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Surface Treatment Technology for Siding Parts of Compressors

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Surface Treatment Technology for Sliding Parts of Compressors

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ABSTRACT

This paper describes a new surface treatment technology for sliding parts of compressors using solid lubricant. Phosphate coating has been commonly used for the surface treatment of sliding parts of compressors. However, the phosphate solution used in the treatment contains nickel which is one of heavy metals. So the process of phosphate coating is unfavorable in the environment and in recycling. This new technology is environmentally friendly because it uses only compressed air and fine particles of molybdenum disulfide that can be reused after the new surface treatment described in this paper. The new technology is superior to the phosphating in terms of sliding characteristics, taking advantage of the self-lubricating characteristic of molybdenum disulfide itself. The new technology has been developed that is effective to improve sliding characteristics and environmentally friendly.

1. INTRODUCTION

Currently, phosphate coating is widely used for the surface treatment of sliding parts of compressors. However, the phosphate solution for this treatment contains nickel, that is unfavorable in the environment. The phosphating has good sliding characteristics because the layer is a porous crystalline that can absorb and hold lubricating oil and has oil-film forming capability during sliding.[1)] Recently, compressors are required high efficiency so the viscosity of lubricating oil becomes lower. And in this result the metal contacts are occurred more often. Therefore it is difficult to make the best use of features of the phosphating. The other side, solid lubricants are used to improve lubrication in response to increasing the metal contact. However present technologies commonly used for surface treatment with solid lubricants require a binder between the metal surface and the solid lubricants. The binder impedes essential capability of the solid lubricant. In these circumstances we developed a new surface treatment technology that fully utilizes the functions of a solid lubricant and applied the new technology to a compressor.

2. TREATMENT EQUIPMENT

2.1 Equipment

This technology is a modification of the fine particle shot peening method, that is, surface modification by blasting fine particles. Bombardment of the surface with high velocity fine particles accelerated by high-pressure air increases the surface temperature of a specimen, instantly melting, and thus modifying its surface. A salient feature of this method is to form high purity solid lubricant layers on the outermost surface of the specimen without using binder.[2)]

The equipment consists of the separation section, the processing section and the collector, as shown in Figure 1. Molybdenum disulfide fine particles, as shot materials, are blasted against a surface of a specimen with the help of compressed air. The specimen on the table rotates while the blasting nozzle of molybdenum disulfide moves vertically, thus fine particles of molybdenum disulfide are blasted onto all sliding surfaces of the specimen. The blasting pulverizes molybdenum disulfide particles. The particles not to adhesive to the specimen are separated into two portions; ones of more than a certain size are returned to the processing section while the others of smaller size are collected. The collected molybdenum disulfide without any foreign materials keeps its virgin characteristics and can be used in other applications.[3)]

