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# ANALYSIS ON STRESS AND STRAIN AFTER ANGLE STEEL'S CONTROLLED COOLING

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This paper established a finite element model of angle steel to have an numerical simulation on angle steel's stress field and strain field in the process of controlled cooling by using the finite element analysis software ansys. Contrasting the natural cooling and controlled cooling, could get angle steel's each parts about the temperature changes and the angle section's temperature field in all directions.Analysis results show that: Controlled cooling could increase the cooling rate, making the temperature distribution of steel more uniform, improve the temperature field distribution, and increase mechanical property and general performance, which have a good reference value for the study to angle steel's controlled cooling on temperature field.

*Keywords:* steel, finite element model, controlled cooling, stress, strain, mechanical proporties

## INTRODUCTION

In the production process of iron and steel, in order to obtain the required strength , toughness and other properties, the corresponding additives will be added, and the temperature will be controlled within a certain range. By placing the steel under such conditions, it will gradually transform from austenite to ferrite, so as to realize the large-scale transformation of its structure, so as to achieve the purpose of increasing the strength of steel[1]. Controlled cooling belongs to the category of controlled rolling. It refers to a purposive control method by people during the cooling process on hot rolled products. Specifically, the so-called controlled is based on the residual heat of rolling piece, using some controlled cooling methods to control the cooling speed to obtain the needed microstructure and performance [2].

One of the most important purposes of controlled cooling is to improve the final structural state to improve steel's performance, which means improving the material strength further in the premise of not reducing the material toughness by controlled cooling. Controlled cooling on the angle steel rolling is to carry out an ultra fast cooling to the rolling steel's surface directly in its austenitic state, reducing the rolling temperature. To ensure the rolled piece won't appear tempering organization after quenching, the final cooling temperature must be higher than the recrystallization temperature of the rolled piece. At the same time, controlled cooling also can reduce the rolled piece temperature before putting on the cold bed, reduce the cold bed pressure, reduce the thickness of iron oxide, destroy the herpes on the oxide skin, increase the plasticity and strength of the rolled piece, and then the angle steel obtained a better combination property. The paper used the Simultaneous cooling method, which means conducting spray cooling on the angle steel as soon as the angle steel was wholly put into the water cooling zone. The spray cooling method has the characteristics of good cooling uniformity, good cooling speed, wide cooling capacity and a wide adjustment range [3]. To choose the equilateral angle steel (model number Q235, size 100 mm x 100 mm x 12 mm) as the research object.

1) Ignore the heat transfer on angle steel's length direction;
2) Ignore the phase change heat, as the angle steel without inner heat source ;
3) The heat capacity and the thermal conductivity of angle steel does not change along the space, but change with; temperature;
4) Angle steel's finishing temperature is 940 °C, while the environment temperature is set to 30 °C;
5) The water jet speed is 10 m/s in the process of water cooling.

## ESTABLISH FINITE ELEMENT MODEL

By using ansys to carry on analysis, there are about 40 kinds of units involved in ansys's thermal analysis, including 14 kinds purely for thermal analysis [4]. To use the unit PLANE77 to solve the established two-dimensional finite element model of angle steel. Use unit SOLID90 of ansys for establishing a three-dimensional finite element model of angle steel.

For the two-dimensional model of angle steel is simpler, it won't takes up a lot of computer resources in the calculation process of ansys.

