Effect of Shot Peening on Delayed Fracture of High Strength Steel

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Abstract

A study has been made on the effect of shot peening on delayed fracture susceptibility of high strength steel at a level of 1300MPa and 1400MPa. By means of bending type testing, It was confirmed that the delayed fracture resistance improves due to an increase in compressive residual stress by shot peening. Further study indicates that the increased resistance to delayed fracture of shot peened specimens is caused mainly by the prolonged incubation period to crack initiation.

KEY WORDS : Delayed fracture, Shot peening, Residual stress, High strength steel

INTRODUCTION

In recent years, automotive structural parts have become compact in accordance with strong demands for light weight. Several investigations have been carried out to develop high strength structural steels for threaded fasteners. It has been generally recognized, however, that the high strength steel is susceptible to the delayed fracture when heat treated to a strength level higher than 1200MPa [1]. Delayed fracture, which is defined as one of the hydrogen embrittlement failures, is phenomenon in which the machine parts fail abruptly when sustained under the static tension. Consequently the improvement of the delayed fracture resistance is one of the essential problems in the development of high strength bolt steels [2][3].

A study was made on the effect of shot peening on delayed fracture of high strength steel at a level of 1300MPa and 1400 MPa. To investigate this effect, three types shots, having different hardness and mean diameter, were prepared to make the different residual stress distribution in bending type specimen. Using these shots, specimens were peened by an air type shot peening device.

It was confirmed that the delayed fracture resistance of each peened specimen was improved compared with those of as quenched and tempered specimens due to an increase in compressive residual stress. By measuring the displacement of moment arm on the testing equipment, it was found that this result was caused mainly by a prolonged incubation period to crack initiation, the reason of which would be that the compressive residual defended hydrogen entry in metal.

EXPERIMENTAL PROCEDURES

The chemical composition of test steel made of JIS SCM435 is shown in Table 1. Normalizing was carried out by holding at 900 ℃ for 2 h followed by air cooling. Roughly machined specimens were austenitized at 850 ℃ for 30 min and oil quenched. Tempering treatments were performed at 400 ℃ and 440 ℃ for 1 h to obtain the strength level of 1300MPa and 1400MPa, respectively. Finally, machine finishing was carried out. Table 2 shows mechanical properties at each strength specimens.

The geometry of the delayed fracture test specimens and the testing method are shown in Fig. 1. The bending moment was applied by the dead weight sustained at the extended end of the test piece in a cantilever type testing device. The test solution, 0.1N HCl, was dropped on the notched part of the specimen with a feeding rate of 16cc per minute. The delayed fracture curve was obtained by plotting the time to fracture against the applied stress to evaluate the delayed fracture resistance.

Shot peening were carried out by air type peening device using three different shot media. Type 1 was shot hardness of HV 550 and shot diameter of 150μm called Shot A, type 2 was HV 800 and 150μm called Shot B, type 3 was HV 800 and 90μm called Shot C. Air pressure was 0.2MPa and peening time was 10 min. The surface residual stress of specimens after shot peening was measured by X-ray diffractmeter with 2θ - $\sin^2\Psi$ method. Stress distribution was obtained by repeating the X-ray measurement and electrochemical polishing successively.

Table 1. Chemical composition (wt%)

C	Si	Mn	P	S	Cu	Ni	Cr	Mo
0.38	0.21	0.80	0.026	0.010	0.11	0.06	1.02	0.16

Table 2. Mechanical properties

Tempered temperature (℃)	0.2% proof stress $\sigma_{0.2}$ (MPa)	Tensile strength σ_B (MPa)	Elongation δ (%)	Reduction of area ϕ (%)
400	1313	1411	16	50
440	1225	1298	18	56