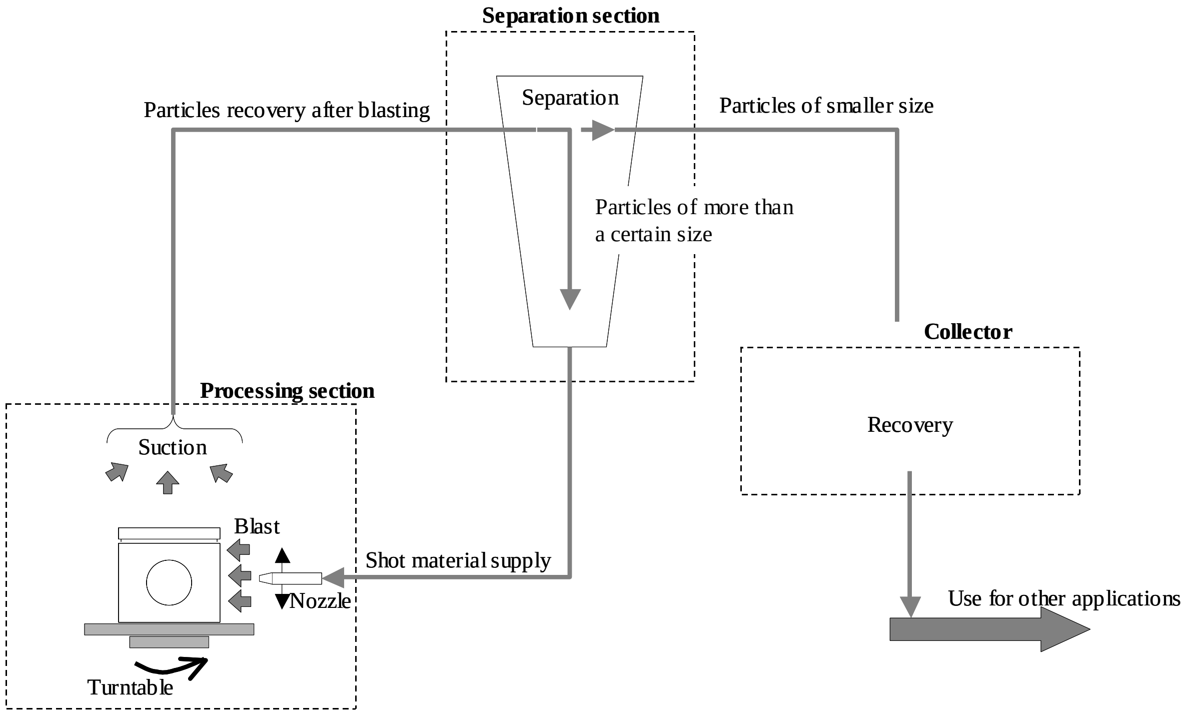


Figure 1: Shot material supply process
(Equipment construction)

2.2 Specimen Preparation

Figure 2 shows fine particles of molybdenum disulfide used as shot materials. The fine particles of molybdenum disulfide are with a purity of no less than 98.5% and an average diameter of 8㎛. The molybdenum disulfide fine particles are blasted against a specimen made of sintered iron-based material, under compressed air pressure of 1.0 MPa to prepare an evaluation specimen.

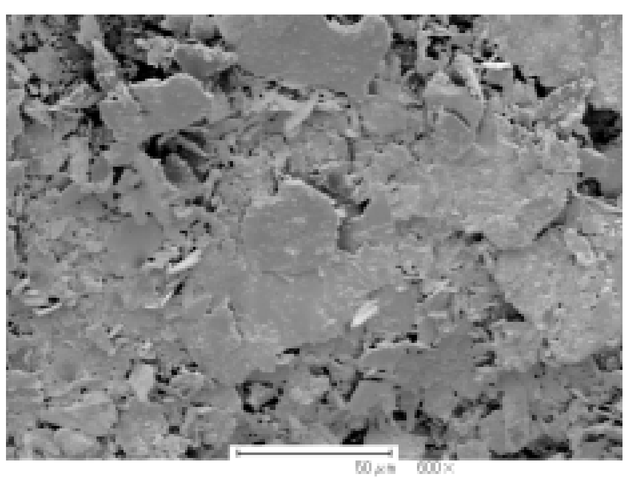
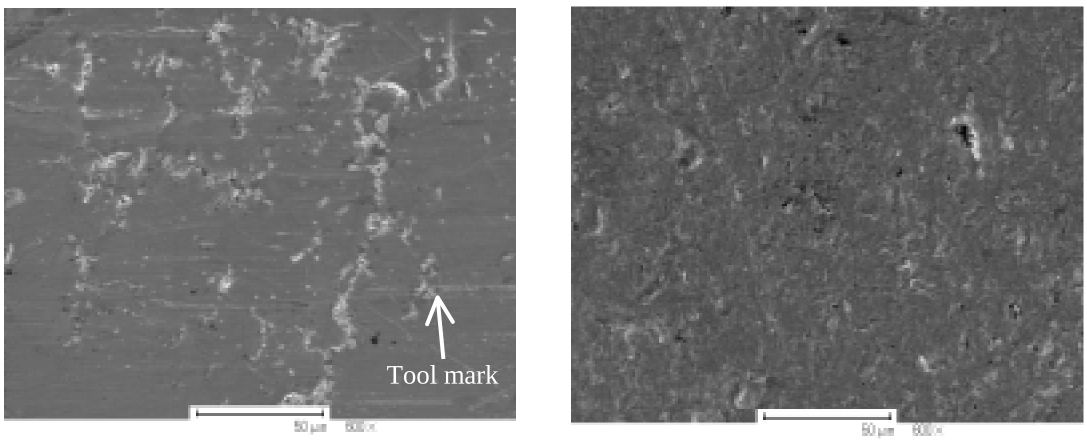


