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BREAKING-IN MECHANISM OF THE SLIDING SURFACE IN A HERMETIC ROTARY COMPRESSOR EMPLOYING AN ION-NITRIDED CRANKSHAFT

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ABSTRACT

Attempts have been made to develop a highly reliable inverter controlled compressor designed for a residential heat pump unit in view of its wide range of speed and long operation period. A significant improvement in its long term reliability has been demonstrated by employing an ion-nitrided crankshaft which helps minimizing wear of the bearing.

This paper presents the dependency of the breaking-in phenomenon in hermetic rotary compressors on the material combination, and discusses the relationship between chemical reaction and wear progression of the sliding surface.

1.INTRODUCTION

Inverter controlled compressors are recently used in household air-conditioners. Higher long-term reliability of the compressor is required for the compressor under more complicated and severer operating conditions than ever before in order to improve comfortableness and save electric energy. Toshiba has developed a new hermetic rotary compressor using an ion-nitrided crankshaft (Fig.1) to cope with the requirement to improve the reliability of the compressor. Ion-nitriding treatment is a method to harden the surface rather simply and without pollution, and is also applicable to large members. Other merits of this method include lower processing temperature; small heat deformation, no post machining, and no peeling of the hardened layer, because the hardened layer is created by modifying the surface of the base meterial.

Conventionally, there are reports on trials to apply ion-nitriding treatment(Fig.2) to harden the surface of the metal material. However, there are not so many reports on the tribological characteristics of ion-nitrided materials applied to hermetic rotary compressor parts. One of the objectives of this paper is to reveal the results of tribological characteristic improvement by employing an ion-nitrided crankshaft to the hermetic rotary compressor. Different compressor crankshafts and bearings were designed for two sets of crankshaft versus bearing materials: ion-nitrided crankshaft against gray cast iron bearing and MoS_2 coated crankshaft against gray cast iron bearing. These two sets of crankshaft versus bearing materials were assembled in practical air-conditioners and were subjected to a durability test. After the test, the sliding surface of the bearing was examined by X-ray photoelectron spectroscopy (XPS). Thus, the relationship between chemical reaction on the sliding surface of the bearing and the progression of wear was compared and examined between the crankshaft materials under ordinary operating conditions of the air-conditioners. The results are reported in the following.

2.EXPERIMENTAL AND APPARATUS

2-1.Durability Tests of Practical Air-conditioner

Test compressors were manufactured for the durability tests of practical air-conditioner using ion-nitrided crankshafts and MoS_2 coated crankshafts based on ductile cast iron(JIS.FCD600) in combination with bearings of gray cast iron(JIS.FC200). Then, the test compressors were assembled in commercial air-conditioners. Durability tests were conducted under various conditions in mineral oil as a lubricant and HCFC22 as a refrigerant.

2-1-1.Test1:Dependency on material combinations

The conditions of Test1 simulated a practical compressor operating condition. Test1 was intended to analyze the structural differences of the bearing surface depending on the crankshaft materials of ion-nitrided crankshaft and MoS_2 coated crankshaft.

2-1-2.Test2:Time variation

The conditions of Test2 also simulated a practical compressor operating condition like those of Test1. This Test2 was intended to analyze the time variation of the surface structure of the bearing using an ion-nitrided crankshaft.

2-1-3.Test3:Accelerated test

The conditions of Test3 was related to a high compression ratio and interval operation, and simulated a highly loaded surface pressure due to a high compression ratio and lack of lubrication owing to intermittent operation.

2-2.X-ray Photoelectron Spectroscopy (XPS)

XPS is a useful means for determining the tribological characteristics of the sliding surface. The measurement principle of XPS is shown in Figure 3. When a substance is irradiated with X-ray, photoelectrons are emitted out of the depth of several 10 A from the surface of the substance. The energy Ek of these photoelectrons equals the difference in the energy hv of the X-ray subtracted by the binding energy Eb of the electrons in the substance and the work function ϕ.

$$Ek = h\nu - Eb - \phi$$

This XPS can identify the elements of the sample substance by measuring Ek with energy analyzer, and also can examine the chemical bonding state from the slight variation of the binding energy Eb. It can also analyze the element distribution in the depth direction by sputter etching with Ar ion.

3.RESULT AND DISCUSSION

3-1.Test1:Dependency on material combination

Figure 4 shows the XPS wide spectra of the bearings surface. The elements detected on the bearings surface were only Fe,O, and C in these wide spectra. Cl considered to be a lubricating element was not detected. The reasons for the above-mentioned non-detection of Cl include the sliding surface temperature being lower than the refrigerant HCFC22 decomposition temperature.