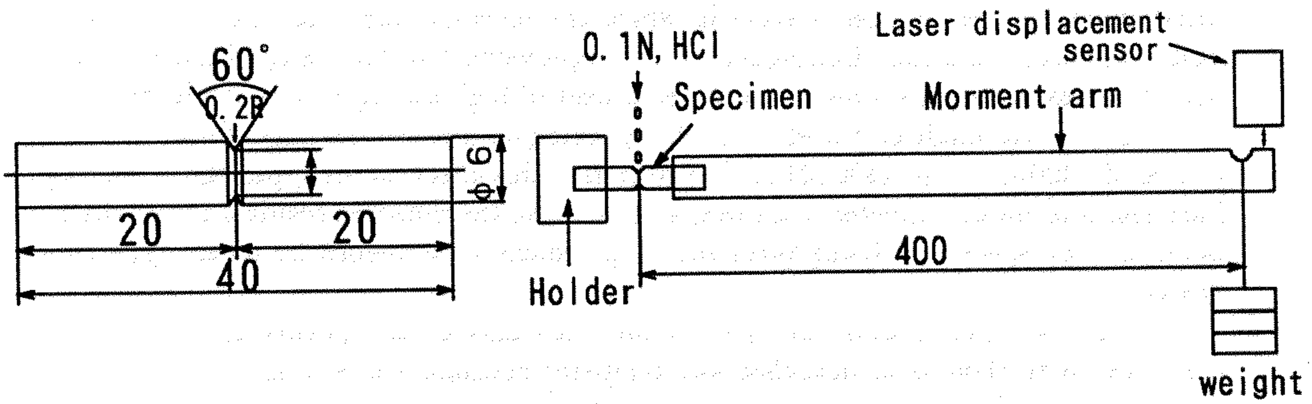

Fig. 1. Specimens geometry and testing device

RESULTS

Fig. 2 shows residual stress distribution of both strength specimens after shot peening. As compared to as tempered specimens, shot peening increases the maximum compressive residual stress value by 450MPa to 600MPa, which results in about 350MPa increase. The change of profiles by shot peening was observed to the depth of about 100μm. At the specimens in a

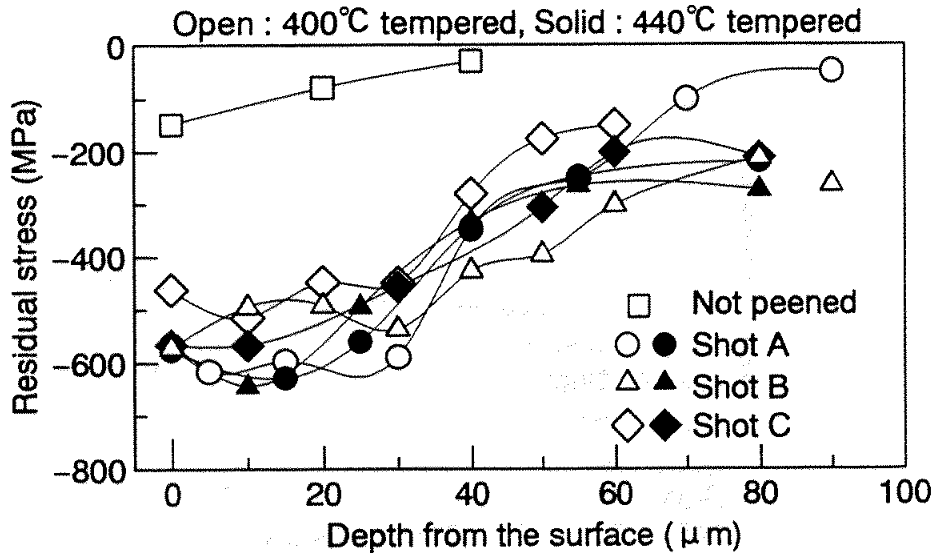

Fig. 2. Residual stress distribution of specimens

strength level of 1400MPa, it was confirmed that the maximum compressive stress and the magnitude of stressed layer peened with shot A and shot B is higher and deeper that that peened with shot C. However, at low strength specimens, same residual stress profiles were obtained by even peened with shot C.

