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The Friction and Wear Characteristic of Iron-based Powder Metallurgy Materials in Scroll Compressor

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ABSTRACT

With the development of materials science and technology, Iron-based powder metallurgy (P/M) antifriction materials gradually used to scroll compressor. In this paper, three kinds of Iron-based powder metallurgy antifriction materials, which are Fe-C-Cu, Fe-C-Cu-Ni-Mo and Fe-P were prepared by the common compacting sintering method. Microstructure and mechanical properties were studied, tribological properties were tested on the friction tester, and surface topographical characteristics and wear mechanism of the Iron-based powder metallurgy materials antifriction were observed and analyzed by scanning electron microscope (SEM). The results showed that, the strength of Fe-C-Cu and Fe-C-Cu-Ni-Mo are higher than Fe-P. The microstructure of Fe-C-Cu and Fe-C-Cu-Ni-Mo are mainly composed of pearlite, Fe-P is ferrite. The impact toughness of Fe-P is better than the other two. Compared the tribological properties of aluminum alloys YZAlSi11Cu3 and powder metallurgy antifriction materials under oil lubrication condition, Fe-C-Cu and Fe-C-Cu-Ni-Mo have excellent wear resistance. The wear rate of Fe-C-Cu-Ni-Mo is equivalent to one sixth of YZAlSi11Cu3. The wear mechanism of YZAlSi11Cu3 was deformation and adhesion. Powder metallurgy antifriction materials were dominated by fatigue and deformation, and accompanied by a small amount of abrasive wear.

1. INTRODUCTION

Scroll compressor, as a new type and high efficiency displacement compressor, widely used in refrigeration and air conditioning areas, possesses non-substitutable advantages over other compression machinery. A number of researches on the scroll line, system dynamics and oil systems were reported, but do less research on the friction and wear properties of scroll compressor materials.

There are many friction pairs inside the scroll compressor. With the prosperity of high working temperature, high frequency and high pressure, so the pump materials must have a higher comprehensive performance. Oldham’s ring as an important sliding part in the scroll compressor, usually with die casting aluminum alloys. It has two protuberant keys in the X, Y directions respectively. These keys make a reciprocating motion in the keyways. The two sides of the keys constitute the contact surface with the keyway sides of orbiting scroll and upper frame. When the heavy load appears on the convex keys, the contact stress on the sliding surface will become bigger. Thus, it is difficult to form continuous oil film on the each sliding surface of convex keys, and aggravate the wear of convex keys.

This paper prepares three kinds of Iron-based powder metallurgy materials, investigating its mechanical properties, observing both the surface and the inner structure, comparing the tribological characteristics between the aluminum alloy YZALSi11CU3 and Iron-based powder metallurgy antifriction materials.
2. SPECIMEN PREPARATION

Table 1 shows the quality percentage of the elements which the powder metallurgy specimens contain. Carbon, copper, nickel, molybdenum are powder materials. Iron powder is spray powder, adding 0.3 percent cutting agent to improve the cutting performance. Powder mixing time is one hour, mould pressure is 500-600Mpa, sintering temperature is 1120 degrees, then steam processing which temperature is 560 degrees and 0.5 hours heat preservation. The density of the three samples is all above 6.5g/cm³.

<table>
<thead>
<tr>
<th></th>
<th>C (%)</th>
<th>Cu (%)</th>
<th>Ni (%)</th>
<th>Mo (%)</th>
<th>P (%)</th>
<th>Cutting agent (%)</th>
<th>Fe (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.5~1.0</td>
<td>2.0~3.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>rest</td>
</tr>
<tr>
<td>b</td>
<td>0.5~1.0</td>
<td>1.0~2.0</td>
<td>1.0~3.0</td>
<td>0.5~2.0</td>
<td>-</td>
<td>0.3</td>
<td>rest</td>
</tr>
<tr>
<td>c</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.4~0.8</td>
<td>0.3</td>
<td>rest</td>
</tr>
</tbody>
</table>

3. EXPERIMENTS AND RESULT

3.1 Mechanical Properties

Figure 1 shows the mechanics analysis of Oldham’s ring. Each protuberant keys suffering two normal pressures from different directions, Oldham’s ring need enough strength and stiffness to resist deformation force. Referring to the China international standard 《the tensile test of sinter metallic materials-GB/T 7963》 and 《the impact test of sinter metallic materials-GB/T 9096》， the tensile strength and impact strength of specimens were evaluated respectively. Furthermore, the surface hardness was also tested. Test result is shown as table 2.

<table>
<thead>
<tr>
<th></th>
<th>Tensile strength/Mpa</th>
<th>Impact strength/J/cm²</th>
<th>Hardness/HRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>480~500</td>
<td>11.86</td>
<td>75~78</td>
</tr>
<tr>
<td>b</td>
<td>445~465</td>
<td>12.85</td>
<td>72~76</td>
</tr>
<tr>
<td>c</td>
<td>340~360</td>
<td>35.58</td>
<td>56~60</td>
</tr>
</tbody>
</table>

3.2 Surface Observation

The Iron-based powder metallurgy antifriction materials with porous structure similar to the oil bearing while there is sufficient strength and hardness, lubricate oil stored in the large number of micron-pores inside the materials. The oil pour out the holes, spread on the contact surface, and two metal surfaces can avoid contact directly when oil film...
formed under the conditions of friction extrusion, thermal expansion and other factors\(^1\). Contact pairs behaviors mixture lubrication. Friction surface on the lubrication condition can reduce the friction and wear. Figure 2 shows the surface characteristics of powder metallurgy antifriction specimens. The surface exhibits porous pores. Size and shape are varied. The average pore size of Fe-C-Cu is 38 \(\mu\) m and maximum pore size is 100 \(\mu\) m, as show in figure 2(a). The average pore size of Fe-C-Cu –Ni-Mo is 60 \(\mu\) m and maximum pore size is 89 \(\mu\) m, as show in figure 2(b). The average pore size of Fe-P is 70 \(\mu\) m and maximum pore size is 127 \(\mu\) m, as show in figure 3(c).