Figure 5 shows the XPS depth profiles of the bearings surface. Figure 6 and Table 1 denote the thickness of the iron oxide layer on the bearing surface and the chemical composition of Fe(Fe2p) on the surface obtained from the depth profile. It has been revealed accordingly that the rate of surface oxidation on the bearing surface using an ion-nitrided crankshaft is larger than that using a MoS2 coated crankshaft. It has been estimated that this difference in the surface oxidation rate depending on the crankshaft material is caused by a non-adhesive property owing to the non-metallic composition of the nitirided layer on the surface of the ion-nitirided crankshaft.

Table 1 Surface structure of bearing surface

Crankshaft material	Iron-oxide thickness	Fe composition(%)			Wear quantity	
		① Fe3O4	② FeO	③ Fe	Shaft	Bearing
Ion-nitirided	277 Å	45.3	27.1	27.6	0.5 μm	0.6 μm
MoS2 coated	196 Å	27.4	27.8	44.8	1.0 μm	1.0 μm

3-2.Test2:Time variation

Figure 7 and Figure 8 show examples of the XPS depth profile of the bearing surface and the relationship between the thickness of the surface oxide layer and wear quantity vs. operating time. It has been revealed according by these results that, under an ordinary air-conditioner operating condition, the thickness of surface oxide layer became about 400 Å after about 2000-2500 hrs operation while stopping wear. This state would be regarded as a competitive reaction process in which a quick oxidizing reaction of the surface and an extremely slow wear of the oxides occurred at the same time. In other words, the so-called breaking-in state was established. Figure 9 and Table 2 show the relationship of operating time vs. chemical composition of Fe(Fe2p) on the bearing surface. In this relationship, too, it is acknowledged that the chemical composition became substantially stationary after 2000-2500 hrs of operating time while stabilizing the surface structure.

Table 2 Time variation of bearing surface structure

Operating time	Iron-oxide thickness	Fe composition(%)			Wear quantity	
		① Fe3O4	② FeO	③ Fe	Shaft	Bearing
Original	147 Å	19.2	23.6	57.2	-	-
1300hrs	248 Å	28.1	27.2	44.7	0.5 μm	0.5 μm
2000hrs	407 Å	39.0	28.5	32.5	0.5 μm	0.7 μm
2500hrs	382 Å	37.2	27.2	35.6	0.7 μm	1.0 μm
4000hrs	420 Å	42.1	29.8	28.1	0.5 μm	1.0 μm

3-3.Test3:Accelerated test

Photo 1 denotes the SEM images on the bearing surface after testing. With an ion-nitrided crankshaft in use, a flattened surface completely free from wear trace or plastic flow is observed. To the contrary, wear trace and plastic flow are recognized on the bearing surface with a MoS2 coated crankshaft.

Figure 10 denotes Fe2p photoelectron spectra in the depth direction of the bearing surface after the test, while Figure 11 and Table 3 indicate the curve fitting results of Fe2p photoelectron spectra on the bearing surface after testing. No progressive wear was acknowledged though the thickness of the iron oxide layer became larger than those in ordinaly operating conditions with an ion-nitrided crankshaft, as shown in Tests 1 and 2. With a MoS2 coated crankshaft, the iron oxide layer on the bearing surface decreased while exposing fresh iron and proceeding with selective wear on the bearing surface of lower hardness.

Table 3 Surface structure of the bearing surface

Crankshaft material	Fe composition(%)			Wear quantity	
	①Fe_3O_4	② FeO	③ Fe	Shaft	Bearing
Ion-nitrided	21.4	54.8	23.8	0.9 μm	1.0 μm
MoS_2 coated	6.6*	25.5	67.9	1.4 μm	<10 μm

(*.Fe_2O_3)

As noted above, it has been recognized that the oxidizing rate on the bearing surface slid against an ion-nitrided crankshaft was larger than that of a MoS_2 coated crankshaft.

The effects of the iron oxide layer created by surface oxidation on the wear resistance of the bearing are as follows.

(1) The shearing stress of the sliding surface decreased with the reduction of the actual contact surface pressure caused by flattening of the surface due to the soft iron oxide layer.

(2) The lubricant film was maintained between the parts, because the lubricant impregnated into the iron oxide layer.

4.CONCLUSION

(1)No chlorine and chloride(ex.$FeCl_3$) were found on the bearing surface after the air-conditioner tests. The results suggests that chlorine atoms have little relation to the tribological characteristics.