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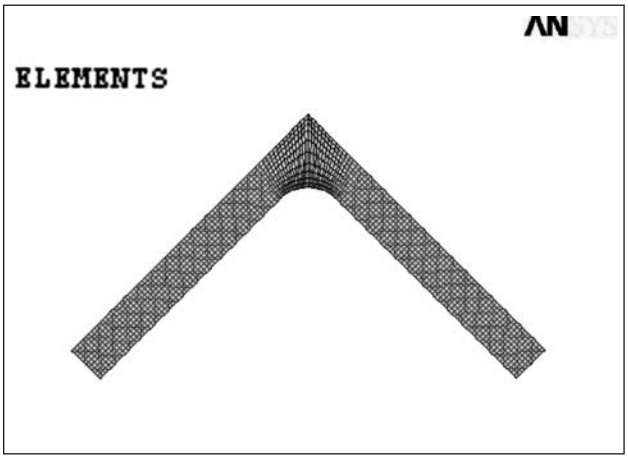


**Figure 1** The grid of angel steel model after meshing

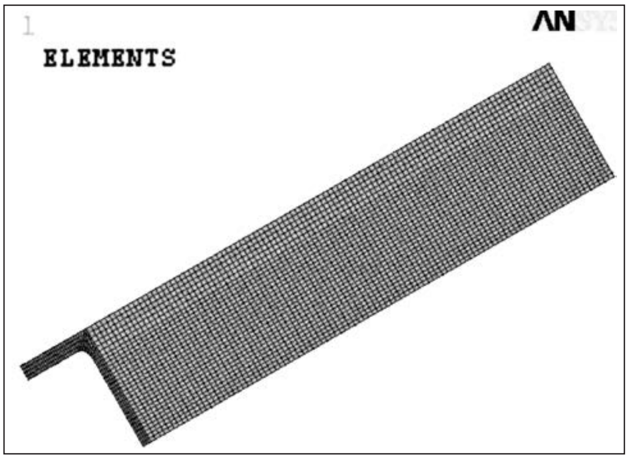


**Figure 2** The finite element model of angle steel

The grids of two-dimensional angle steel model have a meticulous meshing on the density degree as well as a consistency of the length and width direction on the grid size, which is to ensure the accuracy of calculation. The result of meshing is shown in Figure 1. There are 1 600 units and 5 132 nodes after meshing the two-dimensional angle steel model. Figure 2 showed the meshed presentation of the 3d angle steel model. Considering the limitation of computer resources, we take 0,5 m as angle steel's length. As we seen in the table, to ensure accuracy the grids have little difference between length and width, which is similar to square grids. There are 24 000 SOLID90 units and 107 913 nodes in this finite element model, which could meet the needs of calculation speed and precision greatly.

## ANALYSIS ON STRESS AND STRAIN

The final cooling scheme with the best cooling effect is chosen, compared with the calculation results of a variety of different cooling scheme: first air cooling for 3 seconds, then water-cooling for 5 seconds, and at last air cooling for 5 seconds, under the condition of the angle steel's initial rolling temperature which is for 940 , the environment temperature which is for 30  and water jet speed for 10 m/s during the process of water cooling.

### Analysis on stress field

In process of angle steel's controlled cooling, the thermal stress can be produce due to an uneven temperature change of each part which caused different deformation of each part consequently[5]. The internal thermal stress will decrease gradually as long as the temperature of angle steel's each part tends to uniformity in the process of controlled cooling. In the surface of angle steel will produce the phenomenon of stress concentration because of the deformation in process of controlled cooling and the angle steel has a corner, but it will soon disappear.

Figure 3 shows the equivalent stress distribution nephogram after controlled cooling with the biggest stress for 66,6 MPa far that is less than the yield limit 235 MPa of steel model Q235. Figure 4 shows the equivalent stress nephogram of angle steel's middle section, from which we can see, some parts of the angle steel will produce the phenomenon of stress concentration greatly due to the stress concentration in process of controlled cooling, but it will gradually cut off as the end of the tempering process.

