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Design and manufacture of intelligent Cu-based wet friction materials①

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Abstract: The friction sheets working process was analyzed. It is found that its characteristic is microregion instantaneous high temperature and the current cooling method, making the sheets cooled by the lubricating oil flowing through the friction surface, is not very efficient. Then, intelligent materials concept was introduced, the component and microstructure of intelligent Cu-based friction materials were designed, and the intelligent Cu-based wet friction materials as well as sheets were manufactured. And the intelligent friction materials working principle, i.e. the materials cooling the friction microregion in real time or the friction sheets cutting the peak value of microregion instantaneous high temperature during friction process, was given depending on the characteristics of the materials' and friction sheets' working process. Finally, it is indicated that the intelligent friction sheets excell the currently used friction sheets in properties, including anti-heating property, anti-wearing property as well as friction characteristic.

Key words: intelligent materials; Cu-based friction materials; wet friction sheets; track vehicle
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1 INTRODUCTION

Friction sheet is a key organ in a vehicle, and is divided into two kinds, dry and wet. The vehicle's shifting, turning, parking and rule changing are all depending upon it. Modern heavy vehicles generally use the wet one because the working life of the dry is much shorter than that of the wet. The wet cannot satisfy the demand of heavy vehicle's working life and reliability, so it is necessary to increase the working life and reliability of the wet friction sheets. Failure analysis indicated that the friction sheets failure forms belonged to the adhesion, distortion and rupture, and the failure reason was thought as insufficiently cooling. Wet friction sheets are working among lubrication oil in gear box, and the lubrication oil temperature measured was lower than 100 ℃ during the working process, so there existed antimony between the thought of poor cooling and the fact that lubrication oil temperature was lower than 100 ℃. Therefore, it is necessary to study the friction sheets working process deeply and know the main factors affecting their working life and reliability in order to improve the property of friction sheets. Now, the method to improve the cooling effects is to improve the surface oil path of the sheets and increase the oil pressure, but not really effective.

The friction sheet failure reason was analyzed from the microcosmic point of view based upon the characteristic of the friction sheets materials and working process. With this understanding, intelligent materials concept was introduced into friction field as well as friction materials to seek the approach to increase the friction sheets working life and reliability, to design and manufacture intelligent Cu-based friction materials and apply them to the manufacture of wet friction sheets. These would be beneficial not only to solve the problem in engineering but also to develop the investigation fields of materials science and tribology.

2 WORKING PROCESS OF WET FRICTION SHEETS

Actual solid surface consists of many micro convexities, as shown in Fig. 1, the contact between solid surfaces is actually the contacts of some higher micro convexities, and these micro contacts as well as their distortion make up of the real contact area S_r. The real contact area S_r is general several 1% to 0.01% of the solid name contact area S_a, and the rests between the two solids are near or over 10^{-2} μm[1]. It is these micro convexities that transmit the friction force moment and bear most of the friction heat dur-

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ing the friction sheets working process, the heat and stress they bear are much higher than the average value in friction surface S_a. Ref. [2] considered the instantaneous high temperature in actual friction contact regions would be as high as 1 000 ℃ or over, Ref. [3] pointed out that the friction contact micro region instantaneous temperature of Cu-based wet friction sheet might be over 1 100 ℃, this high temperature as well as friction force action on the micro convexities may induce plastic deformation and adhesion wear between friction couple. The measured oil temperature in a gear box is near the average temperature, not the real temperature in the micro convexities contact regions.