![Fig.2 Surface properties of powder metallurgy specimens](image)

**3.3 Section Observation**

![Fig.2 Surface properties of powder metallurgy specimens](image)
Figure 3 shows metallographic photos of powder metallurgy specimens. Pearlite content is around 95% in the Fe-C-Cu, as shown in figure 3(a). Pearlite is very favorable for improving the strength of the material. Pearlite content is around 80% in the Fe-C-Cu-Ni-Mo, as shown in figure 3(b). Ferrite content increased, the toughness of the material was improved and with higher mechanical properties\(^2\). As to Fe-P specimen, most organization is ferrite, as shown in figure 3(c). The toughness of the Fe-P is greatly improved, but the intensity declined, which is consistent with table 2 test results.

### 3.4 Tribology Properties

The tribological properties of YZA1Si11Cu3 and iron-based powder metallurgy antifriction materials were researched by using professional friction and wear machine. The friction pair is pin plate. Evaluated specimens used as plate, and W6Mo5Cr4V2 that its hardness is HRC64 used as pin. The test condition as follows, load is 200N, velocity is 1000r/min, 3 hours, immerse POE lubricate. After tribotesting, the tested regions of wear surface were observed by SEM. The volume wear rate of specimens was tested.

![Graphs of friction coefficient](image1.png)

Fig.4 Friction coefficient of powder metallurgy antifriction materials and YZA1Si11Cu3

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Figure 4 shows the friction coefficient of powder metallurgy antifriction materials and aluminum alloy YZALSi11Cu3 changes. The trend of friction coefficient with time changes can be seen. Friction coefficient of YZALSi11Cu3 fluctuates small in the initial stage. Its value increased with time and temperature raise. The value of Friction coefficient even exceeds 0.1 in the final stage, as show in figure 4 (a). Firstly the friction coefficient of Fe-C-Cu decreases and then increases gradually. Inflection points appear at 4000s. The friction coefficient showed a downward trend, maintained at 0.07 above in the end, as show in figure 4 (b). Through a period of 3000s run and stage, the friction coefficient of Fe-C-Cu-Ni-Mo is relatively stable and with small fluctuation. The coefficient of friction stays 0.063 around, as show in Figure 4(c). The mixture of molybdenum and nickel is the main reason. Molybdenum and nickel can occur solution. Rigid solid solution can reduce the surface contact and the moment of friction heat welding. Friction coefficient of Fe-P show upward trend in the initial stage. Friction coefficient remains stable in 0.065 after 4000s, as show in figure 4(d).

Figure 5(a) shows the friction surface of Aluminum alloy YZAlSi11Cu3. There were shedding phenomenon on the friction surface and a lot of shedding particles can be found on the friction surface. Early in the friction experiments, Friction surface is relatively smooth and friction process is more stable. As the experiment progresses, temperature of friction surface gradually increased, Aluminum alloy plastic deformation intensified. The wear mechanism shift, large amounts of metal transfer produced on the wear surface. Experimental results show that the wear rate of the aluminum alloy is 44.75×10⁻⁸mm³/N.m.

Figure 5 (b) shows the wear surface of Fe-C-Cu. There was crack on the wear surface. It can be observed that toughness of Fe-C-Cu is not very well. Rarely scratches can be found on the wear surface. Fatigue wear as the main form in stable friction stage. Figure 5 (c) shows the wear surface of Fe-C-Cu-Ni-Mo. Porosity was observably reduced on the friction surface. Moreover, friction surface was very smooth. During the relative sliding of the friction pair, Asperity of the surface of powder metallurgy occur deformation and accumulation. Surface pores were filled up. It’s due to the specimens has a lower surface hardness than W6Mo5Cr4V2. When the surface was covered

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with metallic film and lubricate oil, the wear surface can’t be scratched. Therefore, the abrasion is not very obvious. Plastic deformation is the main wear mechanism. Figure 5 (d) shows the wear surface of Fe-P. There are a lot of holes in the surface and part of holes is black. Traces of the black is part of lubricate oil left. There is no phenomenon of adhesion on the wear surface. It’s obviously to observe porosity storage lubricant oil. Its antifriction efficiency can be seen from the chart of friction coefficient.

At the same time, wear rate was tested by means of surface contour method. Figure 6 shows the wear rate of powder metallurgy and YZAlSi11Cu3. Fe-C-Cu-Ni-Mo has the lowest wear rate, following is Fe-C-Cu. YZAlSi11Cu3 is the most.

![Graph showing wear rate comparison](image)

**Fig.6 Wear rate of powder metallurgy and Aluminum alloy**

### 4. CONCLUSIONS

1. Iron-based powder metallurgy antifriction materials represent porous surface, and behave high density, high strength. Its tribological property is better than aluminum alloys YZAlSi11Cu3.

2. The contact surfaces of iron-based powder metallurgy antifriction materials are smooth. Some micron-pores have been filled. The coefficient and volumetric wear rate are lower than aluminum alloys YZAlSi11Cu3. The wear rate of Fe-C-Cu-Ni-Mo is equivalent to one sixth of YZAlSi11Cu3.

3. Aluminum alloys YZAlSi11Cu3 is relatively soft, low melting point. The contact surfaces prone to deformation and adhesive wear. Iron-based powder metallurgy antifriction materials are mainly fatigue and deformation, and accompanied by a small amount of abrasive wear.

### 5. ACKNOWLEDGEMENT

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### 6. REFERENCES


