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Effect of Surface Treatment on Piston Wear in the Oil Hydraulic Piston Pump

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Abstract : Surface treatment technologies are frequently used to improve mechanical properties of surface layers of machinery components in many practical situations. Surface hardness of piston in the oil hydraulic piston pumps is very important about wear resistance. To improve hardness, wear resistance of the oil hydraulic axial piston pump, it is needed to know the surface layer characteristics in the sliding contact parts. This paper reports an experimental study on surface treatment characteristics in the piston of the oil hydraulic axial piston pump. We investigated the surface wear of a piston between untreated and nitriding-treated surfaces. We obviously observed that the surface hardness of piston in the oil hydraulic axial piston pump plays an important role to have wear resistance and remain a longer life.

Keywords : Surface hardness, surface treatment, wear, nitriding, piston

Introduction

The use of axial piston pumps with high overall efficiency are rapidly increasing due to the demand for machines capable of operating at greater rotational speeds and delivery pressures. At the same time, much study has been carried out to improve pump design. Useful design techniques have been developed and used for a number of years. Recently, working pressures and speeds have been improved, so wear of sliding parts has become relatively greater. Therefore, more concern has been shown over a wear-resistant surface, so that the wear problem in hydraulic system must be solved.

Surface treatment processes have gained considerable importance in tribological applications because of their ability to enhance friction and wear properties. Various methods of optimizing composition and microstructure of surface layers of machinery components using suitable surface treatment are known to improve surface mechanical properties of steel materials. However, specific damage mechanisms being important and decisive for different conditions of a material and loading, including environment should be considered.

Surface treatment technologies enable to change either surface microstructure(e.g. by surface quenching hardening or laser treatment), chemical composition(case-hardening, carbonitriding, nitriding) or mechanical properties (for instance by introducing compressive residual stresses), by changing dislocation structure and increasing density as a result of local surface and subsurface plastic deformation (shot peening, grinding, polishing etc.) [1].

In some cases, surface treatment provides the only possibility to increase surface strength with preserving high toughness of a bulk material. This type of structure of components is advantageous, as the bulk material has a big carrying capacity while a hard surface layer is resistant against wear and abrasion, damage processes being localized on or near the surface.

The aim of this paper is to show how all details of both surface hardness and wear in the oil hydraulic piston pump are important to be considered in designs of components that enable to evaluate durability components more exactly.

Surface Treatment and Wear

Wear of a surface depends on chemical and phase composition, on free-surface, and bulk properties, including surface hardness. Several mechanism are involved: adhesive wear arises from plastic yield of a surface following adhesive contact, while abrasive wear is due to material loss from a surface by micro-cracking and local fracture. The adhesive and abrasive wear rates of a surface vary inversely with their hardness, so high hardness can be expected to have low wear rates.

Various kinds of technology are employed in forming surface layer properties, especially those which are the widely applied thermo-chemical treatment. Nitriding belongs to this type of treatments. It is mainly used to improve fatigue resistance and also to increase resistance from corrosion and reduce abrasive wear [2]. The structure of a surface layer and stress states existing within the material after treatment is an effect of various types of physical phenomena (such as: elastic and plastic deformations, thermal effects, diffusion and phase

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transformations) which occur during the treatment.

In general, all technologies for forming surface layer properties cause changes in the stress state of the material. Yet the mechanical properties of nitrided machine parts depend mainly on the stress state in the diffusion layer. In this regard it is essential to produce a suitable stress state which will ensure that the treated part has the desired properties. Such an effect can be obtained by controlling the parameters of the nitriding process, for example, the treatment time, the composition of the gaseous atmosphere and suitable pre-treatment of the nitrided parts.