Figure 2: Molybdenum disulfide particles SEM image

3. EXPERIMENTS AND RESULTS

3.1 The Surface Observation

The specimen was observed through Scanning Electron Microscope (SEM) and analyzed by Energy Dispersive X-ray spectroscopy for component analyses (EDX). The SEM image in Figure 3 shows that tool marks disappeared and rougher surface is formed on the surface by blasting molybdenum disulfide fine particles. It was found that the surface consists of Mo, S and Fe from the EDX analysis as shown in Figure 4. These findings show clearly that the specimen surface after blasting is covered with molybdenum disulfide layers.



No-coating MoS2-shot coating

Figure 3: SEM image of the specimen surface observed

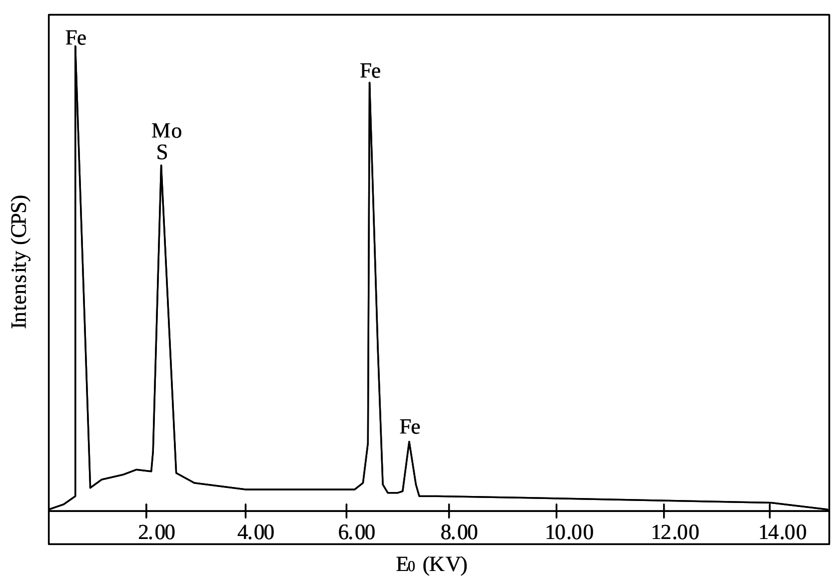
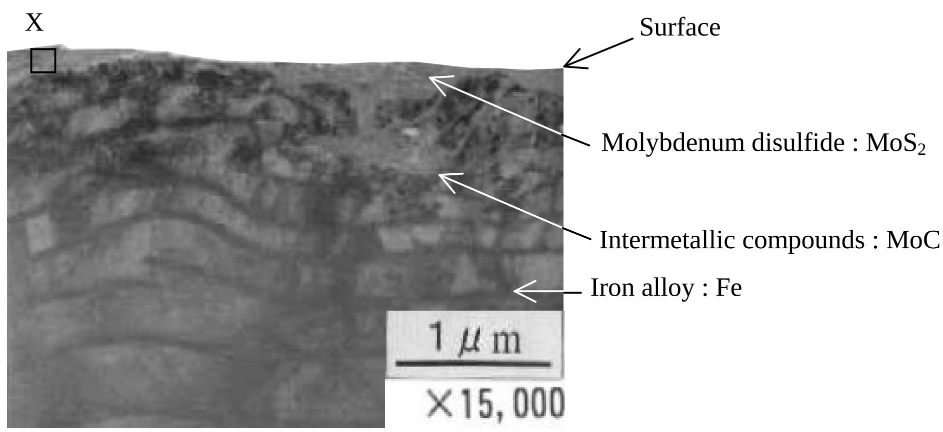


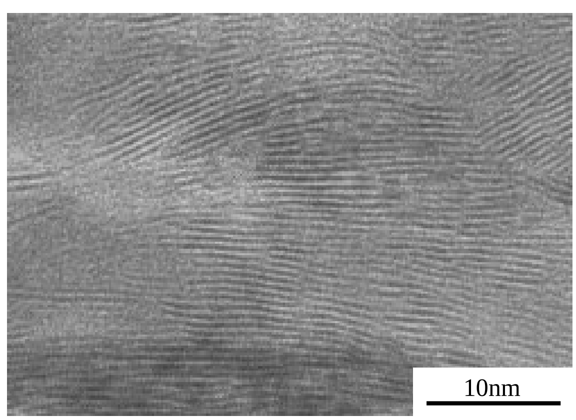
Figure 4: Component analysis result by EDX