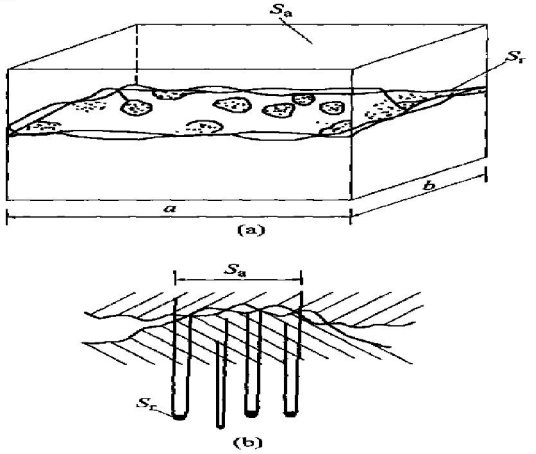

Fig. 1 Sketch about contact area in name S_a and in fact S_r[1] ($S_a = a \times b$)

A sliding friction time is only several seconds in each joining cycle, but it is very difficult for lubricating oil to flow through the contact regions between micro convexities although these regions are high temperature regions and require to be cooled urgently. The heat expansion characteristics of the materials makes the oil path in high temperature region on the friction surface become narrow, and this makes the resistance for oil to flow through the high temperature regions increase. As the micro regions temperature in friction surface increases, the oil flux through the micro regions decreases, the oil cooling effect on the micro regions declines, and all these make a vicious cycle. Actually, as the transmitting friction force moment is certain, the load and heat boron by friction sheets are certain, too. Based on the fact that the oil temperature measured in a gear box does not over 100 ℃, it might be taken in that the friction sheets would not fail if the load and friction heat distributed on the friction surface evenly. But it is well known that some micro convexities transmit the friction force moment from the solids contact characteristic, the friction stress and heat born by these micro convexities are very higher than the average value in friction surface. It is the high temperature and high stress in these micro regions that cause the friction sheets fail.

Then, the friction sheets working characteristic might be considered as microregion instantaneous high temperature, and this characteristic makes the current cooling method, cooling the sheets by lubricating oil flowing through friction surface, not very efficient. This cooling method does not aim to the characteristic of microregion instantaneous high temperature, and the cooling effect lags the instantaneous high temperature badly. It is necessary for materials to response to the microregion instantaneous high temperature in real time to cut the instantaneous high temperature, that is, it is necessary for the friction material to possess intelligence function.

3 INTELLIGENT MATERIALS CONCEPT AND INTELLIGENT AIM

Intelligent materials is a kind of new materials conceiving put forward in 1989, this concept inosculated information science into the materials' physical properties. Its basic idea is that materials and structure possess feeling, estimating and acting functions. Therefore, feeling, estimating and acting functions are three basic elements the intelligent materials must possess[4].

According to the intelligent materials concept, the aim of friction materials intelligentizing, i. e. intelligent friction materials, is to design and manufacture a friction material possessing the feeling, estimating and acting functions. As the temperature of some micro convexities transferring the friction force moment is increasing, the friction materials would feel this increasing immediately, make the countermeasure cut the temperature peak value and take the action to cut the temperature peak value in real time. It should act as "the higher the temperature peak value in the micro convexities, the greater the cutting acting", this would improve the temperature distributing state in friction surface in some extent, and increase the friction sheets working life and reliabili-

ty.

4 PREPARATION OF INTELLIGENT Cu-BASED WET FRICTION MATERIALS

Since the conduct characteristics of copper is excellent, and its friction characteristics is steady in wet medium to some extent, it is often used as a kind of wet friction materials, so the Cu-based materials are chosen as the basic component of intelligent friction materials. According to the requirement of friction materials[5], the elements of resistant adhesion, anti-wear, anti-friction, anti-heating and steady friction characteristics are added to the Cu-based materials, and all these elements are sintered as integer porous framework, the pore size is near 1 ~ 10 μm, the porosity is near 20%. Then, the oil is infiltrated into the porous framework depending on the wettability of the oil to the framework, thus the two phases, solid and liquid phase structure are got.

