Material Thickness Design of Work Clothes in High Temperature Environment

Xinwei Zhang(✉), Yaxiong Li, and Xinzhi Yang

Xi'an Research Institute of High Technology, Xi'an 710025, Shaanxi, China
kins265@163.com

Abstract. When working in high temperature environment, in order to prevent burns, workers need to wear special clothes composed of single-layer or multi-layer fabric materials. This paper aims to study the relationship between the thickness of each fabric layer and heat conduction. By establishing a mathematical model, the temperature distribution model and the optimal thickness of each fabric layer under different temperature conditions are obtained. The dummy is tested in the high-temperature environment. Through data fitting, the temperature distribution curve on the outside of the dummy's skin in the high-temperature environment is obtained. The heat conduction model is established by Fourier heat conduction law and energy conservation, and the model is solved. Experiments show that the model is easy to solve and can effectively obtain the optimal thickness of each layer of special clothing.

Keywords: Temperature Distribution · Fourier's Law · Heat Conduction Equation · Genetic Algorithm

1 Introduction

Wear special clothes for working in high temperature and coal mine to avoid burns [2]. Therefore, how to design work clothes to ensure better thermal insulation performance is a problem worthy of study. High temperature work clothes usually have single-layer fabric and multi-layer fabric. In this regard, literature [6] used the method of finite element analysis to solve the heat conduction equation and designed economical and practical high-temperature special clothing. Literature [5] established the heat transfer model of high-temperature work clothes by using genetic algorithm, and studied the heat transfer effect of special clothes. Literature [3] established a heat transfer model from high-temperature work clothes to the outside of human skin based on Fourier's law. In reference [4], a bilevel linear programming model of heat conduction is established based on the law of temperature distribution. In order to reduce the R & D cost, literature [1] established an unsteady heat conduction model and solved the model.

This paper studies the high-temperature work clothes composed of three layers of fabric materials, which are recorded as layers I, II and III respectively, in which layer I is in contact with the external environment. At the same time, considering that there is still a certain gap between layer III and human skin, this gap is recorded as layer IV.

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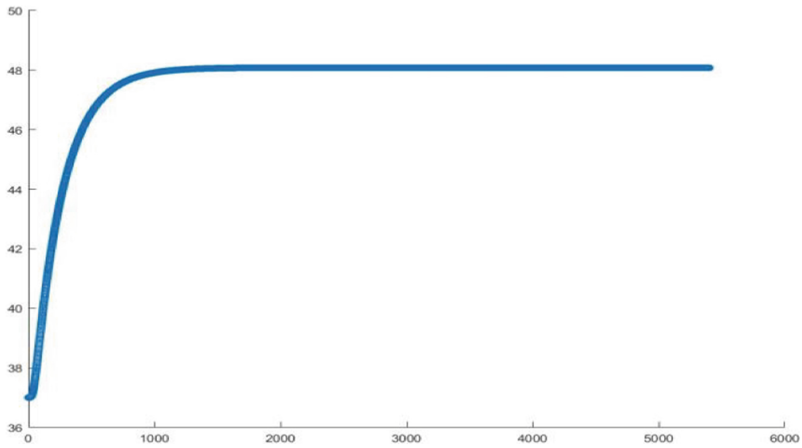

Fig. 1. Measured temperature data curve

2 Establishment of Temperature Distribution Model

In order to obtain the mathematical model of temperature distribution, the dummy with the internal temperature controlled at 37 °C was used in the high-temperature laboratory, and the temperature on the outside of the dummy's skin was measured. Through the analysis of temperature data, the distribution curve is obtained by using Matlab drawing tool, and the curve fitting toll module is used to fit the curve, obtain the distribution function relationship, establish the distribution model, and then use the distribution model to obtain the temperature distribution under the model.

Using Matlab drawing tool, the measured temperature data is substituted to obtain the distribution curve of the measured temperature data, as shown in Fig. 1. Where x-axis represents time and y-axis represents temperature.

