Effect of plasma nitrocarburizing on fatigue behaviour of AISI 1020 steel

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Abstract

AISI 1020 steel was plasma nitrocarburized under different process parameters regarding time (1, 4 and 12 h), temperature (500, 570 and 640 °C) and different CO_2 ratio. The fatigue strength of plasma nitrocarburized AISI 1020 steel has been assessed by using a rotating bending fatigue machine and observed by scanning electron microscopy (SEM). In addition, the obtained results have been compared with the fatigue limits of plasma nitrided AISI 1020 steel. It has been found that plasma nitrocarburizing improves the fatigue strength with increased process times, but the fatigue strength decreases with growing CO_2 ratios. Fatigue strength and fatigue limit depend on treatment temperature. Their maximum was found at 570 °C.

Key words: plasma nitrocarburizing, fatigue strength

1. Introduction

Nitrocarburizing is a thermochemical process that diffuses nitrogen and carbon into the surface of ferrous materials at certain elevated temperatures. Two different structures occur on the surface of steel, known as the compound layer and diffusion region from surface to core respectively as a result of nitrocarburizing. When the nitrogen and carbon activities imposed by the nitrocarburizing agent on the ferrous material surfaces are sufficiently high, a compound layer consisting predominantly of ε-$Fe_{2\text{-}3}$(N,C) and/or γ'-Fe_4(N,C) phases is formed at the surface. The compound layer provides the materials with good physical and chemical properties against wear and atmospheric corrosion. The diffusion region brings about an improvement of fatigue strength when compared to an untreated material. In this region, N and C atoms are dissolved interstitially in the ferritic lattice, and form the nitride precipitates [1–9].

Fatigue strength can be significantly improved by plasma nitrocarburizing. The formation of precipitates in the diffusion layer tends to increase the hardness and create compressive residual stresses. These beneficial stresses lower the magnitude of the applied stresses and hence increase the fatigue life of the component [10, 11].

2. Experimental details

AISI 1020 steel has been used in this study and its chemical composition is tabulated in Table 1. The specimens were normalized at 920 °C for 25 minutes, and then cooled in air. For the plasma nitrocarburizing process, the specimens were placed into the plasma nitrocarburizing chamber after cleaning with alcohol. Chamber was evacuated to 2.5 Pa. Prior to the plasma nitrocarburizing, the specimens were put subject to cleaning by hydrogen sputtering for 15 minutes under a voltage of 500 V and a pressure of 5×10^2 Pa to remove surface contaminates. The plasma nitrocarburizing process of AISI 1020 steel was performed under process parameter times of 1, 4 and 12 h, temperatures of 500, 570 and 640 °C and gas mixtures of $47.5\%N_2+47.5\%H_2+5\%CO_2$, $49\%N_2+49\%H_2+2\%CO_2$ and $50\%N_2+50\%H_2$ (nitriding).

After the surface treatments, the thin compound layer formed on the surface was removed by polish-

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Table 1. Chemical composition of AISI 1020 steel (wt.%)

Element	C	Mn	S	P	Si	Cr	Mo	Ni	Cu	W
(wt.%)	0.18	0.54	0.051	0.019	0.27	0.08	0.010	0.05	0.026	0.031

Table 2. Experimental results obtained after plasma nitrocarburizing of AISI 1020

Process parameters			Experimental results			
Temperature (℃)	Time (h)	Gas mixture	Surface hardness) (HV 0.05)	Compound layer (μm)	Diffusion layer (μm)	Fatigue limit (MPa)
500	4	C	300–340	13–15	160–180	465
500	4	A	250–290	12–14	120–140	455
570	1	A	300–340	15–17	80–100	452
	4	A	370–410	17–20	130–150	492
	4	B	360–400	16–19	100–120	464
	12	A	350–390	16–18	160–180	498
640	4	A	360–400	18–20	190–210	468
untreated	–		183	–		315

A: 49%N_2+49%H_2+2%CO_2 B: 47.5%N_2+47.5%H_2+5%CO_2 C: 50%N_2+50%H_2 (Nitriding)

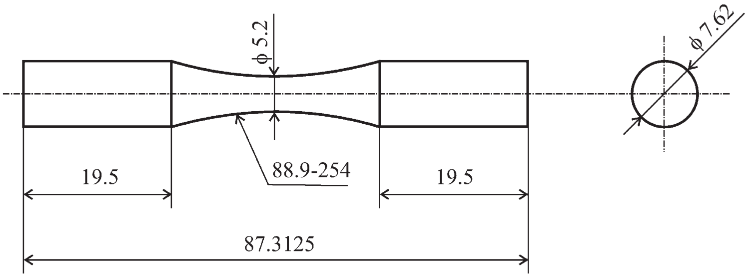

Fig. 1. Rotating bending fatigue test specimen dimensions (in mm).

ing prior to metallographic examination and hardness testing. The hardness distribution was measured by using a Buhler 1600-4980T instrument at a constant load of 50 g and a loading time of 15 s. The surface hardness at 25 μm depth was chosen for comparison so that any possible effects from one of the compound layers would be negligible [12]. The treated specimens were etched in 2 % nital solution after polishing in order to measure the compound layer thickness. Then, the compound layer thickness was examined by using optical microscopy of microhardness instrument. The diffusion layer is defined as the depth at which the hardness is 10 % HV above the core hardness [13].