3.2 The Section Observation

Cross section of the specimen sliding surface was observed through Transmission Electron Microscope (TEM) and analyzed by X-Ray Diffraction (XRD). Figure 5 and 6 show that molybdenum disulfide layers of 0.1 - 1 μm thickness are formed on the surface of the specimen. The molybdenum disulfide layers are parallel to the substrate as shown in Figure 5 (b). As shown in Figure 6, the XRD shows the presence of (002), (004), (006) and (008) planes, indicating the layered structure specific to molybdenum disulfide, which is important for lubrication. In addition, molybdenum carbide (MoC), an intermetallic compound, is found in the molybdenum disulfide layers. The intermetallic compound is formed under the conditions that temperature rises at least several hundred degrees in the presence of carbon in the iron-based sintered material and molybdenum in the molybdenum disulfide fine particles used as shot materials. It is highly probable that a portion of the substrate melted and combined with molybdenum disulfide.

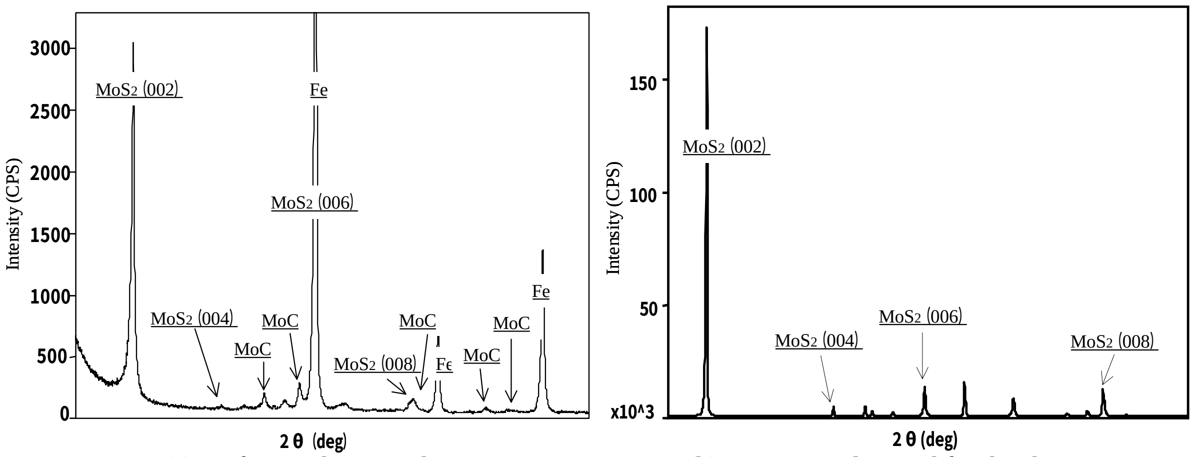


(a) Cross section of the specimen sliding surface



(b) The molybdenum disulfide layers (Closeup TEM image of (X))

Figure 5: Cross section TEM image of the specimen sliding surface



(a) Surface with MoS_2-shot coating (b) MoS_2 particles used for the shot process

Figure 6: X-ray diffraction measurement result

3.3 Sliding Characteristic

Ring on disk tests were performed using a wear tester, shown in Figure 7, to compare the sliding characteristics between phosphating and molybdenum disulfide layers by the new technology. Friction coefficient and wear resistance were evaluated. Table 1 shows ring on disk test conditions.

In general, sliding conditions between a piston and a cylinder of a reciprocating compressor changes among fluid lubrication, mixed lubrication and boundary lubrication by crank angle, lubricating oil viscosity, pressure condition and surface roughness. Figure 8 shows that the friction coefficient of the phosphating specimen decreases with the increasing bearing constant in the range of 10 or less of the constant, and then it increases. This means this ring on disk tests are in the boundary range of mixed lubrication conditions. It was found that the specimens treated by the new technology described in this paper have friction coefficients lower than those of the phosphating specimens in all experimental conditions. The effect of the new technology is high, in particular, in the bearing constant range of 0.1 to 1, that is, in the boundary lubrication condition. As described in the preceding section, we think this effect depends heavily on the presence of the specific structure of molybdenum disulfide that is important for lubrication.

