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Effect of Ultrasonic Shot Peening on Fatigue Strength of High Strength Steel

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Abstract

A study had been made to evaluate the effect of the Ultrasonic shot peening treatment, developed by SONATS, on fatigue strength. This new shot treatment could give the smooth surface after shot peening because of using the polished ball bearings. To investigate the effect and the merit of new treatment, fatigue test were conducted on cantilever type rotating bending fatigue testing machine. It was confirmed that fatigue strength peened by ultrasonic shot treatment is almost the same as that peened by conventional air peening device. Further, mechanism of the fracture was confirmed between roughed specimens by conventional peening and the smooth one by ultrasonic peening.

Key words : Ultrasonic Shot Peening, twofold S-N curve, fish-eye, inclusion, ultra-high-cycle fatigue

1 Introduction

In general, there are two different mechanism of the fracture at the twofold S-N curve in high strength steel, namely surface related initiation in high applied stress region and subsurface crack initiation with a fish eye in low stress region. Further, the fracture mechanism is affected by the surface situation, such as roughness and hardness, etc. On the other hand, shot peening treatment is widely recognized as the one of the method to enhance the fatigue durability by compressive residual stress. However, the fatigue behavior of shot peened high strength steel, which has roughened surface after treatment, is expected to indicate the same twofold S-N curves. Recently, new Ultrasonic Shot Peening, named Stressonic® technology[(1)], was developed by SONATS, France. The mainly characteristic of Stressonic® could give the smooth surface after operating compared to the conventional shot peening because of using polished bearing ball. So, in this study, fatigue test were conducted on cantilever type rotating bending fatigue testing machine to confirm the effect of Stressonic® on fatigue strength and the merit of operating the Stressonic® compared to the conventional one. Further, this paper describes the influence of shot peening in ultra high cycle fatigue regime.

2 Experimental procedures

The chemical composition of test specimens made of JIS SNCM439 is shown in Table 1.

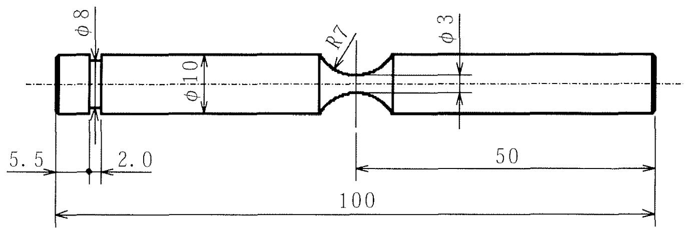
Table 1. Chemical composition (wt%)

C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Fe
0.4	**0.22**	**0.78**	**0.02**	**0.013**	**0.18**	**1.78**	**0.83**	**0.2**	**Bal.**

Table 2. Mechanical properties

Tensile strength $\sigma_B(MPa)$	Elongation $\sigma(\%)$	Reduction of area $\phi(\%)$	0.2% proof stress $\sigma_{0.2}(MPa)$
2274	4	39	1515

Figure 1. Geometry of specimen



Roughly Machines specimens were austenitized at 850°*C* for 60 min and oil quenched. Tempering treatment was performed at 620°*C* for 120 min. Table 2 shows the mechanical properties of specimens after heat treatment. After heat treatment, specimens were polished by grinder to improve the surface roughened by machining. The geometry of specimen is shown in Figure 1. Fatigue tests were conducted by cantilever type rotating bending fatigue testing machine of 3,150 r.p.m. in cyclic speed in laboratory atmosphere. 10^9 cycles were taken as limiting number for evaluation of fatigue properties. The characteristic of the very high cycle fatigue property should be twofold S-N curves: the one for surface fatigue and the other for internal fatigue[(2)]. There are two fatigue limits: the surface fatigue limit, σ_{ws} and the internal fatigue limit, σ_{wi} although the latter has not yet observed clearly. The surface fatigue life is shorter than the internal fatigue life. In this study, we evaluate the both fatigue limit to evaluate the effect of Ultrasonic treatment.

Shot peening was carried out by Stressonic® and conventional air peening device using three kinds of shot media, bearing ball, tungsten carbide and conditioned cut wire. Figure 2 shows the schematic illustration of Stressonic® process and the appearance of treatment to specimens. A piezo-electric transducer emits the ultrasonic wave at 20 kHz. The waves are amplified when they travel through an acoustic booster, in a housing which contains the parts to be treated and the shot. The shot strike the vibrating walls and are reflected off the surface. Then they collide with one another. The balls are scattered randomly throughout their encasing. A homogeneous treatment is then obtained on the surface of casing. At this study, the amplitude of sonotrode was 90 micrometer. Table 3 (a) and (b) shows the shot peening conditions. Here, shot peening time were decided to obtain 100% coverage at ultrasonic shot peening and 300% coverage for air shot peening. The hardness, density and diameter of each shot media are also shown in Table 3.

