Experimental Research on the Heat Transfer Characteristics on Train Body of Bullet Train

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Abstract. In order to know the characteristic of heat transfer performance on train body, the DRH-300 instrument was used to investigate equivalent thermal conductivity coefficient of hollow-structure aluminum of bullet train “Fuxing”. It was analyzed that the same hollow-structure aluminium was under different temperature difference; while the equivalent thermal conductivity coefficient with different position of train body was under same temperature difference. The experimental results showed that the equivalent thermal conductivity coefficient of the same hollow-structure aluminum was the same under different temperature difference; the impact of the equivalent thermal conductivity coefficient on different hollow-structure aluminum was different under the same temperature difference. It showed that heat convection in the hollow was tiny, compared with heat conduction. On the practical application, the reasonable structure was selected in accordance with practical needs, so as to reduce heat transfer and energy consumption of train.

1. Research Background and Significance

With the higher and higher demand of speed for rail train body, it is obviously necessary to further realize the lightness of train body structure and obtain better heat insulation under the condition of making sure the train body strength and stiffness. After 1990s, hollow-structure aluminum became main materials of high-speed train body in the world [1]. Also, the first section of aluminum train body on the railway is completed to manufacture at Changchun bus factory [2], until now, the train body material of high-speed railway, motor car and subway have been mostly realized the change from carbon steel to stainless, aluminum alloy, and the body structure replaces the solid material with hollow-structure.

With the requirement of passengers for the comforts of trip, the new demand on the air conditioner of train is asked, while the impact on train body material’s heat transfer characteristics of air conditioner’s loading is very large, but the study of heat transfer of the hollow-structure aluminum for train body is still weak. Although there are some studies on this aspect [3-5], it will take a long time to get the results. In order to provide reference for optimized design of train body structure, some hollow-structure aluminum of Bullet train “Fuxing” are tested and analyzed in this essay.

2. Test Principle and Equipment

2.1. Test Principle

The experimental instrument used is the DRH-300 steady state thermal conductivity tester, which is measured on the thermal conductivity rate for the samples based on heating plate method. Based on
Fourier’s one-dimensional steady-state heat transfer principle, the thermal conductivity is calculated through testing temperature difference, heating flow and thickness between cold and heat plate:

\[
\lambda = \frac{Q \cdot d}{S \cdot \Delta Z \cdot \Delta T} = \frac{P \cdot d}{S \cdot \Delta T} = \frac{U \cdot d}{S \cdot \Delta T} \left[ \frac{W}{(m \cdot K)} \right]
\]  

(1)

Where: \( \Delta T \)—the average temperature difference between cold and heat plate, K;
\( \Delta Z \)—test interval, h;
I — hot pole current, A;
U — electric heating voltage, V;
\( d \)—sample thickness, m;
S—the effective heating area of sample, m²;

2.2. Test Equipment

The experimental instrument used is the DRH-300 steady state thermal conductivity tester, which instrument can measure the thermal conductivity of plastics, glass, fiber, foam, insulation materials, etc. And the instrument has good stability, convenient operation, and can quickly and easily export experimental data. The physical map of the equipment is shown in figure 1.

![Figure 1. The steady state thermal conductivity tester (DRH300)](image)

The main technical indication of instrument:
1. The requirement of sampling size: 300 × 300 × (10-90) (mm) single sample;
2. The instrument can be controlled experimental temperature, the heating range: room temperature ~ 100°C, temperature resolution 0.01°C, testing accuracy 0.05°C, cooling range: 0 ~ 60°C, temperature resolution 0.01°C (constant water sink with high precision of -5°C to 99°C);
3. Heating power 35W ± 1%;
4. Automatic test of computing control with automatic calibration function;
5. Working condition: 1) environmental temperature 10 ~ 35°C; 2) relative humidity ≤ 80%RH.

2.3. Test Objects

The main structure of the train body is shown in Figure 2. It is mainly constituted by top plate, side wall plate and floor, and it is composed by longitudinal distribution of multiple cavity structure, and welded by extruded hollow-structure aluminum of hollow section with triangular hollow cavity.
Figure 2. The main structure of train body

In accordance with the structural characteristics and train body contour distribution, the experimental sample, which including top plate 1, side wall plate 9, side wall plate 3, side wall plate 2 and floor 1, was selected, and the area of sectional samples is 300x300. See figure 3 for details.