(2)The thickness of the iron oxide layer on the bearing surface increased with the lapse in operating time. The surface characteristics varied depending on the crankshaft material as follows:

(a)In case of using an ion-nitrided crankshaft - wear of the bearing ceased when a sufficient thick film of iron oxides formed on the bearing. It was found in a typical result that a breaking-in of the bearing was produced when iron oxide layer about 400 Å thick was formed.

(b)In case of using a MoS_2 coated crankshaft - the rate of surface oxidation was smaller than that of an ion-nitrided crankshaft. Especially, abnormal wear occurred on the bearing under a specific condition.

Considering that the formed iron oxide layer on the bearing was sufficiently thick and stable, it can be explained that the reliability of the rotary compressor is improved with an ion-nitrided crankshaft / gray cast iron bearing combination which gives minimum wear. Thus, employing an ion-nitrided crankshaft greatly contributes to the improvement in the reliability of a hermetic rotary compressor.

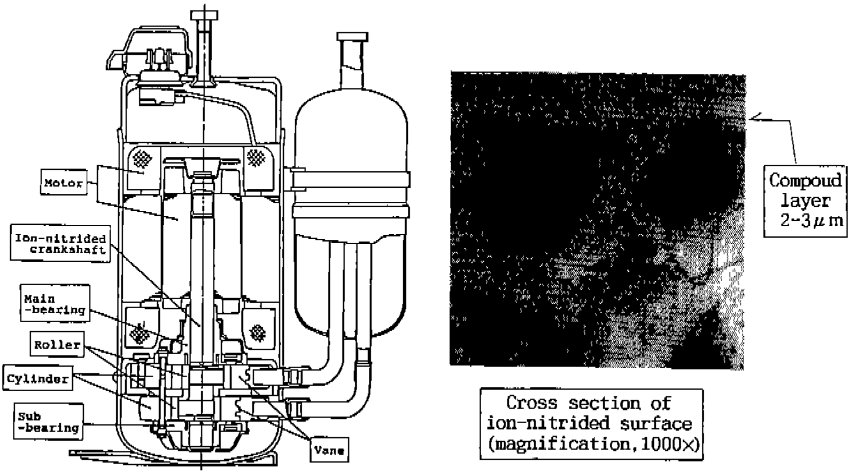


Figure 1 Schematic figure of hermetic rotary compressor

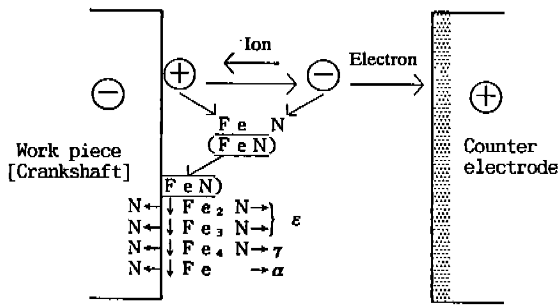


Figure 2 Treatment principle of ion-nitriding

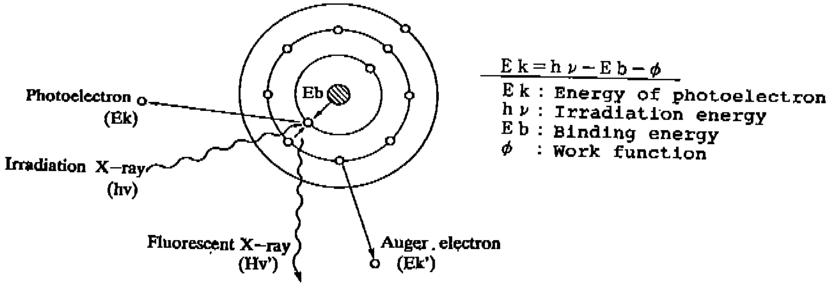


Figure 3 Measurement principle of XPS

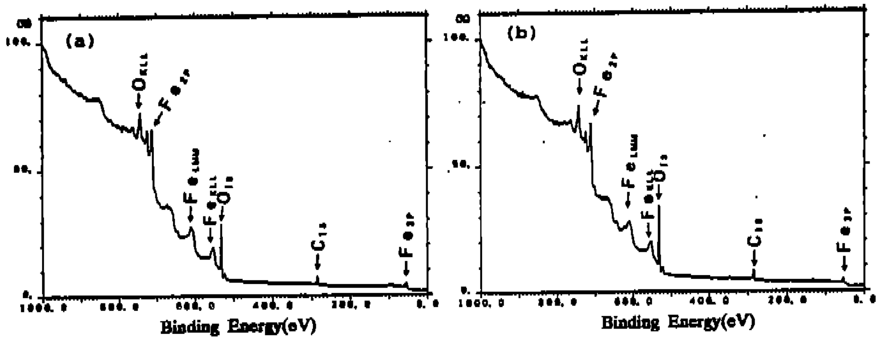


Figure 4 Wide scan spectra for bearing surface after Test 1
:(a)vs.ion-nitrided crankshaft,(b)vs.MoS2 coated crankshaft