Figure 9 shows that the wear depth of the specimens treated by the new technology is 1/3 that of the phosphating specimens, indicating the superiority of the new technology in terms of wear resistance. We think there are two things contributing to the superiority, that is, the effect of molybdenum disulfide as a solid lubricant as mentioned in the discussion of the friction coefficient, and strong adhesion of molybdenum disulfide to the substrate through the formation of the intermetallic compound, as mentioned in the preceding section.

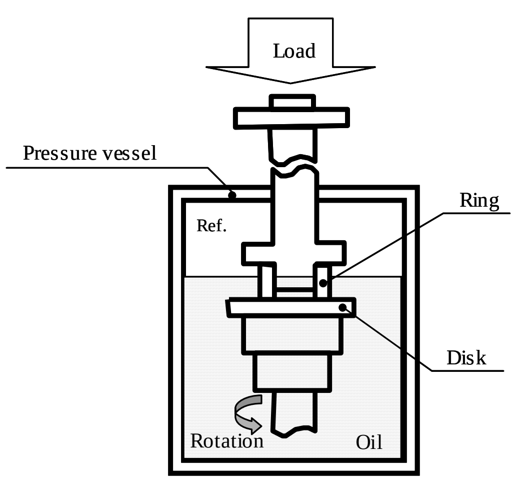


Figure 7: Ring on disk test image

Table 1: Test conditions

	Friction coefficient test	Wear test
Load	10～1800 N	100 N
Rotation Speed	0.5～1.0 m/s	1.0 m/s
Refrigerant Pressure	0.4 MPa (R134a)	
Oil Temperature	60℃	
Viscosity Grade	VG8～VG22	VG8

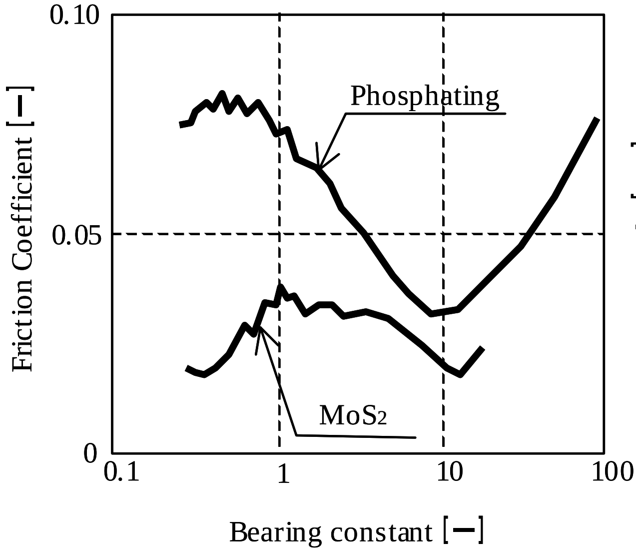


Figure 8: Friction coefficient

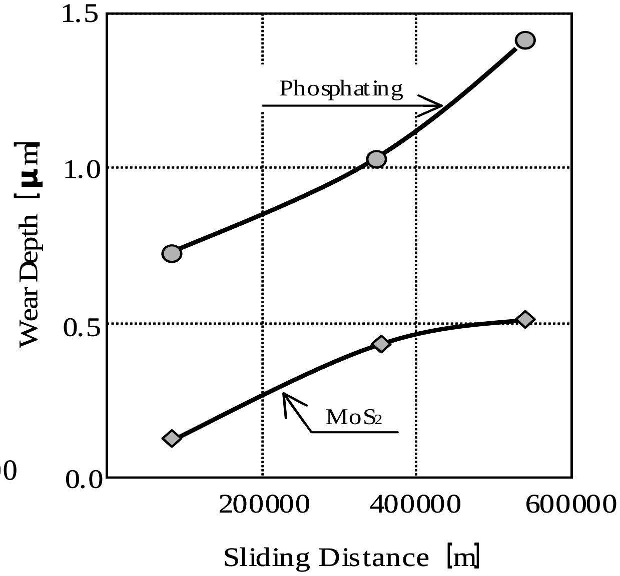


Figure 9: Wear depth

Next, reliability tests were performed to confirm the effect of the treatment on the piston assembled into an actual reciprocating compressor for hydrocarbon refrigerant used mainly in the market. Table 2 shows reliability test conditions.