Fig. 3 and Fig. 4 show the delayed fracture diagram of as tempered specimens and shot peened specimens at a strength level of 1400MPa and 1300MPa. These specimens at each strength level exhibit the same static bending strength respectively, 4250MPa for specimens at the strength level of 1400MPa, 4180MPa for 1300MPa. At both strength specimens, shot peened specimens fail after much longer loading time than as tempered specimen, and at same loading time, the former withstand a higher applied stress than the latter. So it was confirmed that shot peening treatment improve the delayed fracture resistance. By the way, the delayed fracture strength of the specimens peened with shot A and shot B were higher than that peened with shot C especially at the strength level of 1400MPa. It is explained that the difference of the results is due to the higher maximum residual stress and deeper stressed layer of peened specimens with shot A and shot B than that of peened with shot C, previously shown in Fig. 2. In the range of loading time longer than 30 hours, however, the superiority of shot peened specimens decrease. It is considered that the reason of this is due to the dissolution of compressive stressed layer by corrosion attack.

Fig. 5 shows the relation between tensile strength and strength ratio (σ_{30h}/σ_{SB}). σ_{SB} means static bending strength of specimens and σ_{30h} means delayed fracture strength in loading time of 30 h that is disappeared the corrosion as mentioned above. At each specimens, the strength ratio decrease with increasing tensile strength as the result of increasing susceptibility of delayed fracture. And at tensile strength level of 1400MPa, the strength ratio of specimens peened with shot A and shot B are higher than two others. This results means that shot peening treatment against delayed fracture is effectual even at high strength steel.

DISCUSSION

In general, the delayed fracture process is composed of three stage, which is the incuba-