Table 3 (a). Shot peening conditions on Stressonic®

Type of shot media	The ball bearing (SUJ2)	Tungsten carbide ball (WC)
Density (g/mm^3)	7.86	17.5
Diameter (mm)	0.82	0.86
Hardness (HV)	HV1000	HV1500
Distance between spec. and Sonotrode	20mm	20mm
Amplitude of Sonotrode	90 μm	90 μm
Frequency	20kHz	20kHz
Rotating speed of specimen	12r.p.m.	12r.p.m.
Quantity of media (g/sonotrode)	4.2g	7.3g
Peening time(100% coverage)	90sec	90sec
Arc height (mmA)	0.21mmA	0.26mmA

Table 3 (b). Shot peening conditions on air type peening device

Type of shot media	Rounded cut wire shot (RCW)
Density (g/mm^3)	7.86
Diameter (mm)	0.88mm
Hardness (HV)	HV700
Air pressure (MPa)	0.25
Distance between nozzle and spec.	160mm
Rotating speed of specimen	12r.p.m.
Quantity of shot media	4,750g/30sec
Peening time (300% coverage)	30sec
Arc height (mmA)	0.483mmA

Figure 2. Appearance and illustration of Stressonic® treatment

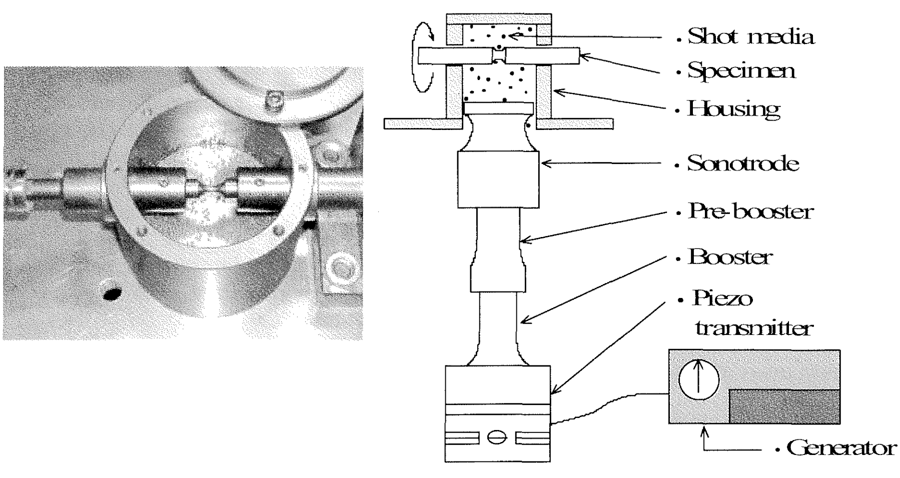
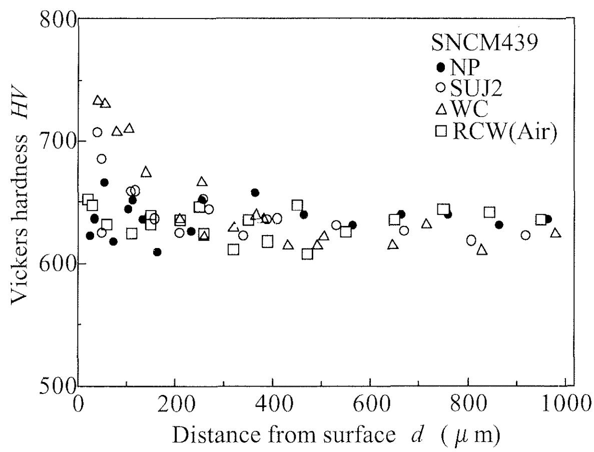


Table 4. Surface roughness (μm)

Treatment	Media	Ra	Ry	Rz
Stressonic	SUJ2	0.45	3.46	2.41
	WC	0.75	5.30	4.23
Air	RCW	0.93	7.55	5.74

Figure 3. Hardness distribution



3 Results

3.1 Surface roughness and hardness distribution

Table 4 shows surface roughness after shot peening treatment. Surface roughness of specimens peened by Stressonic® was smaller than that by conventional air peening. The reason of this results was considered that the shot velocity on Stressonic® is lower compared to air type and the surface conditions of SUJ2 and WC, which used for ultrasonic, are much better than RCW for air type. SUJ2 and WC ball were polished to get smooth surface because of the purpose of usage. On the other hand, roughness of WC was bigger than that of SUJ2 because of different density and hardness.

Figure 3 shows hardness distribution for the specimens after each shot peening treatment. In case of using WC ball at Stressonic®, the increase of 100HV was observed compared to non-peened specimen. At the comparison between the both treatment, increase by conventional was smaller than ultrasonic. It is explained that the difference of the results is due to the higher hardness of WC and SUJ2 than that of Rounded cut wire.