Nitriding is a process of diffusional saturation of nitrogen into surface structure under high temperature conditions. The gaseous atmospheres consist of a mixture of gases. The nitrogen introduced to the structure enters into a partial reaction with the iron contained in the steel leading to defined formation of structures, which have high hardness. In addition, during the process, the nitrogen enters into reactions with the alloy elements contained in the steel. The reaction process lead in turn to creation of nitrides of these elements, through which the above mentioned increases in hardness. The results are, then, a differentiation of structure in the surface layer of the material. After the process, significant compressive stresses are registered. The surface layer arising during the nitriding process possesses a zone structure consisting of a zone of compounds, as well as a diffusion zone (a solution of nitrogen in iron nitrides of metal alloys). The main useful effect of this process is an increase in fatigue strength as well as the tribological and anti-corrosive properties of the material.

Several conditions encountered in deformed layer definition and thickness measurements are shown in Fig. 1 [3]. These are exemplified as follows:

(a) *Mild or lubricated wear.* The Highly Deformed Layer (HDL) is most uniform although usually relatively thin. Sometimes it is very difficult to resolve and may require electron microscopy. The HDL thickness may not exceed surface finishing damage created during original component fabrication

(b) *Fatigue wear-spalled surface.* Loss of spalled or localized delaminations may require judicious selection of measurement locations to fairly assess the depth of sliding traction-induced deformation.

(c) *Severe wear with hard asperity plowing.* Here, the surface conforms to asperity shapes. HDL tends to remain relatively constant and follows the surface topography.

(d) *Transfer and/or debris infilling.* Load bearing conditions and transmission of shear stresses into the bulk vary due to transfer layers and deposits of compressed debris. This can make unambiguous HDL identification and measurements nearly impossible.

(e) *Subsurface ductile fracture.* HDL due to the tractions from the moving counterface should be distinguished from the deformation remaining after volumes of bulk material fracture, and are pulled away leaving adjacent deformed regions behind.

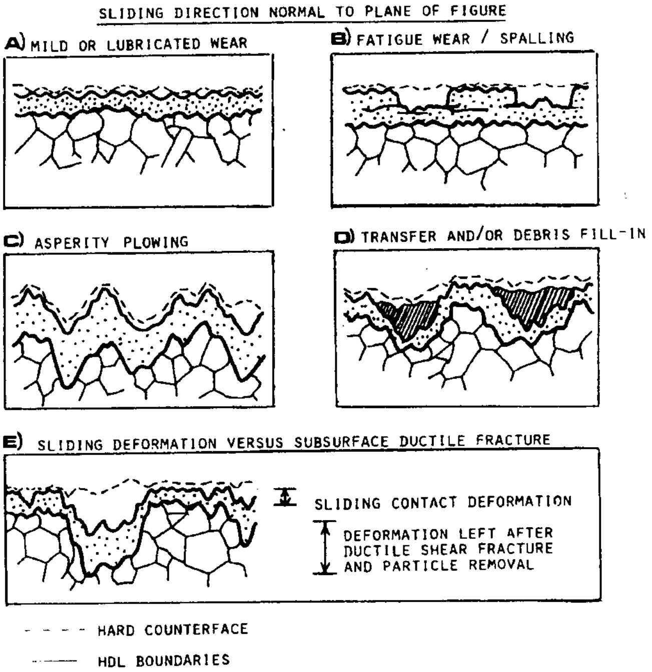


Fig. 1. Examples of microstructure damage due to several kinds of wear modes.

Experimental Apparatus and Methods

A schematic diagram of the bent-axis type axial piston pump is shown in Fig. 2. On rotation of the drive shaft, the cylinder is caused to rotate by seven pistons flexibly mounted in a circular arrangement on the drive shaft. The cylinder slides on the spherical valve plate which has two kidney ports. The forces on the pistons are generated directly by the torque on the drive shaft. Piston stroke is dependent upon the offset angle between the shaft and the center line of the cylinder block.