According to the Huadong Sintering Model[6, 7] and its mathematics token[8-11], the Cu-based integer porous framework may be manufactured by powder metallurgy sintering through adjusting the interacting between expanding mechanism and shrinking mechanism in sintering process. Since it is too difficult for metal atom to diffuse through graphite, the graphite may resist metals to form sintering necks, so it was chosen as the element to enhance the sintering expanding mechanism. The graphite possesses the function of anti-friction and the ability of bearing high temperature. Its existence may resist the adhesion between the friction couple. So the graphite may take the role of resistant adhesion in friction, anti-friction, anti-heating as well as steady friction characteristics in the Cu-based materials, but it is harmful to the materials strength, its content was decided by considering the factors in Refs. [12 ~ 14].

The Cu-based integer porous framework was made according to Ref. [15], the oil was immitted into the framework according to Ref. [16]. Then, the intelligent Cu-based wet friction material was obtained. The manufacture route of intelligent Cu-based wet friction sheet is shown in Fig. 2.

It is known according to Ref. [17] that the pores would be nearly all interconnecting as the porosity is near or over 20%, and this makes it possible for oil to be immitted into the pores of materials. Of course, the sintering body does exist closed pores according to the sintering model[6, 7], they could not store oil, not benefit the intelligent function, and is harmful to the materials strength, so the closed pore contents should be decreased as soon as possible. Actually, as the porosity is near or over 20%, the closed pore contents are very low, their influence may be negligible.

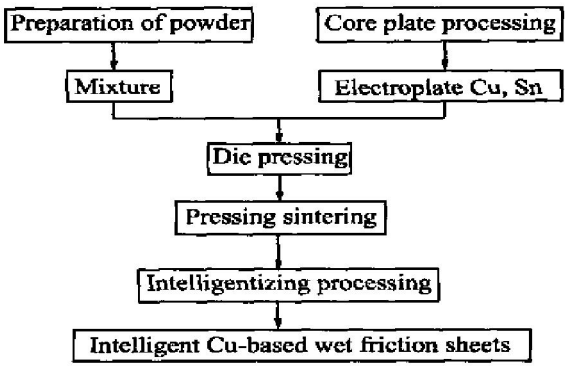

Fig. 2 Manufacture route of intelligent Cu-based wet friction sheets

5 WORKING PRINCIPLE OF INTELLIGENT WET FRICTION MATERIALS

Intelligent friction materials consist of solid, pores and oil. For convenience cause, the materials construction was treated as the following physical model: 1) The materials is made up of the microelements with the same structure; 2) Every microelement consists of three parts, solid, pores and oil; 3) Pores are interconnecting; 4) The oil wets the solid and is stored in the pores; 5) The oil volume stored is equal to that of the pores; 6) Pore volume may be compressed, but the solid and oil not.

As the materials working, under the action of friction force and normal load, the micro convexities transmitting force are pressed on the friction surface, and the friction heat makes the temperature of these micro convexities as well as the near micro regions increase. With the compressibility of pores and the flowability of oil, as soon as the friction sheets are pressed, the oil stored in the material would be compelled to flow to the friction surface. This would reduce the friction coefficient, friction force and friction heat.

At the same time, as the temperature of the micro regions in friction surface increases, the pore volume in friction sheet would reduce and the oil volume stored expands with the matter expanding characteristics when heated, all these would compel the oil to flow to the friction surface to reduce the friction coefficient, friction force and friction heat.

As the friction microregion instantaneous high temperature over the flash point of oil, the oil would gasify and its volume would expand with an exploding style. This exploding would bring the friction heat to all round, cut the microregion instantaneous temperature peak value, similar to that described in Ref.

[18]. As the oil exploding is brought with the friction microregion instantaneous high temperature, the exploding is very effective for cutting the microregion temperature peak value. As the oil exploding is instantaneous, the exploding oil amount is very small, and the friction sheets are marinated in the lubrication oil in the gear box, the gasified oil would be fluidified by the lubrication oil and dissolved as the same, all these assure the exploding to be useful and harmless. Whether the flowing or the gasifying of oil, the oil would take some heat away. This may prevent the temperature in some micro region to become too high. And then, the feeling, estimating and acting functions would be done in real time by the materials. The temperature distribution in friction surface would accommodate automatically to avoid some friction micro regions temperature being too high, and the higher the temperature peak value in the micro convexities, the greater the cutting temperature acting.

