FATIGUE STRENGTH OF ION-NITRIDED STEEL AT ELEVATED TEMPERATURE

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Fatigue strength of ion-nitrided Steel at elevated temperature, 300 and 500 degree centigrade, is determined. High temperature and oxidation are considered as weakening factors. As the strengthening mechanism of fatigue on ion-nitrided steel is not the hardness of the surface layer but the strength and residual stress of inner matrix, fatigue strength at elevated temperature is lowered apparently. To avoid the effect of oxidation, fatigue test was carried out in argon gas. Temperature dependency of fatigue strength and the inner oxidation of inclusion is discussed.

INTRODUCTION

Ion-nitriding is one of the surface modifying technology to improve the fatigue strength and wear resistance of steels and other metals. Authors (1) had reported about strengthening mechanism of ion-nitrided steel in rotating bending fatigue tests.
Fatigue behavior of ion-nitrided steel at elevated temperatures, 300 and 500 degree centigrade, is determined. As high temperature and oxidation are considered as weakening factors, environmental effect is discussed. Ion-nitriding duration affect on the fatigue strength. By nitriding, surface layer of specimen is hardened to 1100 Hv, and fatigue strength is improved up to 140 percent of untreated ones. It is clarified that main mechanism of high fatigue strength is caused not by the hardness of this layer but by the strength and residual stress of inner matrix. Origin of fracture site locates in the

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"fish-eye", which is within the softer section of specimen. Some researchers (2) determined on the fracture of nitrided steels in the view of defects and the internal stresses. Otherwise, at elevated temperature, fatigue strength is apparently lowered. To investigate the effect of atmosphere, tests were carried out in air or in argon gas. It is supposed that the oxidation causes the shortening of fatigue life by the rapid crack propagation from the inclusion. In this study, temperature dependency of fatigue strength of ion-nitrided steel was discussed.

EXPERIMENTALS

Materials used were two types of tool steels. The one (Japan Industrial Standard SACM-645) contains about one weight percent aluminum element to promote ion-nitriding. The other (HPM-31, Hitachi Metals Co.) has some alloying elements such as Chromium, Molibdem and Vanadium, to get higher ductility and fine grains. The chemical compositions are shown in Tables 1. The micrograph of HPM-31 is shown in Figure 1. This material HPM-31 has finer structure than SACM645. The fatigue specimens were machined by a centerless grinder, and were ion-nitrided at 550 ℃, for 3 or 15 hours, as shown in Figure 2 and Table 2 in detail. Fatigue tests were carried out by a rotating bending tester, "Ono-Type H-6" machine (3000 revolutions per minute). Fracture surfaces were observed by a scanning electron microscope and an EPMA, JXA-8900R (JOEL Co).

TABLE 1- Chemical Compositions of Material Used (wt%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Al	V
SACM645	0.5	0.21	0.36	0.17	0.02	0.09	0.04	1.49	0.15	1.03	---
HPM31	0.7	1.0	0.5	0.25	0.01	---	1.3	8.0	1.3	---	0.9

TABLE 2- Conditions of Ion-Nitriding

Gas Composition	Temperature	Gas Pressure	Duration
N_2: H_2 = 3:1	550 [degree]	5[Torr]	3 or 15 hours

EPERIMENTAL RESULTS AND DISCUSSION

Hardness Tests of Ion-nitrided Steel.

Vickers hardness distribution from the surface into the depth is shown in Figure 3. Material SACM-645 shows a gradual change of hardness within 150 micronmeter depth. While the hardness of material HPM-31changes steeply. Alloying elements may disturb the diffusion of nitrogen atoms in thin layer of the specimen. It is supposed the diffusion is disturbed mainly by a mount of carbon content. The maximum hardness shows the same value, 1100 Hv.

Fatigue Strength of Ion-Nitrided Specimens at Elevated Temperature.

Fatigue strengths of ion-nitrided specimens both at room temperature and at 300 and 500 degree centigrade are determined. Figure 4 shows the characteristics at 300 degree. Fatigue strength of 15 hours ion-nitrided specimens is higher than that of 3 hours nitrided ones at every temperature. At higher temperature, the declining tendency of fatigue strength and life is apparent. The change of matrix and oxidation will occur at these temperature. At elevated temperature above 300 degree, oxidation of the surface is remarkably observed, and also fracture surface is covered by an oxide layer. To avoid the surface oxidation, some tests were performed in argon gas atmosphere. The fatigue life tested in argon gas at 300 degree centigrade shows slightly longer than that in hot air. It means the oxidation may shorten the fatigue life of ion-nitrided steels. It will need to clarify the precise mechanism of weakening by oxidation, but some mechanisms can be suggested. One is the diffusion of oxygen atoms in steel can be caused in repeated loading at elevated temperature, because the atomic sizes of nitrogen and oxygen are similar. The second reason is the presence of inclusion can cause the inner oxidation near it, as the oxide will make larger volume.

Fracture Analysis of Fatigue Failure.

All the fracture surfaces show the "fish-eye" patterns on their inner part of hardened layer. The reason why the fish-eye was located at the inner part of hardened layer was reported in the previous paper (1). The inclusion is observed in center of the every fish-eye, in Figure 5. And the elements are aluminum nitride for SACM-645 material, and calcium sulfate for HPM-31 material. The approximate size is 20 by 30 micronmeters, as shown in Figure 6. It is supposed to eliminate inclusions and impurities in the steel making process, but it is desirable to make more small size.

CONCLUSIONS

For two kinds of ion-nitrided steel, fatigue tests at elevated temperature were carried out. And following results are obtained:

(1) The fatigue strength of ion-nitrided steel is declined remarkably at elevated temperature, because of the change of matrix and oxidation.