3.2 Residual stress distribution

Figure 4 shows residual stress distribution for specimens peened by both shot. The residual stresses were determined by X-ray diffractometer with $\sin^2\psi$- method. The residual stress distribution was obtained by repeating the X-ray measurement and electrochemical polishing

Figure 4. Residual stress distribution

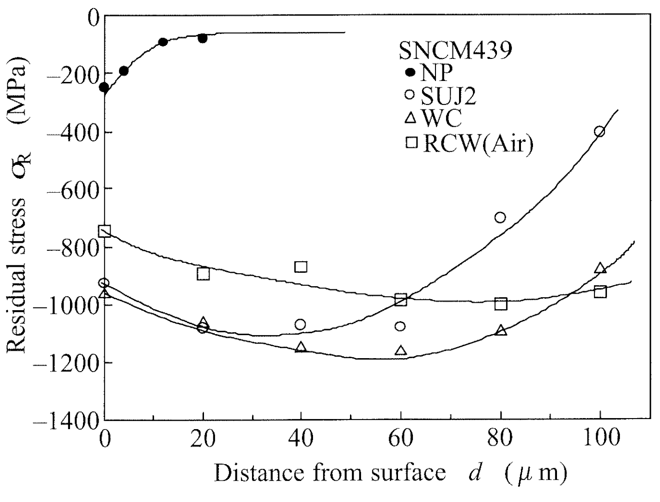
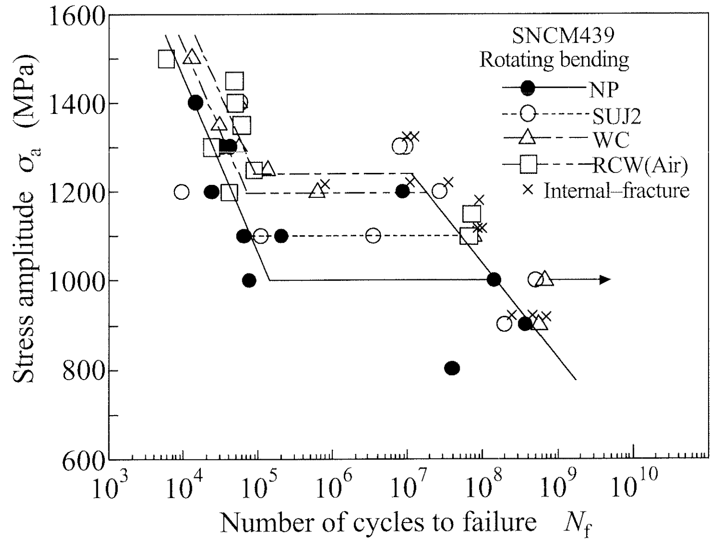


Figure 5. Influence of shot peening treatment on fatigue properties of SNCM439



successively. No difference was observed between WC on Stressonic® and RCW on conventional type in the depth direction. However, surface value of conventional type was lower than that of WC. Further, at Stressonic® process, compressive residual stress of WC was much higher than SUJ2. As the same results of hardness, this is derived from the difference in hardness and density.

3.2 Fatigue test

Figure 5 shows the S-N curve for the each shot peened specimens. The results of non-peened specimens are also shown. In this figure, (×) means that specimens failed from the internal crack. The fatigue properties of every shot peened specimens were higher than that of non-peened specimens at the surface fatigue limit, σ_{ws}. However, there were no difference at the internal fatigue, σ_{wi}. The reason of this result was considered that the depth of internal crack initiation site is deeper than compressive residual stress layer.

(1) On the other hand, the surface fatigue limit of WC shot by Stressonic® was raised up to 1250MPa and highest in all of another treatment. The reason of this result is considered that the surface roughness of WC was better than that of specimen peened by RCW and residual stress profile at both treatments was almost the same, as mentioned before. As the results, new technology, Stressonic®, is useful and is expected to be alternate treatment as the method to enhance the fatigue durability without surface roughened. In addition, this technology should contribute to improvement of environment because of quite small quantity of ball usage as shown in Table 3.

4 Conclusions

In the present study, to confirm the effect of ultrasonic shot peening treatment, Stressonic®, on fatigue properties, fatigue test were conducted by cantilever rotating bending fatigue machine by using several shot peening conditions.

Following is a summary of the results obtained;

(2) Surface roughness of specimens peened by Stressonic® was smaller than that peened by conventional air type treatment. And almost the same residual stress profile was observed between Tungsten carbide ball (WC) on Stressonic® and Rounded cut wire shot (RCW) on conventional peening.

(3) The surface fatigue limit of WC shot by Stressonic® was raised up to 1250MPa and highest in all of another treatment. New technology, Stressonic®, is useful and is expected to be alternate treatment as the method to enhance the fatigue durability without surface roughened. In addition, this technology should contribute to improvement of environment because of quite small quantity of ball usage.

5 References

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