be extracted from the analysis results, and they are shown in Fig 8. We can see that, from the diagram, with the number of passes increasing the roll forming force enlarges. Otherwise, as the temperature increases, roll forming force will reduce; further verify the initial temperature of the material can affect the processing quality and difficulty.



200℃ 400℃ 600℃

Figure 8 Roll forming force

Springbuck analysis. After the simulation, the condition of plate bending can be obtained which are shown in figure 9 below. From the picture, the bending angle in white areas are more than 50° (units of the mark's angle is the radian in the figure).And these cornering parts all appear in the incision of the slot, which is shown that the stress of the incision is concentrated in this process. As with the increase of temperature, the white area grows larger, and the biggest bending angle also becomes larger slowly. This shows that the material of liquidity become well and the material are more processing as the initial temperature increase. The biggest cornering Angle is 53.7 °, only 3.7°to the target angle. The red areas as target processing area are increased slowly with the increase of the temperature from the picture. And the springback is related to the processing speed, the slower the speed is, the harder the springback is. The yellow areas appear larger springback which are mainly in the side panel of the discharging end, for the specific angle 41.5°, the springback angle 8.5°.



200℃ 400℃ 600℃

Figure 9 Springback analysis

Conclusion

By analyzing the simulation results of the roll forming production line with fixed mound and moving roll of variable cross-section under the condition of different temperatures, the main research harvests are as follows:

1. Under the condition of the heating, DP980 high strength steel plate was simulated with the model processing way fixed mound of and moving roll, we can found that the status of the sheet metal forming is one of the best when the Initial temperature is 600℃. The forming force of sheet is lower in this temperature, and the stress is more uniform after forming.

2. According to the results of the analysis of temperature field, the high temperature area mainly concentrated in the bending forming part, Not forming part is almost the same as room temperature, and Temperature appear even radioactive diffusion from the district heating to the surrounding. In the deformation area, the heat produced by the friction between the roller and the sheet is similar to the heat conduction from the sheet to the roller and the mound, so there is not much influence to the results.

3. The processing speed can affect the quality of forming. In the simulation, the slower pace in the first half, forming quality is better, stress distribution is uniform, defects such as fundamental wave endless; But in the second part, when the speed increase, the forming quality declined.

4. The initial temperature of plank influence the resilience rates in the molding process, the higher the initial temperature of plank, the smaller the resilience rates amount, and resilience rates area is smaller. And the amount of resilience rates in wide section area is bigger than narrow section area.

Therefore, the control system of the production line could meet the needs of actual production, which is reasonable and feasible.

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