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The Effect of Normal Force on the Coupled Temperature Field of Metal Impregnation Carbon/Stainless Steel under the Friction and Wear with Electric Current

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Abstract

Temperature field model for aluminum-stainless steel composite conductor rail (stainless steel)/collector shoe (metal impregnation carbon) under the coupling of contact resistor-friction thermal was established by FE software ANSYS. The temperature field distribution model of the friction pair was simulated and the maximum coupled temperature changing with different normal force was researched. The results show that the maximum coupled temperatures decrease firstly and then rise with the increasing of normal force under the constant displacement, current and relative sliding speed. There is an optimal normal force making the maximum coupled temperature to be the lowest for the friction pair of the metal impregnation carbon and stainless steel. The normal force can be used as the working normal force in order to reduce the abrasion induced by temperature rising.

Keywords: Normal force; Temperature field; Friction heat; Resistor heat; ANSYS

1. Introduction

Metal impregnation carbon has excellent electrical and tribological performances, and is one of the best collector materials. The current-carrier abrasion is the friction and wear behavior in the current under the electric and magnetic fields in the special working condition. It has the characteristics of both mechanical wear and electrical contact characteristics [1]. Under the effect of loads and the relative sliding of friction pairs, the surface temperature rising of friction pair was affected by the mechanical friction heat coupled

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with contact resistance heat [2]. For the contact points of current-carrier friction abrasion are changing, the temperature of contact area are difficult to measure accurately in the actual engineering and experiments, but the temperature has an important influence on the life of friction pair, and the normal force is an important parameter affecting the temperature.

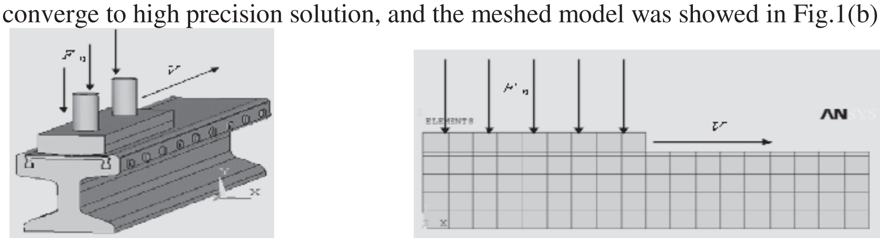
2. Model and experimental process analysis

Taking the third collector rail in subway electric current transmitting system as engineering object, the conductor rail and the collector three dimension models are established in the Fig.1 (a) [3]. The working conditions of the model is dry friction, the current *I* passes through the electrodes, the normal force is *Fn*, and the relative sliding velocity is *V*. In the process of FE testing, the heat which entered into upper sample (collector shoe), middle sample and lower sample (aluminum-stainless steel composite conductor rail) by the form of heat flux respectively was coupled by sliding friction thermal and contact resistor thermal at contact areas. In order to make the problem be dealed with more easily but meaningfully, the hypotheses were as follow [4]: Heat loss caused by heat releasing and radiating was ignored. Power loss caused by eddy current was ignored. The material parameters for each layer were isotropic. The little heat carried away by abrasive debris was ignored. All of the areas for the sample exists convection, and the convection coefficients keep constant. The density and conductivity of the sample vary with temperature rarely, and it may be ignored. The thermal converted from the energy of friction force in contact areas and the joule thermal produced by contact resistor all were absorbed by frictional parts.

3. The finite element simulation about temperature field based on ANSYS

3.1. Finite element analysis about model Structure

According to the middle profile of the sample Fig.1(a), the two dimension finite model was established according to actual size in Fig.1(b), the geometry size of the figure were as follow: the upper sample which was made of metal impregnation carbon material dimensioned as 270 mm× 27 mm, and the middle sample which was made of stainless steel material dimensioned as 540 mm×6 mm, then the lower sample which was made of aluminum material dimensioned as 540 mm × 100 mm. The middle sample adheres to the lower sample, which represents the aluminum-stainless steel composite conductor rail. The finite model expresses temperature field distribution and stress distribution of aluminum-stainless steel composite conductor rail/collector shoe contact pair clearly. The thermal-mechanical coupling element plane13 was used for the three samples. The two dimension area-area contact element in thermal-structural coupling field was used for contact pair. The top surface of the middle sample was taken as contact surface and set as contact element CONTACT172. The bottom surface of the upper sample was taken as target surface and set as CONTACT169. The meshing density of the model was controlled properly in order to make the calculation converge to high precision solution, and the meshed model was showed in Fig.1(b).