As the friction microregion temperature decreases from the instantaneous temperature peak, the pore among the microregion would expand, this makes the pore volume becomes bigger than that of the oil in the pore. Since oil wets the friction materials, the oil in the gear box would pours into the pore immediately till the pore volume is equal to that of the oil in the pore. All these ensure the friction materials to meet the need of cutting another microregion instantaneous temperature effectively and intelligently.

The mathematics model about the friction sheets micro convexities temperature field may be found in Ref. [3], it made a numerical value simulating about the temperature field with finite difference method. The simulating result showed that the highest temperature in the micro convexities of intelligent friction sheet surface was 261.6 ℃, lower than that of the currently used friction sheets under the same working condition, that is, the intelligent friction materials or sheets possess the function of cutting down the micro convexities temperature peak value.

6 MATERIAL APPLICATION

The intelligent Cu-based wet friction sheet shown in Fig. 3 was made with the manufacture route shown in Fig. 2, the sheets properties were tested both in clutch and vehicle. The test items included anti-heating property, anti-wearing property and friction characteristics, these three items represent the sheet's working reliability, life and quality, respectively separately. The clutch experiment was done in the clutch dynamic property test-bed during January and March in 2002. The results were shown in Table 1, Table 2 and Fig. 4.

The physical meaning of some parameters related to the experiment was illuminated as follows:

1) Sliding friction work(W), the work consumed during a sliding friction jointing cycle for friction sheets.

2) Sliding friction power(N), the ratio of sliding friction work W to sliding friction jointing time (t).

3) Sliding friction work per square millimeter (E), the work consumed per unit of friction sheets area during a sliding friction jointing cycle.

4) Sliding friction power per square millimeter (P), the sliding friction power(N) consumed per unit of friction sheets area.

5) Anti-heating coefficient(R), a physical par-

Table 1 Anti-heating property of intelligent Cu-based wet friction sheets

Friction sheet item	Rotative rate/ ($r \cdot min^{-1}$)	Sliding friction work/ ($J \cdot cm^{-2}$)	Highest sliding friction power/ ($W \cdot cm^{-2}$)	Anti-heating coefficient
Current friction sheets	1 971	185	340	62 900
Intelligent friction sheets	2 039	193	358	69 094

Table 2 Anti-wearing property of intelligent Cu-based wet friction sheets

Friction sheet item	Rotative rate/ ($r \cdot min^{-1}$)	Contacting times	Wear magnitude/ mm	Wear rate/ ($10^{-9} cm^3 \cdot J^{-1}$)
Current friction sheets	1 600	Former 1 000	0.023	15.7
		Latter 1 000	0.006	4.59
Intelligent friction sheets	1 600	Former 1 000	0.021	14.3
		Latter 1 000	0.003	2.12