Due to the existence of chute and material surfaced, the thermal conductive silicon wafers are laid on the top and bottom of the hollow-structure aluminum in order to satisfy with the requirement of measuring instrument sampling.
3. Experimental Results and Analysis

3.1. Analysis of Equivalent Thermal Conductivity of Hollow-structure Aluminum Under Different Temperature Differences

According to different seasons in actual operation, the temperature difference between the inside and outside of the train is constantly changing. The change of equivalent thermal conductivity coefficient of the floor 1 and side wall plate 2 at 5 different temperature of 2°C, 5°C, 10°C, 15°C, 20°C, 30°C is listed at table 1.

| Material              | Temperature Difference |
|-----------------------|------------------------|
|                       | 2°C   | 5°C   | 10°C  | 15°C  | 20°C  | 30°C  |
| floor 1               | 12.3664 | 12.3658 | 12.3642 | 12.3689 | 12.3652 | 12.3641 |
| side wall plate 2     | 10.0135 | 10.0141 | 10.0108 | 10.0123 | 10.0120 | 10.0146 |

According to the data in Table 1, it can be clearly seen that there is no obvious change in the equivalent thermal conductivity of the hollow-structure aluminum with temperature changes. Therefore, the impact of the temperature difference on equivalent thermal conductivity coefficient of hollow-structure aluminum can be ignored basically, and the natural convection heat transfer in the cavity is limited.

3.2. The Analysis of Parts on Different Position

According to the experimental result of temperature difference, the rest hollow-structure aluminum material is taken measure under the condition of 20°C for temperature difference, count the concrete parameter of experimental sample as well as organize experimental data, which is listed at table 2.
### Table 2. Hollow-structure aluminum parameters at different position

| Material             | Number of Cavities | Sample Thickness mm | Wall Thickness mm | Rib Thickness mm | Effective Thermal Conductivity W/(m·K) |
|----------------------|--------------------|---------------------|-------------------|------------------|--------------------------------------|
| Floor 1              | 11                 | 40                  | 2.2               | 2                | 12.3652                              |
| Top plate 1          | 7                  | 50                  | 2.2               | 2                | 8.2200                               |
| Side wall plate 9    | 7                  | 84.5                | 3.5               | 2                | 11.9810                              |
| Side wall plate 3    | 6                  | 65                  | 4                 | 2                | 10.4340                              |
| Side wall plate 2    | 6                  | 83.95               | 5                 | 2                | 10.0120                              |

It can be concluded as below in accordance with the data analysis of table 2:

1. For the hollow-structure aluminum represented by floor 1, its density of hollow cavity (the number of hollow cavities with unit length) is biggest and the equivalent thermal conductivity coefficient is also biggest.
2. For the hollow-structure aluminum material represented by top plate 1 and side wall plate 3, its density of hollow cavity is basically same, but the whole thickness of top plate 1 is larger and its equivalent thermal conductivity coefficient is also larger.
3. From the analysis of heat transfer characteristics, the heat transfer of hollow-structure aluminum is the coupling of heat conduction of aluminum material and natural convective heat transfer of cavity, however, for the temperature difference of changing hollow-structure aluminum’s two ends, its equivalent thermal conductivity coefficient is basically stable, therefore, the main heat transfer process that determines the equivalent thermal conductivity of hollow-structure aluminum is the thermal conductivity of aluminum, among which, the natural convective heat transfer doesn’t play an important role in the cavity.

4. **Conclusion and Prospect**

From the consequence of experimental research, conclusions can be drawn.

1. The thermal conductivity of aluminium is the main factor affecting the heat transfer characteristics and thermal conductivity of hollow-structure aluminum. And the natural convection heat transfer in the cavity is limited.
2. Among the structural parameter of hollow-structure aluminum, main impact on equivalent thermal conductivity coefficient is the density (the number of hollow cavities with unit length) of hollow cavity and thickness of hollow-structure aluminum. The bigger the hollow cavity’s density is, the bigger thickness of hollow-structure aluminum is, and the bigger equivalent thermal conductivity coefficient is also.
3. On the subsequent study works, the means of experimental study and numeric simulation computing will be combined, the other structure’s parameter will be carried out to study for hollow-structure aluminum in addition to hollow density and thickness, and explore its effect on the heat transfer of hollow-structure aluminum.

5. **References**

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