### Strain field analysis

It induces inconsistent deformation in angle steel's each part due to uneven temperature change of each part

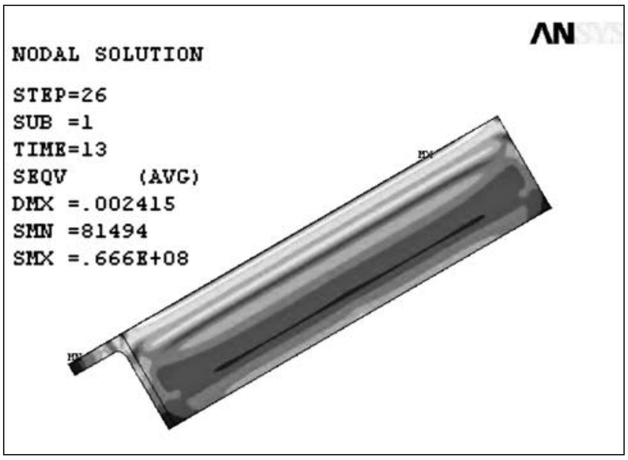


**Figure 3** The equivalent stress after controlled cooling

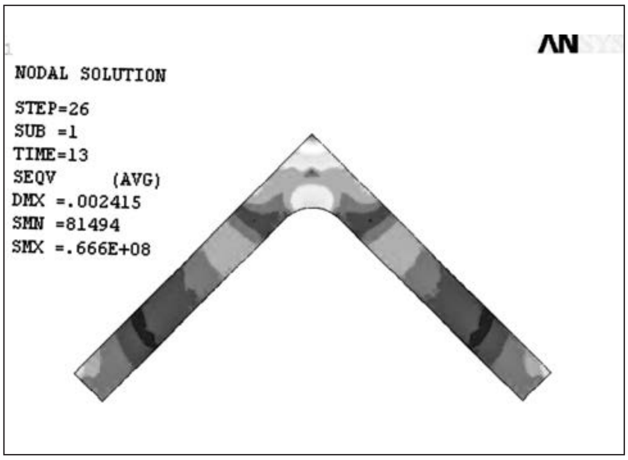


**Figure 4** The equivalent stress of middle section

in the process of controlled cooling. Figure 5 describes the equivalent strain distribution for angle steel, while Figure 6 shows the equivalent strain distribution for angle steel's mid section. In Figure 5 we can see that the equivalent strain have a symmetrical characteristic. The equivalent strain value attains to the lest of the node on angle steel's middle interface, while the two ends' equivalent strain value attains to the biggest in the process of the angle steel's controlled cooling. The minimum equivalent strain distributed in the middle waist of the angle steel, while the maximum value distributed on both ends of angle steel. The maximum node displacement is about 2,4 mm, which displays a small deformation after angle steel's controlled cooling overall.

## EXPERIMENTAL RESEARCH

To select the model steel (100 mm * 100 mm * 12 mm, length for 0,5 m) as study object carries out controlled cooling experiment research of angle steel, setting the final rolling temperature between 900~1 000 . The main purpose of the experiment is to study the effect of controlled cooling parameters on angle steel's organizational performance. Experiment steps are as follows:

1) For the convenience of result comparison, select 5 set of steel models (100 mm * 100 mm * 12 mm) as sample to do simulation experiment;
2) Before the trial, install the spray cooling device ready and then adjust the parameters of controlled cooling to the predetermined value;
3) Put the sample in high temperature electric resistance furnace, and then heat it to the required temperature. Considered the heat loss in the process of experiment as well as the heat conduction on the trial rolling line, the experiment need heat the angle to about 50  a higher temperature than the original required value, which can ensure that the original cold temperature of the specimen closes to the final rolling temperature of simulation experiment;
4) Put the specimen on the roller table for a 3 s natural cooling. In consideration of the heat loss, the time of natural cooling can be ignored. Start the roller table, then open water, gas path, and form a water mist flow finally after the whole specimens being put into cooling area; To use the at the same time cooling method: on the limitation of water area's length, the experiment suspended roller table after the whole specimens entering into cooling zone, then closed water and gas path after 5 s' water cooling, and open the roller table at the same time for conveying the specimens out of the water cooling area.

During the experiment, the main parameters of controlled cooling are as follow:

Length of cooling zone: 5 m~8 m;

Roller speed: 1 m/s~3 m/s;

Finishing rolling temperature: 900~1 000;

Final cooling temperature:650~700.