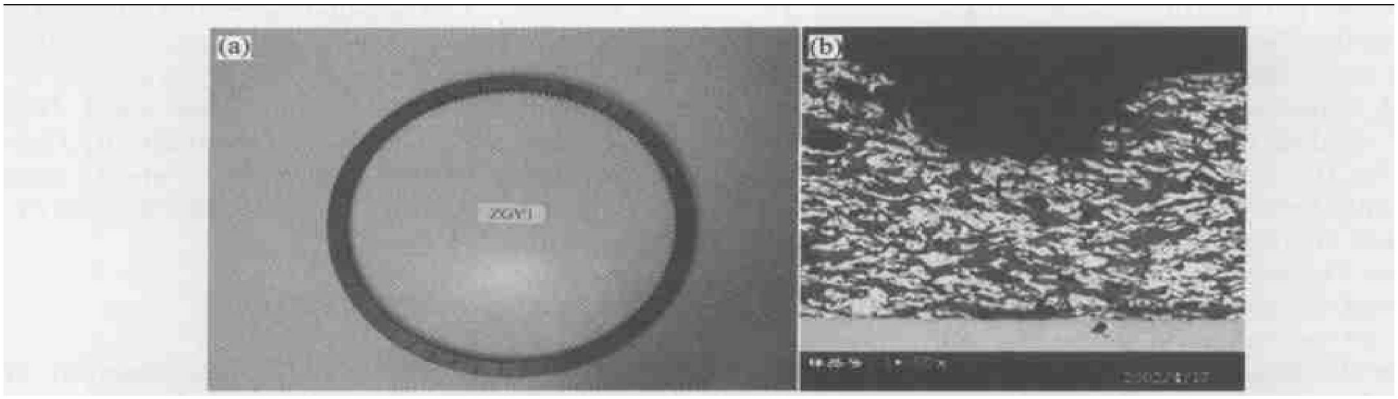

Fig. 3 Intelligent Cu-based wet friction sheet
(a) —Friction sheet panorama; (b) —Friction sheet section microstructure
(Concave region above was surface oil path, plane below core plate)

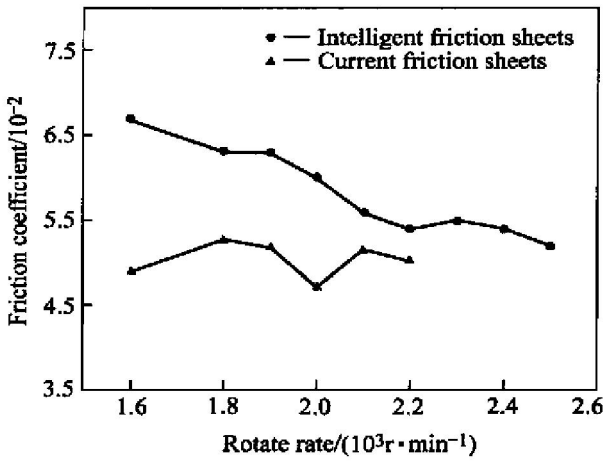

Fig. 4 Friction coefficient vs rotate rate of friction sheets

rameter describing the materials capacity of bearing the friction heat, it represents the working reliability of friction material or sheets.

$$R = E \cdot P_{max} \quad (1)$$

where P_{max} is the maximum instantaneous sliding friction power per square millimeter.

The clutch testing showed that the anti-heating property and anti-wearing property of intelligent Cu-based wet friction sheets excel those of current friction sheets, the value were 10% and 24% higher than those of current friction sheets respectively; the friction coefficient curve to rotate rate was higher than that of current friction sheets, i. e. the friction characteristics excels that of the current. This proved that the design, sintering, intelligentizing processing as well as their matching about intelligent Cu-based wet friction sheets were adequately successful.

Now, the intelligent Cu-based wet friction sheets have passed the whole examining about the X type burden track vehicle.

7 CONCLUSIONS

1) The friction sheets working characteristic is micro region instantaneous high temperature and this makes the current cooling friction sheets method, making the sheets cooled by lubricating oil flowing through friction surface, be not very efficient. And it is necessary to make use of intelligent materials to suit the micro region instantaneous high temperature characteristic.

2) With the design of intelligent materials components and structure, and with the proper manufacture method and process, the intelligent Cu-based wet friction materials and sheets can be manufactured. This material possesses the feeling, estimating and acting functions, and can cut by itself the peak value of instantaneous high temperature in friction contact micro regions in real time, accommodate the friction surface temperature distribution automatically to avoid these micro regions temperature too high.

3) The colligation property of the intelligent Cu-based wet friction sheets excels that of the current friction sheets.

4) The manufacture of the intelligent Cu-based wet friction sheets is feasible.

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