Temperature Field Analysis of Light Steel Structure Beam-column Composite Joint

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Abstract. The ABAQUS analysis software is used to establish a finite element theoretical analysis model of the thin-walled steel beam-column composite node under the ISO-834 fire temperature rise curve. Through the parameter-analysis of the temperature-time curve of the thin-walled steel beam-column node, the influence of material parameters on the fire resistance of the structure is obtained.

Keywords: Finite Element, Beam-Column Composite Joint, Fire Resistance

1. Introduction
The thin-walled steel light steel keel combination structure is a new structural form that has appeared in recent years, and is mainly composed of thin-walled plates or thin-walled components [1-3]. In this paper, the finite element analysis software ABAQUS is used to theoretically analyze the temperature field distribution of thin-walled steel beam-column joints under fire. By comparing the materials with different parameters and the distribution of different parts, the heat insulation performance of the structure in different parts and the influencing factors are obtained [4-6].

2. Establishment of Finite Element Model

2.1. Heating Curve
The research institutes of many countries have developed corresponding models, among which the most widely used is the ISO-834 standard fire temperature curve formula as follows [7]:

\[ T = T_0 + 345 \log_{10}(8t + 1) \]  

(1)

Where \( T_0 \) is the initial ambient temperature and \( t \) is the time after the fire (min).

According to the above formula, the following heating curve can be obtained, as shown in Figure 1:
2.2 Model Selection
The members are C-shaped steel with a width of 140mm, a height of 41mm, and a thickness of 1.37mm, and c-shaped steel with a width of 140mm, a height of 41mm, and a thickness of 1.37mm. The material is Q235 steel. The overall node model is shown in Figure 2:

![Node structure model](image)

2.3 Unit Selection
In this paper, the ABAQUS finite element analysis software is used to analyze the temperature field of the nodes. The three-dimensional thermal solid element DCC3D8: eight-node convection / diffusion six-plane element is used to model and simulate the three-dimensional heat conduction between the components. The unit has three directions of heat transfer capabilities and achieves uniform heat flow transfer. This element has eight nodes and each node has only one degree of temperature freedom, which is suitable for 3D finite element thermal analysis [8-10]. The grid division is shown in Figure 3:

![Overall meshing](image)

2.4 Boundary Conditions
When simulating the temperature field of a joint in a fire, this article assumes that the upper surface of the steel beam and the connection angle plate are the joint fired surfaces. The steel beam flanks are assumed to be covered, regardless of their fire. In the finite element simulation, the coefficients of the heat transferred to the joint members by radiation and convection during the fire temperature load are shown in Table 1.

| Element                          | Action surface                        | coefficient |
|----------------------------------|---------------------------------------|-------------|
| Surface heat exchange conditions | Heat dissipation coefficient          | 0.025       |
|                                  | of fire mask layer                    |             |
|                                  | Heat dissipation coefficient          | 0.0064      |
|                                  | of non heated mask layer              |             |
| Surface radiation                | Emissivity of fire surface            | 0.7         |

Note: Ignore the influence of heat radiation on the fire surface, take 20 °C at room temperature.

2.5 Finite Element Model for Temperature Field Analysis
The composite beam-column joints of light steel structures studied in this paper are beam-column joint types of columns in composite structures, and the joints are welded. Weld a piece of angle-shaped connection at the joint. The location of the fire application is shown in Figure 4:

![Figure 4 Location of the fire receiving surface](image)

3. Finite element Analysis of Node Temperature Field

3.1 Temperature Field of the Node
In this paper, the joint temperature field of the C-shaped steel beam-column composite joint after the joint has been uniformly heated within 6 hours of a fire without a protective layer is calculated. When the fire temperature field is applied, it is considered that there is a heat exchange between the fire area and the surrounding environment. The standard fire temperature load is evenly applied to the nodal fire surface by means of heat radiation and convection, and the symmetry surface is set as an adiabatic surface. According to the finite element calculation results, the temperature field distribution cloud diagrams of the beam-column joints of the composite structure at 480s, 600s, 720s, 900s, 1200s, and 21600s are extracted, as shown in Figures 5-10, and the temperature unit is °C.
Figure 5 Temperature field distribution at 480s

Figure 6 Temperature field distribution at 600s

Figure 7 Temperature field distribution at 720s

Figure 8 Temperature field distribution at 900s

Figure 9 Temperature field distribution at 1200s

Figure 10 Temperature field distribution at 21600s

When simulating the temperature field under a nodal fire, only the temperature of the nodal fire is considered. It can be seen from Figure 5 that when the fire heats up for 480s, most of the belly of the C-shaped steel beam has reached 600 °C. At this time, most of the bearing capacity for ordinary steel is basically lost. From Figure 6 and 7, the cloud diagrams of the temperature field distribution at the nodes from 600s to 720s show that the belly of the C-shaped steel beam heats up faster than the edges.

From Figures 8 and 9, from 900s to 1200s, it can be seen that the beam-column joint is gradually reaching 600 °C, losing its bearing capacity. From Figure 10, at 21600s, the C-shaped steel beam has lost its bearing capacity, and the beam-column joint connection has exceeded 600 °C. It can be seen that the heat transfer of the steel beam loses its bearing capacity more quickly, the heat transfer at the joint is slower, and it has less impact on the C-shaped steel columns and better thermal insulation performance.
3.2 Temperature Field Analysis at the Same Location

In order to study the temperature distribution law of the same node at the same position and different material thickness in the fire temperature field, take 1.37mm thick C-shaped steel member as test piece 1, 1.5mm thick C-shaped steel as test piece 2, and take a unit at the node as the research object. See Figure 11, extract the temperature value under the action of fire, and plot the time-temperature relationship as shown in Figure 12.

![Figure 11: Research unit](image1)

![Figure 12: Time-temperature curve of test pieces 1 and 2](image2)

It can be seen from Figure 12, it can be seen that the 1.37mm thick C-shaped steel heats up faster than the 1.5mm thick C-shaped steel. The 1.37mm C-shaped steel basically reaches its limit value at 1000s, while the temperature of 1.5mm C-shaped steel continues to rise, and it is basically stable until about 2000s. Therefore, it shows that the heat transfer speed of 1.37mm C-shaped steel is faster and the temperature is higher, which has reached 600 °C in about 1000s. It can be known from this that the 1.5mm C-section steel has better fire resistance than 1.37mm C-section steel.

4. Conclusion

In this paper, ABAQUS software is used to conduct a certain temperature field heat transfer analysis, and the following conclusions are obtained.

1) The heat transfer of steel beams is faster and it is easier to lose its bearing capacity. The heat transfer at the joints is slower. The impact of C-shaped steel columns is smaller, the heat insulation performance is better, and the C-shaped steel beam-column composite structure has better fire resistance.

2) The thickness of the component material has a certain effect on heat transfer and fire resistance. The thicker the component material, the better the fire resistance.

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