From test result data of Table 1 we know: after controlled cooling, the higher yield strength (Rv) and tensile strength (Rm) of angle steel has been gotten as the lower final cooling temperature, and then a decreasing elongation rate with the final cooling temperature decreases; the conclusion above is applicable to the same specification and model angle steel that the experiment acquired higher yield strength (Rv) and tensile strength (Rm) as well as a decreasing elongation rate; the mechanics performance index of angle steel is better in a final cooling temperature for 655

The experiment obtained a better yield strength, a greater refinement degree of pearlite content and grain and stronger comprehensive mechanical properties when the starting cold temperature is controlled at

Table1 The **measured data of Q235**

| times | temperature | | Yield strength Rv / Mpa | Tensile Strength Rm / Mpa | Elongation rate A / % |
|---|---|---|---|---|---|
| | Finished rolling | Final cooling | | | |
| 10s | 957 | 940 | 276 | 423 | 39,6 |
| 8s | 992,8 | 696,7 | 298,2 | 431,2 | 38,3 |
| 7,5s | 959,8 | 664,2 | 302,1 | 458,8 | 34,9 |
| 7s | 942,3 | 653,2 | 329,6 | 476,6 | 32,1 |
| 6s | 958,2 | 655 | 317,4 | 463 | 33,4 |

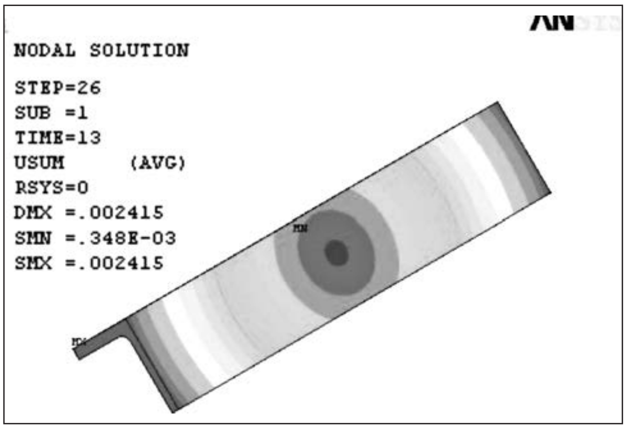


**Figure 5** The picture of equivalent strain

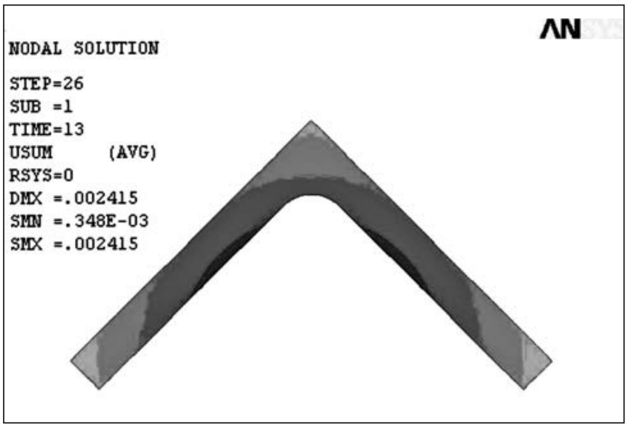


**Figure 6** The strain of middle section

around 940 as well as the final cooling temperature is controlled between 650 ~ 700

## CONCLUSION

After calculating the stress field distribution of controlled cooling angle steel by using ansys accurately, the experiment got the conclusion that it is symmetrical to the equivalent strain distribution. The minimum equivalent strain is distributed in the middle of angle steel's waist part; the maximum one distributed on both ends of angle steel. To control the cooling speed, the starting cold temperature and the final cooling temperature reasonably can improve the mechanics performance indicators including yield strength and tensile strength of angle steel effectively by analyzing the experimental data.

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**Note:** The responsible translator for English language is L.Y. Huang, Anshan, China