Curve fitting the temperature data through the curve fitting toll module in. After observing the measured data, it can be found that after the working time reaches 1645 s, the measured temperature outside the dummy's skin basically remains unchanged, which is also in line with the law of Fourier's law that the smaller the temperature difference is, the slower the heat flow is. Therefore, we use the measured data of the first 1000 s, the first 2000 s and the first 5000 s respectively for curve fitting, and compare the error with the measured temperature data curve, as shown in Fig. 2. After comparison and analysis, we finally adopt the temperature distribution function fitted by using the measured temperature data in the first 3000 s, and the distribution function is $y = 48.23 * e^{(-0.000001\ 32\ *x)} - 12.67 * e^{(2.7,-0.00\ 399\ *x)}$.

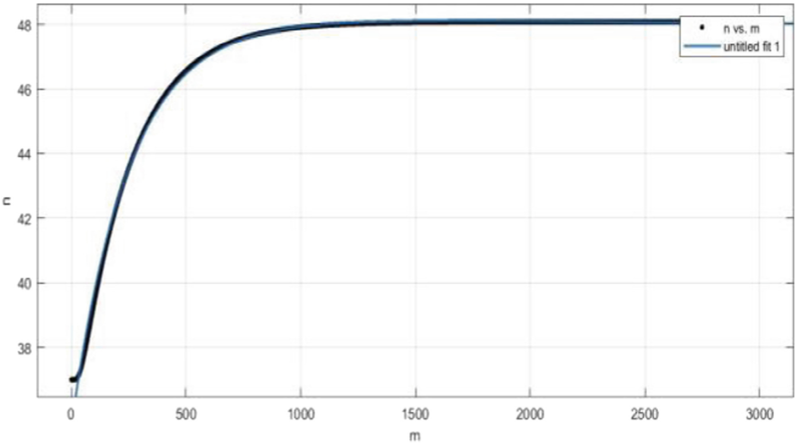

Fig. 2. Data comparison chart

3 Establishment and Solution of Model 1

Model 1 assumes that the ambient temperature is 65 °C and the thickness of layer IV is 5.5 mm. The optimal thickness of layer II is determined to ensure that the temperature outside the dummy's skin does not exceed 47 °C and the time exceeding 44 °C does not exceed 5 min when working for 60 min.

The heat conduction equation is established by Fourier heat conduction law and energy conservation, and the constraint conditions are substituted. The algorithm is designed and the heat conduction model is constructed. Then the genetic algorithm is used to optimize the model, and finally the optimal thickness of layer II is obtained.

The heat conduction equation is established by using the law of energy conservation and Fourier's law on heat conduction. In dt time, the heat dq flowing along the outer normal direction of an area element ds is directly proportional to the temperature change rate $\partial u/\partial n$ on both sides of the area element, and the proportion coefficient is k, that is:

$$dq = k\frac{\partial \mathrm{u}}{\partial \mathrm{n}}\overline{e}_n dsdt = k\nabla udsdt \tag{1}$$

where k is the thermal conductivity and $\overline{e}_n$ is the external normal unit vector of the panel. For a closed volume element Ω, the internal heat change in dt time is dq. Through the closed area division of the volume element, the following is obtained:

$$dQ = \oiint dqds = \oiint k\nabla udsdt \tag{2}$$

For time integration, we can get the amount of heat Q_1 flowing into the volume element from time t_1 to time t_2, that is:

$$Q_1 = \int_{t_2}^{t_1} \oiint k\nabla udsdt \tag{3}$$

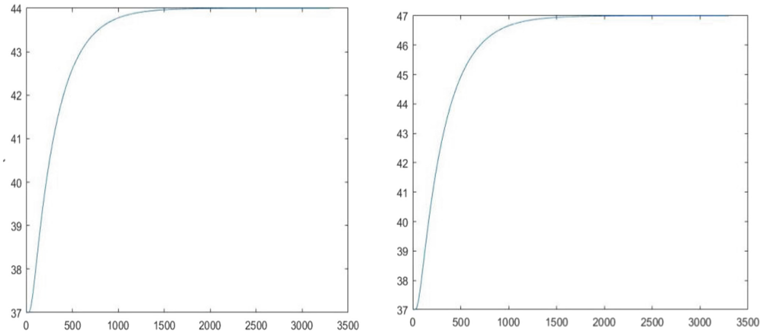

Fig. 3. Temperature variation diagram

From Gauss formula:

$$Q_1 = \int_{t_2}^{t_1} \oiint k\nabla u ds dt = \int_{t_2}^{t_1} \iiint_{\Omega} \nabla(k\nabla u) dv dt = \int_{t_2}^{t_1} \iiint_{\Omega} k\Delta u dx dy dz dt \quad (4)$$

$$Q_2 = cm\Delta u = \iiint_{\Omega} c\rho[u(x, y, z, t_2) - u(x, y, z, t_1)] dx dy dz \quad (5)$$