(a) (b)

Fig. 1. (a) conductor rail /collector model; (b) meshing figure

3.2. Material properties

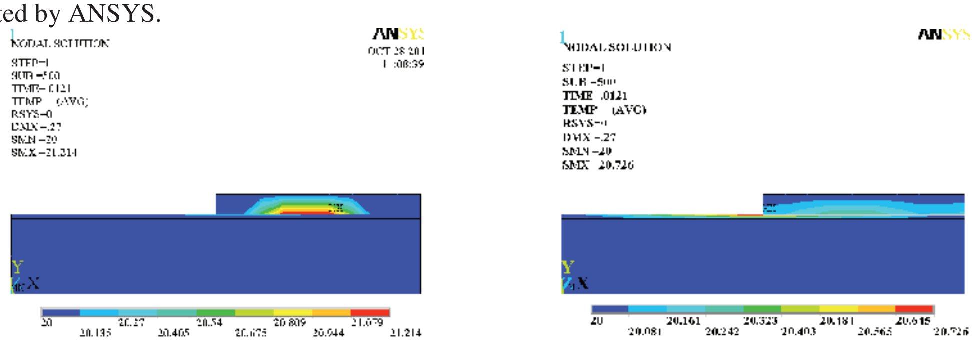
The friction coefficient between upper sample and middle sample was 0.2 and bilinear equivalent strengthen material constitutive model was adopted for Metal impregnation carbon, stainless steel and aluminum. The properties of three materials were in Tab.1 [4].

Table 1 Properties of three materials

Materials	Density /(kg·m-3)	Specific heat thermal /(J·kg-1·℃-1)	Conductivity /(W·m-1·℃-1)	Elastic modulus /Pa	Poisson ' s ratio	Thermal expansion /(×10-6·℃-1)	Resistivity /(Ω· m)
Metal impregnation carbon	2400	469	28	12.6 E9	0.425	3.5	10E-6
Stainless steel	7930	502	12.1	190E9	0.3	16	0.73E-6
Aluminum	2700	902	238	70E9	0.3	23	2.9E-8

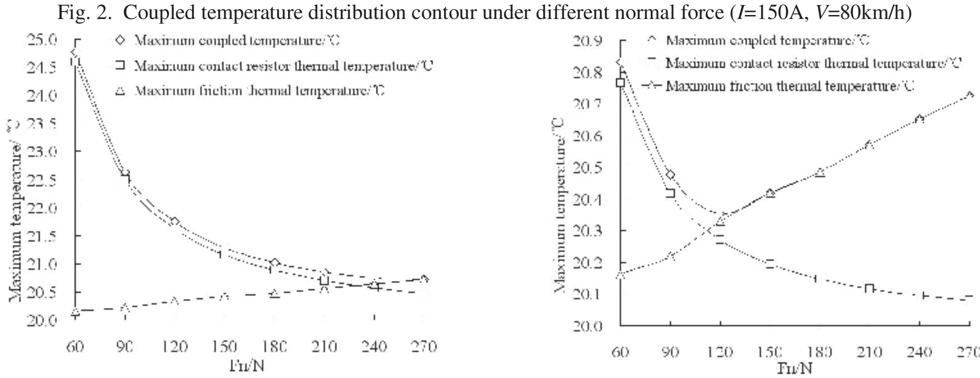
3.3. Analysis of the results and discussion

Fig.2 is the distribution nephogram of coupled field for metal impregnation carbon material, when relative displacement is 0.27mm and the current is 150A and relative sliding velocity is 80km/h. The figures show that the maximum coupled temperature rising with different normal force is respectively 1.214℃[Fig.2(a)] and 0.726℃[Fig.2(b)]. It can be found that the maximum coupling temperatures are calculated by ANSYS.



(a) *Fn*=60N (b) *Fn*=270N

Fig. 2. Coupled temperature distribution contour under different normal force (*I*=150A, *V*=80km/h)



(a) *V*=20km/h (b) *V*=120km/h

Fig. 3. Maximum coupled temperature of collector shoe changing with normal force (I=150A)

Fig.3 is the maximum coupled temperature of collector shoe (metal impregnation carbon material), when the electric current is 150A and relative sliding velocity is 20km/h and 120km/h. The maximum temperatures induced by contact resistance thermal decrease with the increasing of normal force. The maximum temperatures induced by pure mechanical friction thermal increase with the increasing of the normal force. As the result of couple, the maximum coupled temperature firstly decreases and then increase with the increasing of normal force. In the Fig.3 (a), optimal normal force scope is in between 260N and 270N when the relative velocity is 20km/h. But in Fig.3 (b), the optimal normal force scope is between 115N and 125N when the relative velocity is 120km/h. The competition of contact resistance heat and mechanical friction heat results in the maximum temperature curve showing the "*U*" shape. In process of friction and wear with electric current, the total heat is the coupled result of mechanic friction heat and contact resistance heat. The two kinds of heats are competitive with each other. When the normal force decreases, the mechanic friction heat decreases, then the contact resistance heat increases and become the main heat source. But when the normal force increases, the contact resistance heat decreases, then the mechanic friction heat increases and become the main heat source.

4. Conclusion

For the friction pair of metal impregnation carbon and stainless steel, the maximum coupled temperature firstly decreases and then increases with the increasing of normal force under the constant displacement, current and relative sliding velocity. In the process of coupling between mechanical friction heat and contact resistance heat, an optimal normal force scope exists in friction and wear with electric current, and the maximum coupled temperature is least under the scope. In order to reduce friction and wear caused by the temperature rising, the scope of optimal normal force can be selected as the real working parameter in subway electric transmitting system.

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