The piston pump under test is driven by a variable electric motor (75 kW). We can change the motor speed from 0 to 2,500 rpm by using a vector inverter motor controller. The piston pump is connected to a driving motor by means of chain coupling. The pressure, flow, and temperature sensor is

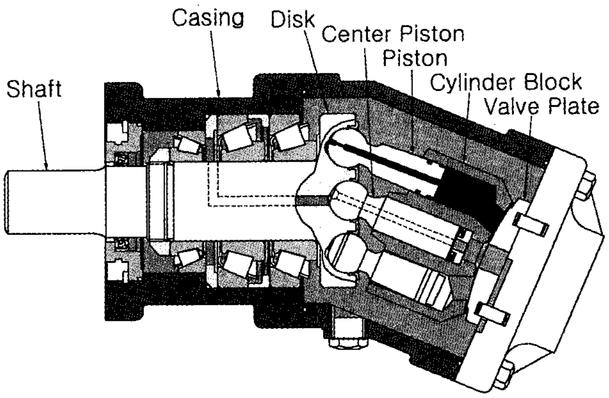


Fig. 2. Hydraulic axial piston pump.

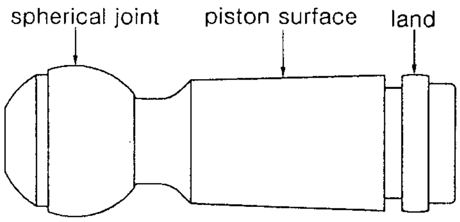


Fig. 3. Structure of piston.

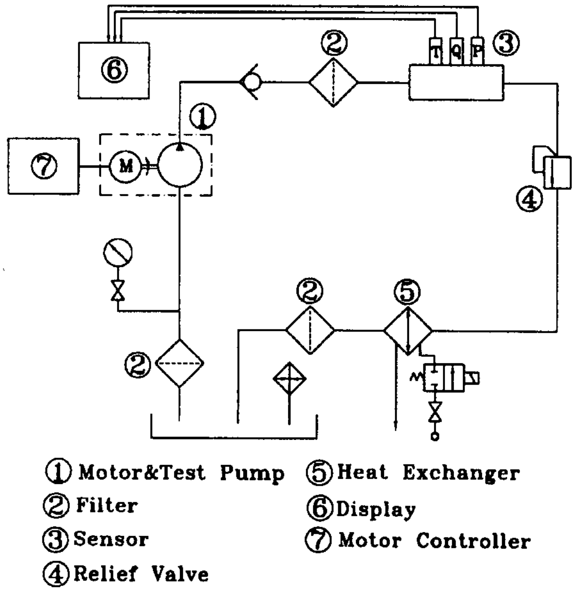


Fig. 4. Hydraulic circuit.

mounted in delivery line. The relief valve controlled the delivery pressure from 0 to 35 MPa in test pump. We used the heat exchanger to control the oil temperature in test unit [4,5].

We designed two samples piston to investigate the effect of surface hardness. We changed the surface hardness of the piston by means of heat treatment. The surface hardness in sample 2 obtained over Hv700 by nitriding. The specifications of the sample are shown in Table 1, and the specification and dimension of the test pump is shown in Table 2.

Hardness tests were performed on the surface of two piston samples by means of micro Vickers hardness tester. The piston surface was surfaced-ground, lapped, and polished to a mirror finish. Wear tests were carried out under the working condition of axial type piston pump. Experiments were carried out with a discharge pressure of up to 35 Mpa that was applied to the test pump. Thereafter, surface variation was investigated before, during, and after the test on each sample, and the nature of worn surfaces during the tests shows that the process is essentially one of abrasion of the surface-treated layer. The experimental conditions are shown in Table 3.

Table 1. Material and heat treatment

	Parts Name	Material	Heat treatment
Sample 1	Piston	SCM435	Quenching Tempering
	Cylinder Block	SCM435	
Sample 2	Piston	31CrMoV9	Quenching Tempering Nitriding
	Cylinder Block	SCM435	

Table 2. Specification and dimension of test pump

	Size
Displacement	90 cc/rev
Max. speed	1,800 rpm
Max. swivel angle	23°
Number of piston	7 EA
Diameter of piston	24 mm