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$$Q_2 = \int_{t_1}^{t_2} \iiint_{\Omega} c\rho \frac{\partial u}{\partial t} dx dy dz dt \quad (6)$$

According to the conservation of heat, the following is obtained:

$$\int_{t_2}^{t_1} \iiint_{\Omega} k\Delta u dx dy dz dt = \int_{t_1}^{t_2} \iiint_{\Omega} c\rho \frac{\partial u}{\partial t} dx dy dz dt \quad (7)$$

Therefore, the heat conduction equation can be established as follows:

$$\frac{\partial u}{\partial t} = \frac{k}{c\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \quad (8)$$

Through the established heat conduction equation, the constraints in the model are substituted, and the algorithm is designed by MATLAB. Because the actual heat conduction process is nonlinear and there is inevitable rounding error, the genetic algorithm is used to optimize the model. Draw the temperature change diagram, as shown in Fig. 3. Where x-axis represents time and y-axis represents temperature.

It can be seen that the temperature outside the dummy's skin reaches 44 °C when the working time is 3300 s and 47 °C when the working time is 3600 s, which meets the requirements of the model. At this time, the optimal thickness of layer II is 1.2 mm.

4 Establishment and Solution of Model 2

Model 2: the ambient temperature is 80 °C. Determine the optimal thickness of layers II and IV to ensure that the temperature outside the dummy's skin does not exceed 47 °C and the time exceeding 44 °C does not exceed 5 min when working for 30 min.

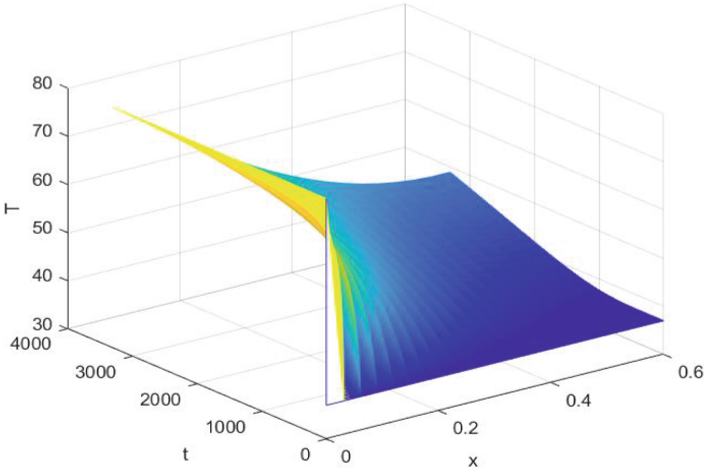

Fig. 4. Three dimensional diagram of temperature conduction

Through the heat conduction equation and heat conduction model established in model 1, the constraints of model 2 are substituted, and the distribution is processed to obtain the three-dimensional diagram of temperature conduction as in Fig. 4.

It can be seen from the image that when the working time is 30 min, the temperature outside the dummy's skin does not exceed 47 °C, and the time exceeding 44 °C does not exceed 5 min, meeting the constraints. At this time, the optimal thickness of layer II is 1.2 mm, and the optimal thickness of layer IV is 0.6 mm.

5 Conclusion

This paper studies the material thickness design of special work clothes under high temperature. By establishing the temperature distribution under two temperature conditions, the temperature distribution outside the dummy's skin is obtained. The heat conduction equation is established by Fourier heat conduction law and energy conservation, the heat conduction model is established by MATLAB, and the model is optimized based on genetic algorithm. The model is easy to understand but has strong feasibility and practicability.

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