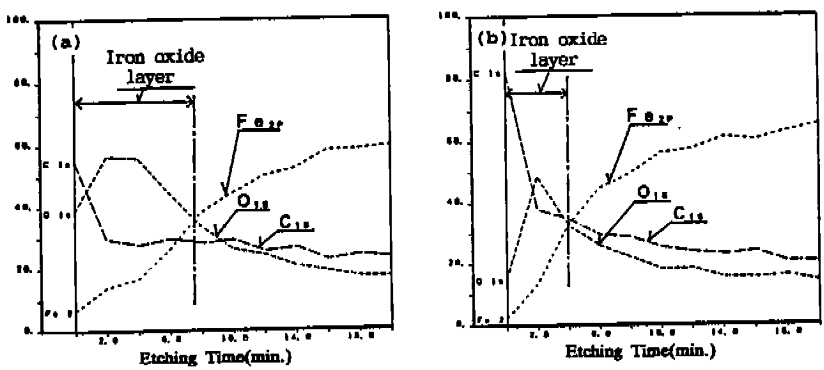


Figure 5 Depth profiles for bearing surface after Test 1
:(a)vs.ion-nitrided crankshaft,(b)vs.MoS2 coated crankshaft

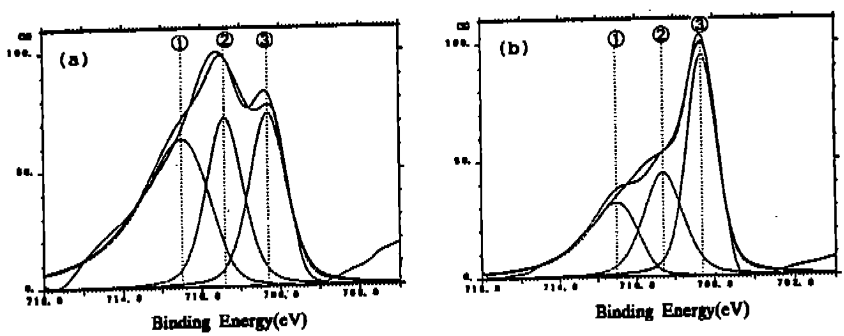


Figure 6 Curve fitting results of Fe2p photoelectron spectra on bearing surface after Test 1
:(a)vs.ion-nitrided crankshaft,(b)vs.MoS2 coated crankshaft

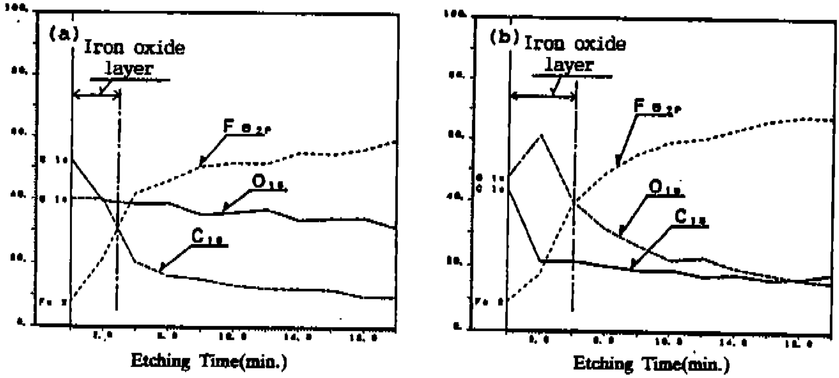


Figure 7 Examples of depth profile for bearing surface before and after Test 2 :(a)original surface,(b)after Test 2(1300 hrs)