Fatigue strength was determined using a rotating bending fatigue machine. The geometry of specimens that were used for fatigue testing is shown in Fig. 1. Rotating bending fatigue tests were performed at 6000 rpm in laboratory air atmosphere and carried out until the complete failure of specimens. The machine was provided with a digital counter that showed the number of load cycles endured by the test specimen. The fatigue test machine stopped automatically as soon as the specimen failure occurred. 26 specimens were used to determine the S-N curve for plasma nitrocarburized and untreated specimens; i.e. 15 specimens for the fatigue life (3 specimens at each of five levels of stress amplitude), and 11 specimens for the finite fatigue life region. The staircase method was employed to determine fatigue strength. In each test, the number of cycles to fatigue failure was noted on semi-log (S, log N) graphs. The fracture surface was examined by a SEM.

3. Results and discussion

The experimental results obtained after plasma nitrocarburizing of AISI 1020 steel are given in Table 2. While the surface hardness of untreated specimens was measured as 183 HV 0.05, the hardness values

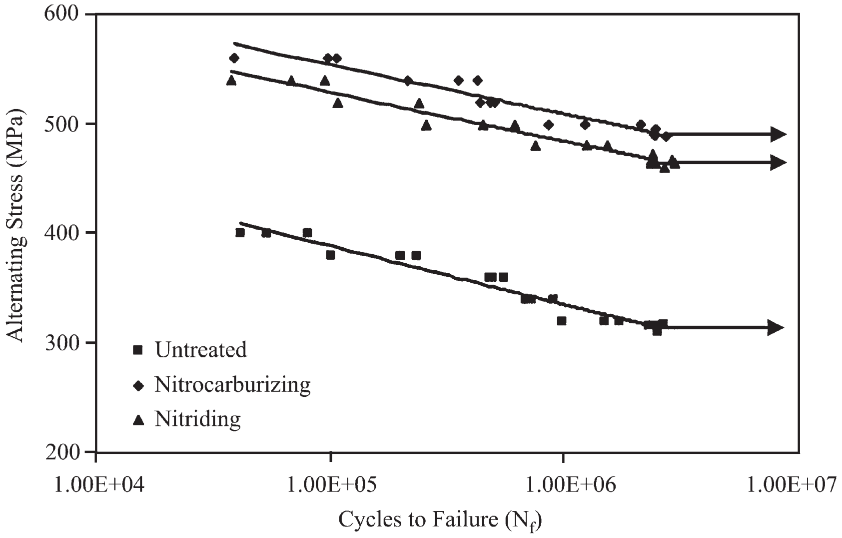

Fig. 2. The *S-N* curves of untreated, plasma nitrided (500 ℃, 4 h) and plasma nitrocarburized (570 ℃, 4 h) specimens.

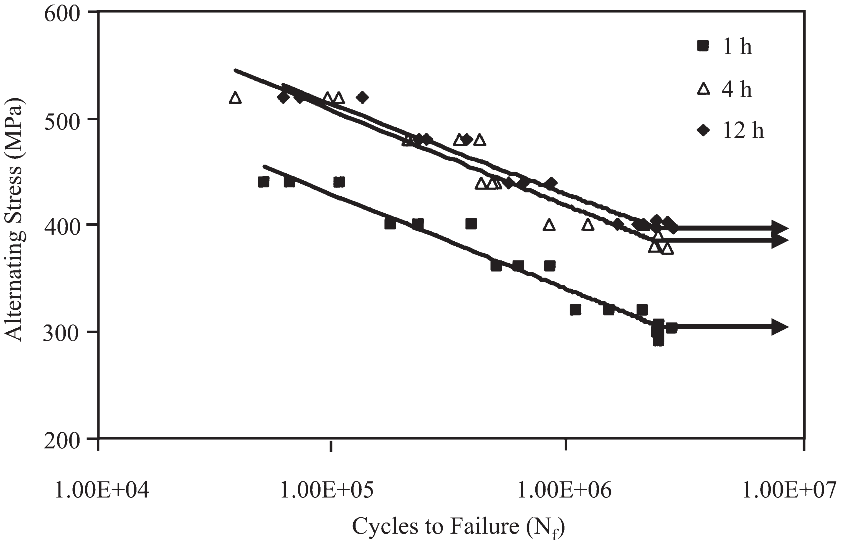

Fig. 3. The *S-N* curves of plasma nitrocarburized specimens for different treatment times and at 570 ℃ temperature.

increased approximately two-fold after nitrocarburizing depending on process parameters. It was seen that compound and diffusion layer thickness increased as treatment time and temperature increased.