Table 3. Test conditions

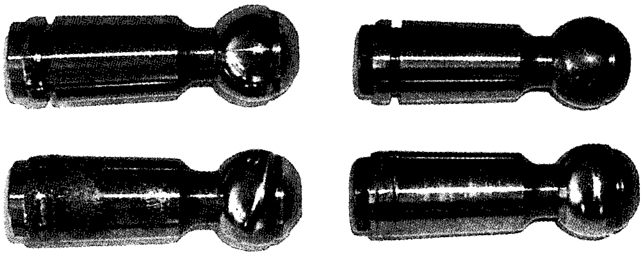
	Test conditions
Discharge Pressure	0-35 Mpa
Rotational Speed	1-1,800 rpm
Oil Temperature	50±5°C
Working fluid	VG 46

Results and Discussions

The piston surface of sample 1 occurred severe wear at 29 Mpa during the experiment, so that in sample 1 there was no more working about test conditions. But in sample 2 there was not any special problems during all test conditions in the experiment.

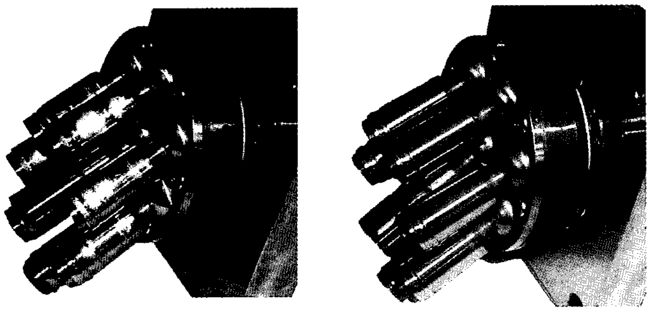
When comparing the wear performance of sliding parts, different surface treatment as well as hardness of the respective surface layers must be taken in account. A convenient way of achieving this is first to estimate the time it would take to abrade away the hardened surface layer at the relevant wear rate. The rate of wear would be expected to be related to hardness of surface-treated layer.

Figs. 5 and 6 present photographs of the topography of worn pistons of untreated and nitriding-treated samples. In Fig. 5, the sample 1 of untreated piston occurred severe wear on almost surface of piston. But in sample 2, the nitriding-treated piston shows that wear scar in piston surface is very slight and mild. Comparing sample 1 with sample 2 after test in Fig. 5,



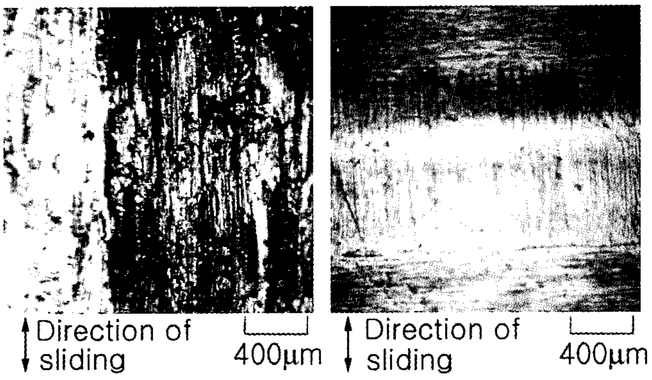
(a) Sample 1 (b) Sample 2

Fig. 5. Before and after test.



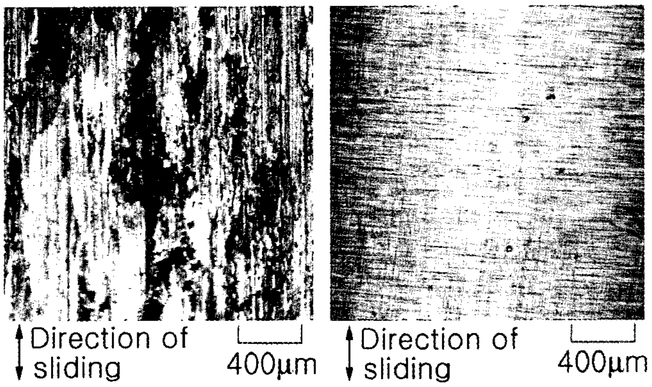
(a) Sample 1 (b) Sample 2

Fig. 6. Wear scar of surface after test.