(2) The mechanism of inner oxidation is discussed.

REFERENCES

(1) Onuki, A. Yanagi, N. Satoh, N. and Takase, F., "Fatigue Strength of Ion-Nitrided Steel", Preprints of the Ninth European Conference on Fracture, Varna, Bulgaria, "Reliability and Structural Integrity of Advanced Materials", Edited by S. Sedmak et al, EMAS, U.K., pp. 377-382.

(2) Cowling, J.M. and Martin, J.W., "Fatigue of Nitrided En41B Steel: Effect of Internal-Stress Distribution", Metal Technol., August (1981), pp. 289-296.

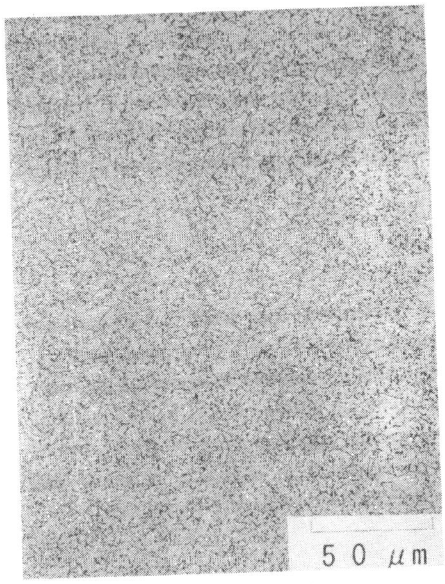

Figure 1 Micrograph of HPM-31

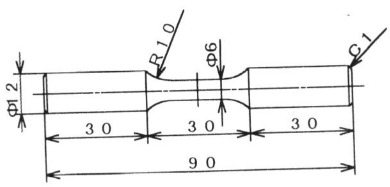

Figure 2 Dimension of the specimen

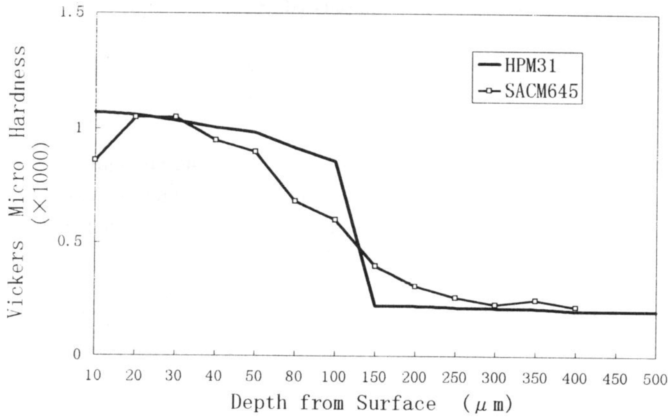

Figure 3 Hardness distribution curves from surface

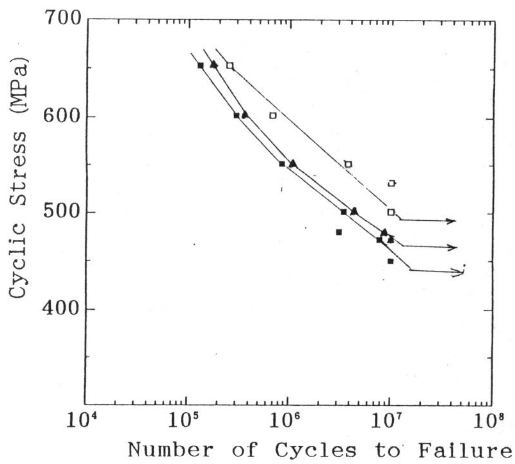

Figure 4 Fatigue strength of ion-nitrided steel

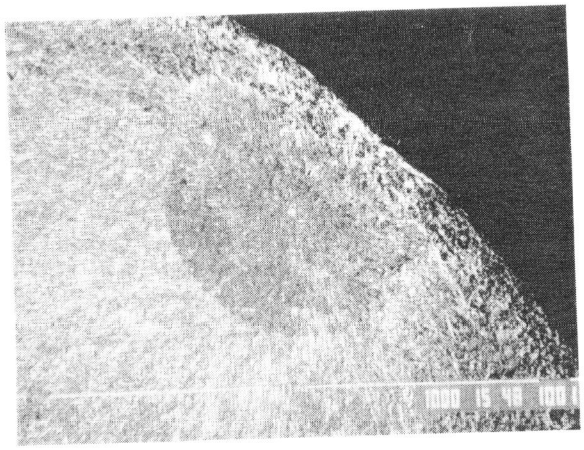

Figure 5 Fish-eye pattern on fracture

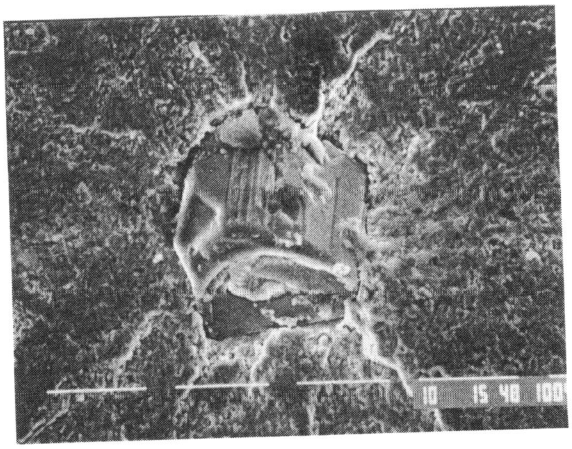

Figure 6 Inclusion on the center of fish-eye, consist of calcium