As shown in Figure 10, the test results by compressor also show that the wear depth of the piston treated by the new technology described in this paper is 1/3 that of the phosphate coating piston. In the performance evaluation, it was found that coefficient of performance (C.O.P.) of the piston treated by the new technology is improved by about 0.01 (W/W) compared to that of the phosphating piston. Thus the improvement of sliding characteristics using the new technology is confirmed with an actual compressor.

Table 2: Reliability test condition

Cylinder volume	10cc
Refrigeration	R600a
Oil	Viscosity grade : VG10
Discharge pressure	0.70MPa
Suction pressure	0.06MPa

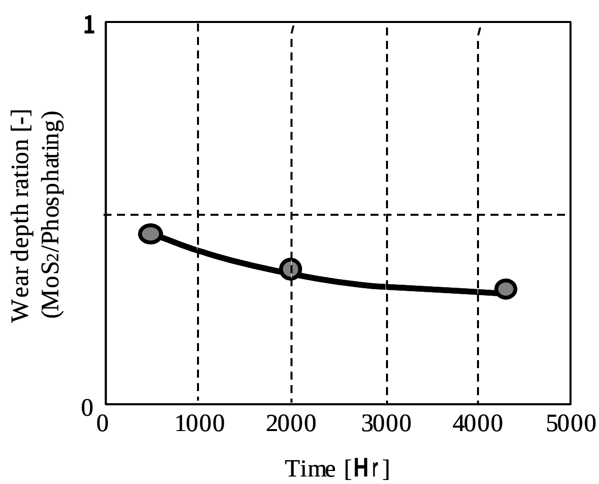


Figure 10: Reliability test result

4. DISCUSSION

The crystalline structure of molybdenum disulfide sufficiently explains why the new technology is better than the phosphate coating in terms of wear resistance and friction coefficient, resulted in better efficiency of the compressor. Molybdenum disulfide is a hexagonal layer compound made from one molybdenum atom and two sulfur atoms, with molybdenum atoms positioned diagonally below the sulfur atoms.[4)] The chemical bond between Mo and S in the layer is a covalent bond, with very high bonding energy and a bond length of about 1.5 A. While the interlayer bond between S - S separated about 3 A is formed only by Van der Waals force, which is far weaker than the force of the covalent bond. Molybdenum disulfide layers are strong against force perpendicular to the layers because of the covalent bond in the layers, while the layers slide easily in directions parallel to the layers when a force is applied in that direction. This is because the Van der Waals force in the layers is weak. TEM observation confirmed that the molybdenum disulfide layers prepared by the new technology are parallel to the surface of the specimen. This is a reason why a better and stable friction coefficient is obtained. From these findings, we think the improved friction coefficient and wear resistance of the specimens treated by the new technology are brought about heavily by the crystalline and layered structure of molybdenum disulfide, which is not affected by the viscosity of lubricating oil.

Another reason why the characteristics of molybdenum disulfide are fully utilized is the development of the new molybdenum disulfide blasting process, which enables the formation of high purity, more than 98 %, molybdenum disulfide layers without employing a binder. Molybdenum disulfide particles blasted against a specimen made of Fe-C alloy increases the surface temperature of the specimen, melting the surface, diffusing thermally into the melted Fe-C alloy, the basic material of the specimen, and forming intermetallic compound of Mo and C, probably through mutual thermal diffusion of the basic material and molybdenum disulfide. The intermetallic compound thus formed acts as an agent to bond Fe-C alloy to the molybdenum disulfide layers. The presence of the intermetallic compound helps realize peel strength of molybdenum disulfide layers that is higher than the strength in the absence of the compound.

The new surface treatment technology described in this paper improves the performance of compressors, utilizing fully the self-lubricating characteristics of molybdenum disulfide

5. CONCLUSIONS

The following results were obtained in this research.

- Friction coefficient can be decreased.
- Wear resistance can be improved.
- Pulverized molybdenum disulfide, the only chemical substance discharged in the process, can be 100% recycled.

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