The *S-N* curves of untreated, ferritic plasma nitrocarburized at 570 ℃ for 4 h and plasma nitrided at 500 ℃ for 4 h specimens are given in Fig. 2. The fatigue strength of the AISI 1020 steel specimens improved after both of the surface treatments. It was determined less increment in the fatigue strength of the AISI 1020 steel after nitriding in comparison with nitrocarburized specimens because of consisting insufficient alloying elements for nitriding of AISI 1020 steel. This is due to performing of the nitriding at a lower temperature than plasma nitrocarburizing, because process temperature is the most significant parameter affecting the diffusion.

The *S-N* curves in Fig. 3 show the effect of treatment time on the fatigue strength of nitrocarburized AISI 1020 steel. It was observed that the fatigue strength increased with the increase in the treatment time. But, it was seen that improvement of the fatigue strength was almost the same with treatment times longer than 4 h. This is due to limited change of diffusion layer thickness.

The effect of the treatment temperature has been investigated and obtained *S-N* curves are given in Fig. 4. It was observed that the fatigue strength increased as the treatment temperature increased. However, it was determined that the fatigue strength for the specimen nitrocarburized at 640 ℃ decreased in

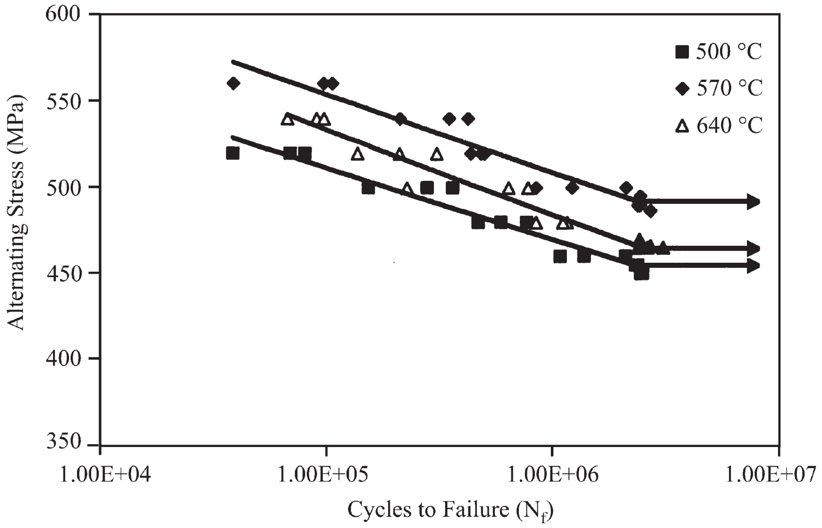

Fig. 4. The *S-N* curves of plasma nitrocarburized specimens, at different treatment temperatures for 4 h.

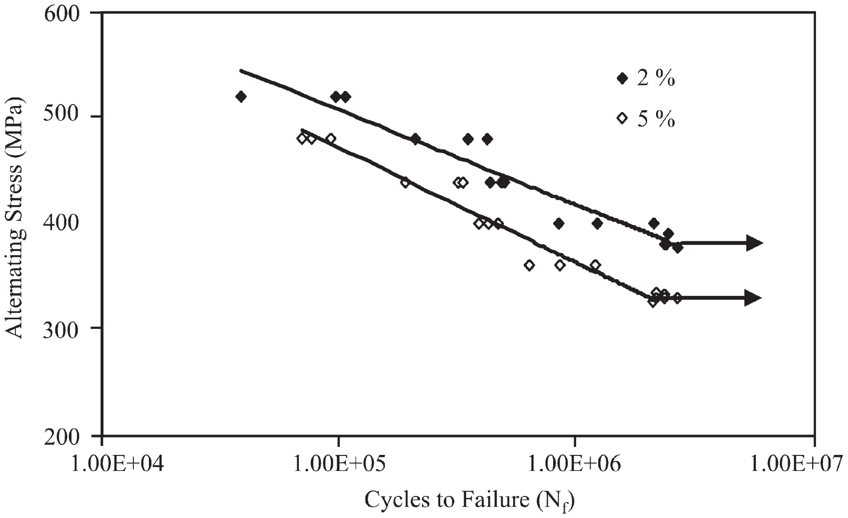

Fig. 5. The *S-N* curves of plasma nitrocarburized specimens, at 570 ℃, for 4 h and at different CO_2 ratios.

comparison with the nitrocarburized one at 570 ℃. This result can be explained with limited change of diffusion layer thickness and tempering effect at 640 ℃. In addition, the compound layer that was formed at 640 ℃ may have easily caused the nucleation of the fatigue crack, because the compound layer formed at 640 ℃ was thicker and included more porous structure.