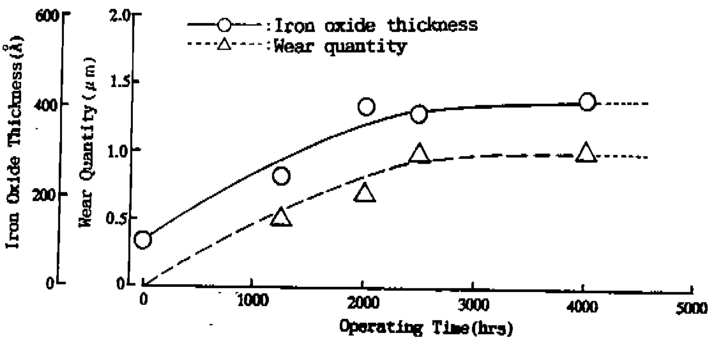
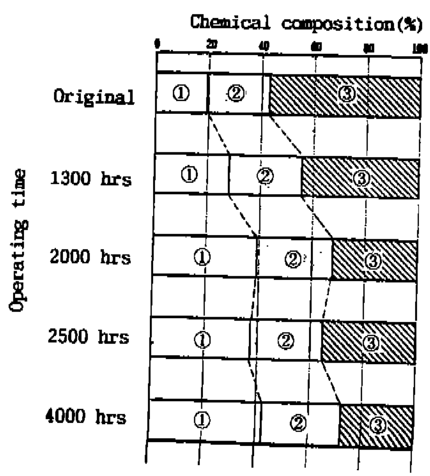


Figure 8 Relationship between wear quantity and thickness of surface oxide layer of bearings vs. operating time after Test 2



Fe composition

①: Fe_3O_4
②: FeO
③: Fe

Figure 9 Chemical composition of bearing surface after Test 2

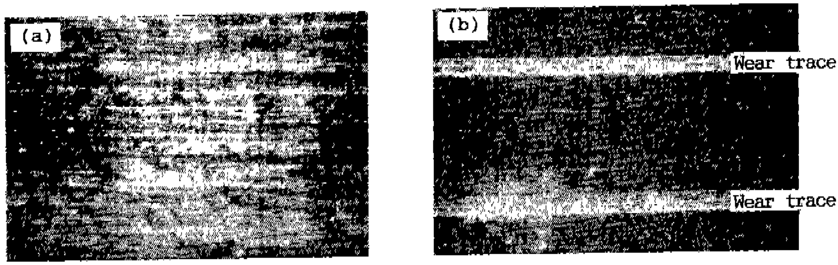


Photo 1 SEM images of bearing surface after Test 3
:(a)vs.ion-nitrided crankshaft,(b)vs.MoS2 coated crankshaft

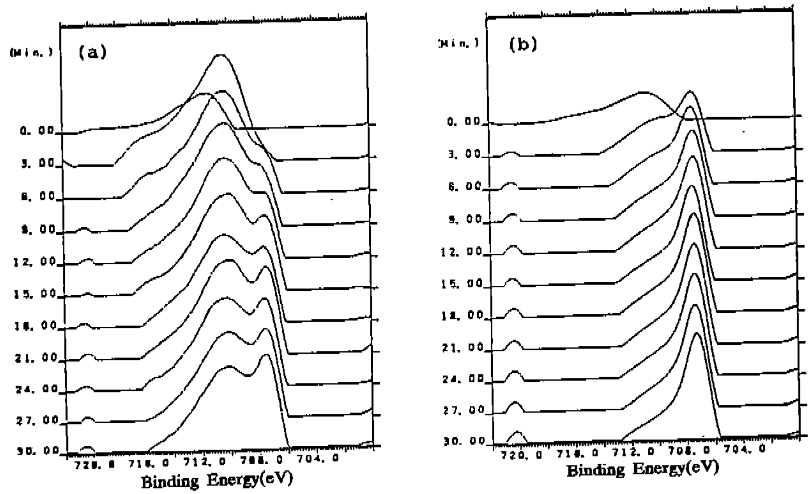


Figure 10 Fe2p photoelectron spectra in depth direction for bearing surface after Test 3
:(a)vs.ion-nitrided crankshaft,(b)vs.MoS2 coated crankshaft

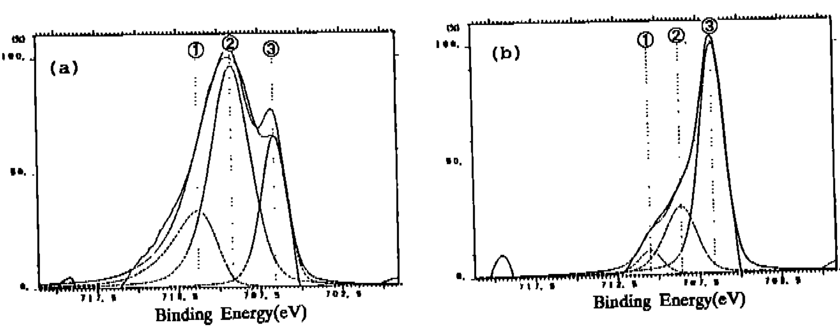


Figure 11 Curve fitting results of Fe2p photoelectron spectra on bearings surface after Test 3
:(a)vs.ion-nitrided crankshaft,(b)vs.MoS2 coated crankshaft