(a) Sample 1 (b) Sample 2

Fig. 7. Microphotograph of land surface.



(a) Sample 1 (b) Sample 2

Fig. 8. Microphotograph of piston surface.

we obviously noted that the effect of surface treatment was very great.

Microphotography of the sliding wear scar of untreated and nitriding-treated piston are shown in Figs. 7-8. The features of untreated piston included severe scoring lines, areas of plastic flow, ploughing, and transfer of particles. The worn surfaces of nitriding-hardened piston exhibited less plastic flow and ploughed regions and finer scoring lines than that of untreated piston. The worn surfaces of nitriding-treated piston exhibited less plastic flow and ploughed regions and finer scoring lines than that of untreated piston. Severe wear occurs via adhesion or plastic deformation and subsequent material removal by delamination or fatigue process [6].

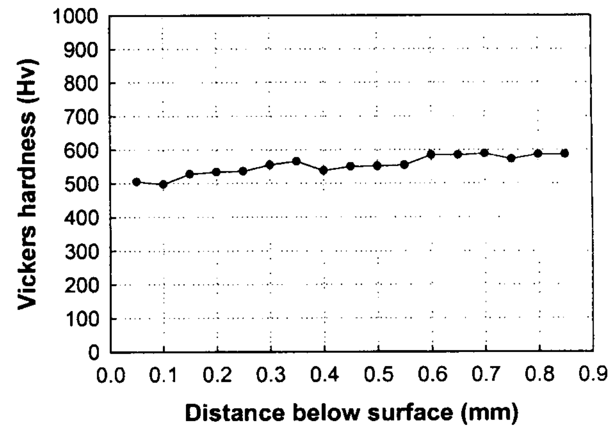


Fig. 9. Surface hardness of piston (sample 1).

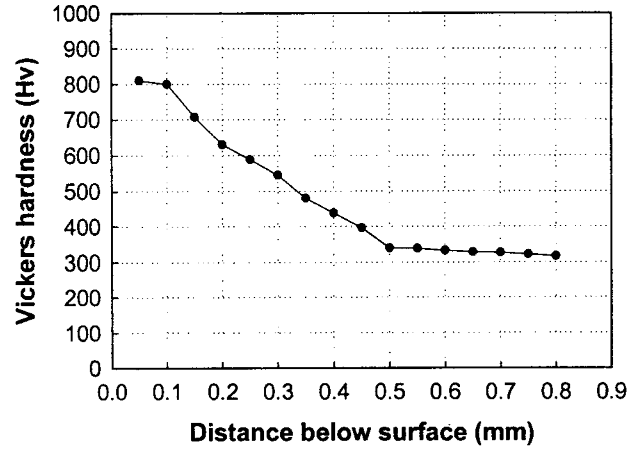


Fig. 10. Surface hardness of piston (sample 2).

Figs. 9 and 10 shows the distribution of surface hardness on piston in each samples. In sample 1 of untreated surface investigated the uniform hardness distribution of Hv500-Hv600 from surface to 0.9 mm depth. In sample 2 of nitridng-treated surface presented gradually decrease hardness distribution from Hv800 to Hv320 and these types have strongly resistance to wear. Eventually, the main effect of surface treatment is an increase in wear resistance as well as the anti-corrosive properties of the sliding surface.

Conclusions

Through the investigation of the surface wear of the rubbing parts and microphotograph observations, it was noted that the wear closely related surface hardness. The dominant factors influencing the tribological behavior are the distribution of hardness near the surface. A dramatic improvement in resistance to scuffing and sliding wear was obtained in nitriding.

Therefore, in surface hardness acquired in surface treatment, it was very important to have strongly wear resistance and anti-fatigue properties in the oil hydraulic piston pump. Furthermore, we obviously noted that the surface hardness of the piston must be gained at least above Hv700 using the oil hydraulic piston pump at 35 Mpa conditions.

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