Figure 5 shows the effect of different CO_2 ratios in gas mixture on the fatigue strength. Increasing the CO_2 ratios in the gas mixture has a negative effect on the fatigue properties of the specimens. This negative effect is due to the fact that diffusion layer thickness decreases with increasing CO_2 ratios in the gas mixture.

Figure 6 shows SEM micrographs of the fracture surface and their details of the specimen nitrocarburized at 570 ℃ and for 12 h. As seen in Fig. 6a, the fatigue crack initiated from point *A* and beach marks were also observed. After the fatigue crack reached a certain length, the cross-section did not endure the applied load and the final fracture occurred on point *B* by cracking compound layer. Detailed SEM micrographs of the fatigue crack initiation and the region of final fracture in the compound layer are given in Fig. 6b,c, respectively. The sign of radial lines of the brittle fracture was observed in the region of the final fracture near the surface.

4. Conclusions

The effect of plasma nitrocarburizing on the fatigue properties of AISI 1020 steel was investigated

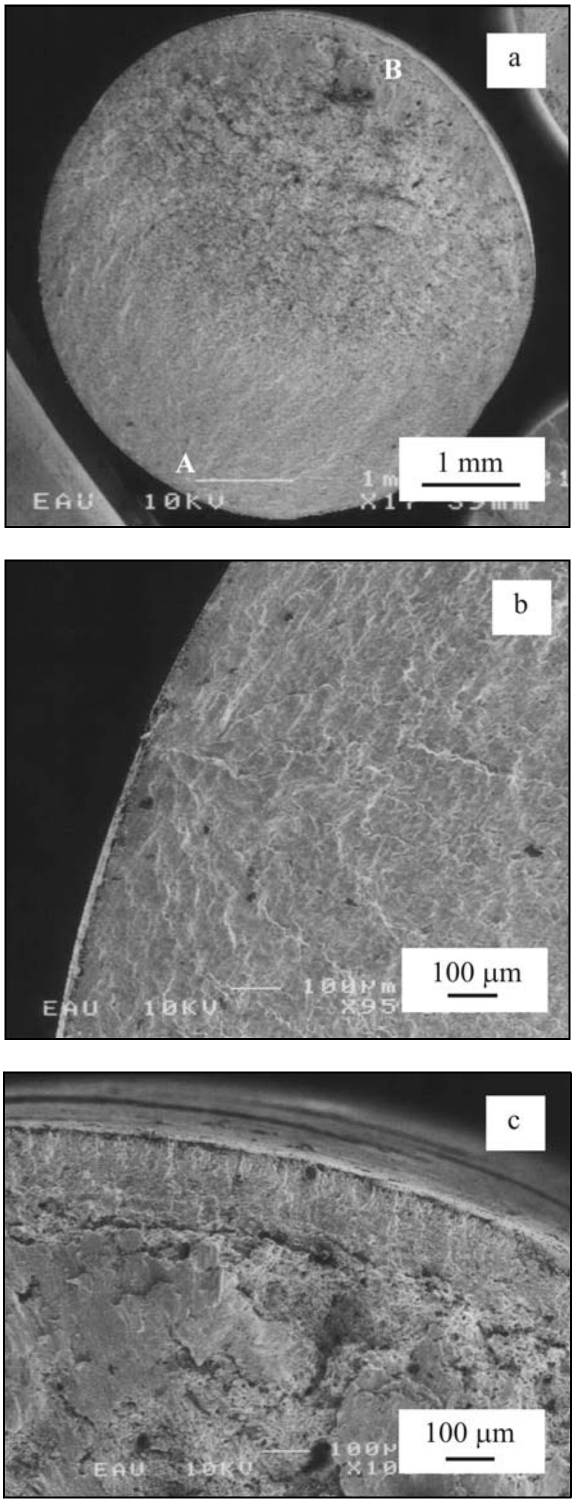

Fig. 6a,b,c. SEM micrographs of the nitrocarburized AISI 1020 steel for 12 h ($\sigma = 460$ MPa, $N = 257.000$ cycles).

by using different treatment temperatures, times and gas mixtures and the following results were obtained:

– The surface hardness of plasma nitrocarburized specimens increased about two times in comparison with untreated ones.

– It was seen that the fatigue strength of the specimens improved after both plasma nitriding and plasma nitrocarburizing treatment.

– Fatigue strength and fatigue limit increased as the treatment time increased and decreased with growing CO_2 ratios. They depend on the treatment temperature. Their maximum was obtained at 570 ℃.

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