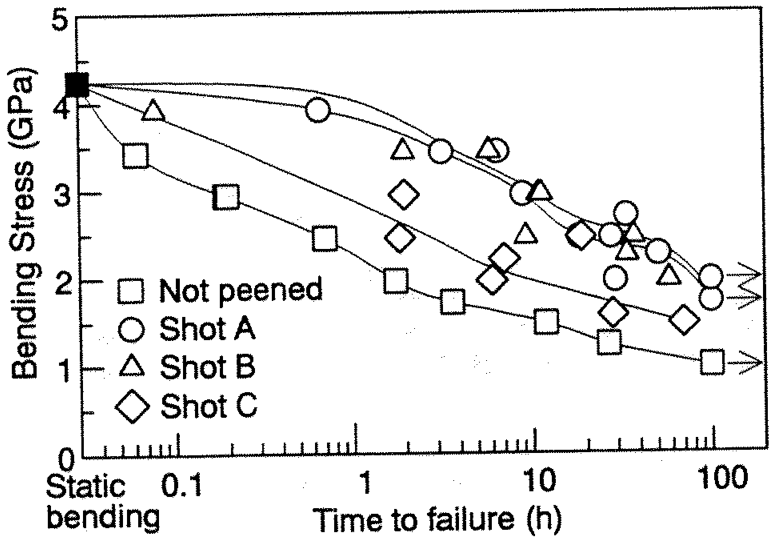

Fig. 3. Delayed fracture diagram of specimens at a strength level of 1400MPa

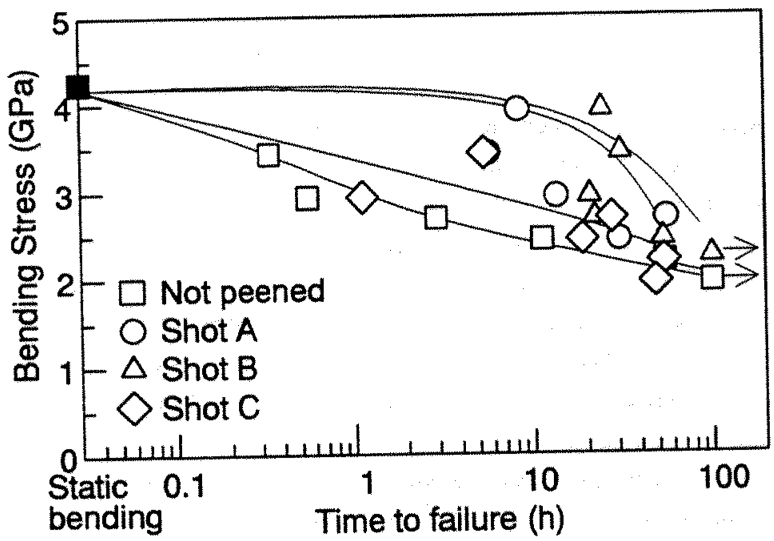

Fig. 4. Delayed fracture diagram of specimens at a strength level of 1300MPa

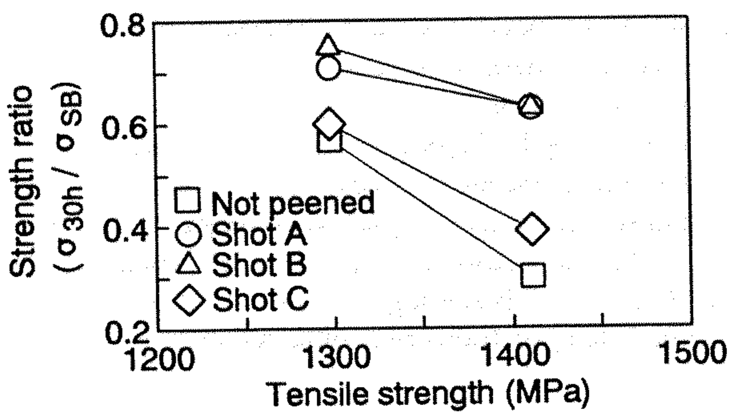

Fig. 5. The relation between tensile strength and strength ratio (σ_{30h}/σ_{SB})

tion period, the crack propagation stage, and the final fracture stage [4]-[6]. Since the delayed fracture test applied in this study is unable to observe crack propagation of specimen at notch root directly, some supplementary investigations, which is reading the change of displacement at the extended end of moment arm by laser displacement sensor, were performed to clarify the effect of shot peening on delayed fracture strength.

Fig. 6 shows the relation between loading time and the displacement of moment arm for the specimens with strength level of 1400MPa at a bending stress of 2450MPa. It was confirmed that the displacement gradually increases with increasing loading time, and then rapidly increase up to failure. And gradually increasing period of peened specimens is 10 to 50 times longer than that of as tempered specimen. Same behavior were obtained at another strength specimens and another bending stress. Here, three stage of the delayed fracture process as mentioned above in this behavior of displacement is considered to be expressed by representation shown in Fig. 7. Namely, incubation period is equivalent to the range of slow increasing displacement. So, test was stopped at proper displacement to examine whether crack is initiated or not. Fig. 8 shows the fracture surface after testing. It was confirmed that crack is not initiated at the range of slow increasing displacement. These results lead to the conclusion that shot peening prolongs the incubation period to crack initiation.

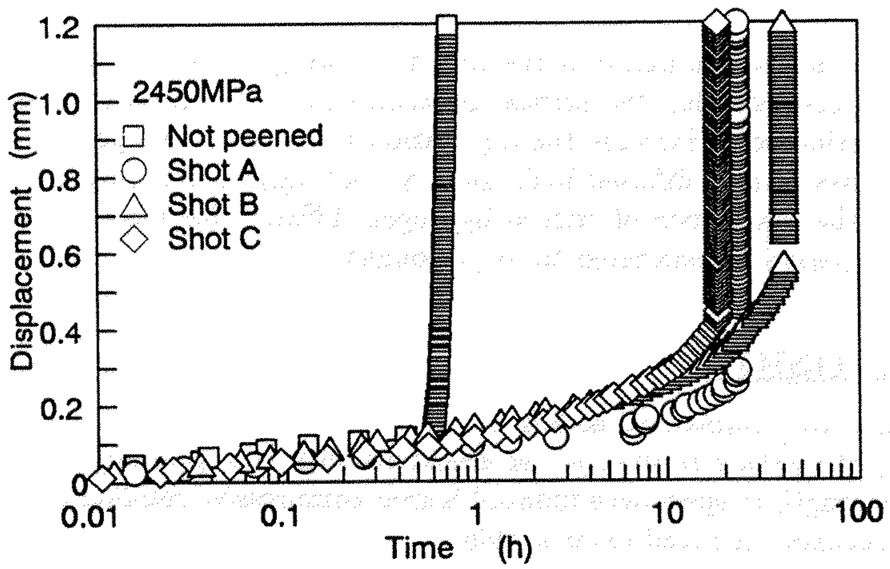

Fig. 6. The relation between loading time and displacement of moment arm at bending stress 2450MPa

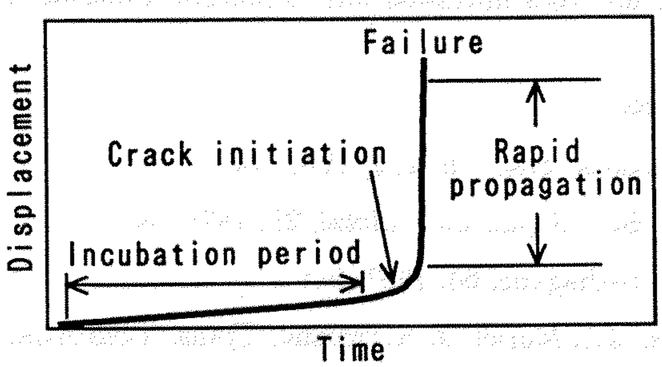

Fig. 7. Representation between loading time and displacement

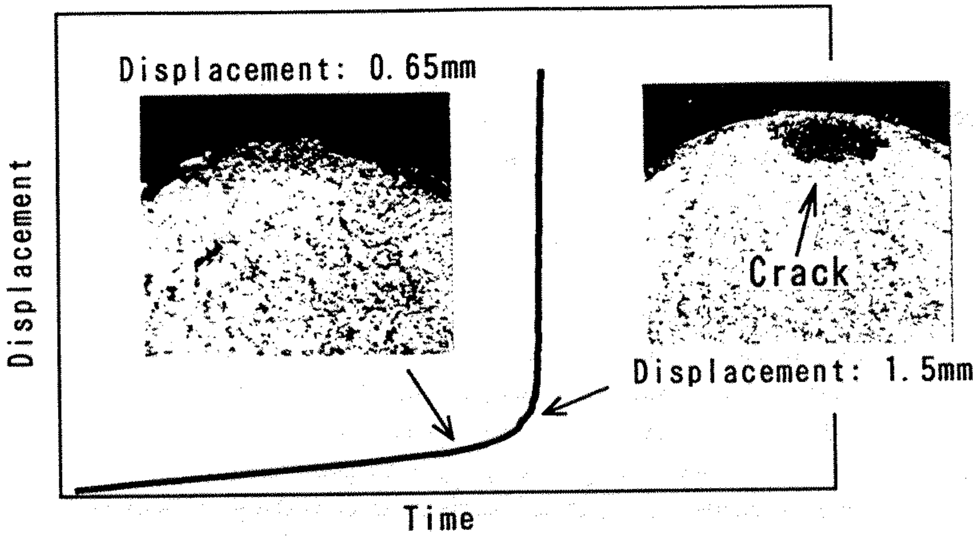

Fig. 8. Photomicrogragh of crack initiation for the specimen with strength level 1400MPa and bending stress 2450MPa

The incubation period is the time for hydrogen which is absorbed from atmosphere to diffuse and then develop the critical concentration. On the other hand, shot peening treatment is considered to increase the dislocation at the surface layer. And increased dislocation has properties to trap diffused hydrogen. Accordingly, it is concluded that in the shot peened specimens the magnitude of critical hydrogen diffusion for crack initiation decrease, and the incubation period is considered to be prolonged.

CONCLUSIONS

Test results are summarized as follows;
(1) Delayed fracture resistance was enhanced with shot peening treatment. And the delayed fracture strength of specimens induced higher compressive residual stress profile is higher than that of specimens induced lower profile.
(2) Further study measuring the displacement of extended end of moment arm indicated that the increased delayed fracture resistance by shot peening is mainly caused by the prolonged incubation time for crack initiation due to increased dislocation trapping diffused hydrogen.

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