Improvement of bending fatigue limit by cavitation peening for carbon steel specimens containing an artificial surface defect

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ABSTRACT

It is well known that surface defects such as surface cracks and non-metallic inclusions are decreased the fatigue strength of vehicle parts. However, the study on overcoming the surface defects by using surface refining methods is hardly reported.

The cavitation peening (CP) method is in the limelight as a new possible surface refining method, which is a shot-less peening method and increases compressive residual stress. On studying the effects of the CP to the defects, the authors conducted an experiment using the two types of specimens with an artificial semi-circular slit, whose slit diameter (2a)=0.08, 0.15 and 0.20mm on the surface of specimens, and evaluated their refined surface characteristics and fatigue limits. The results obtained are: 2a of the acceptable defect with the smooth and that with notched specimens were 0.08 and 0.15mm, respectively.

Key Word: Fatigue, Cavitation, Peening, Steel, Defect, Residual stress

INTRODUCTION

The market demands for the environmental and fuel economy expectations of vehicles have increased. Under this circumstance, vehicle companies are directing their efforts toward improving the fatigue strength of the component parts. For this purpose, overcoming the surface defects such as surface cracks and non-metallic inclusions is a top priority. As one of the techniques to overcome the defects, there is a Shot Peening method [K.Takahashi,2007]. However, this technique has the possibility that the surface roughness deteriorates.

The cavitation peening (CP) method is in the limelight as a new possible surface refining method, which is a shot-less peening method and is hardly changed the surface roughness. Therefore, for studying the effects of the CP to the surface defects, an experiment using the two types of specimens with an artificial semi-circular slit on the surface of specimens was conducted and their refined surface characteristics and fatigue limits were evaluated. (Then, the influences of CP on the defects were analyzed.)

EXPERIMENTAL METHOD

The specimens in this study were made of JIS S50C, whose main chemical composition is: 0.50%C-0.30%Si-0.79%Mn. Fig.1 shows the manufacturing process of specimens. The geometries and dimensions of the smooth and notched specimens are shown in Fig. 2. After being machined to the shape without slit as shown in Fig.2, these specimens were induction hardened and tempered. The hardness was approx. 500HV. Then, these specimens were introduced an artificial slit such as surface defect to the central part by the electric discharge method. The slit geometries were semi-circular shapes and the diameters of the slits (2a) were 0.08, 0.15 and 0.20mm.

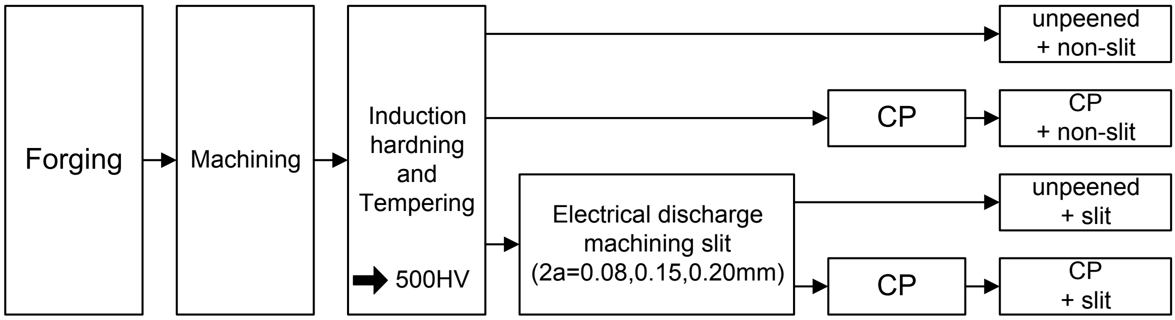


Fig. 1 Flowchart of specimen manufacturing process

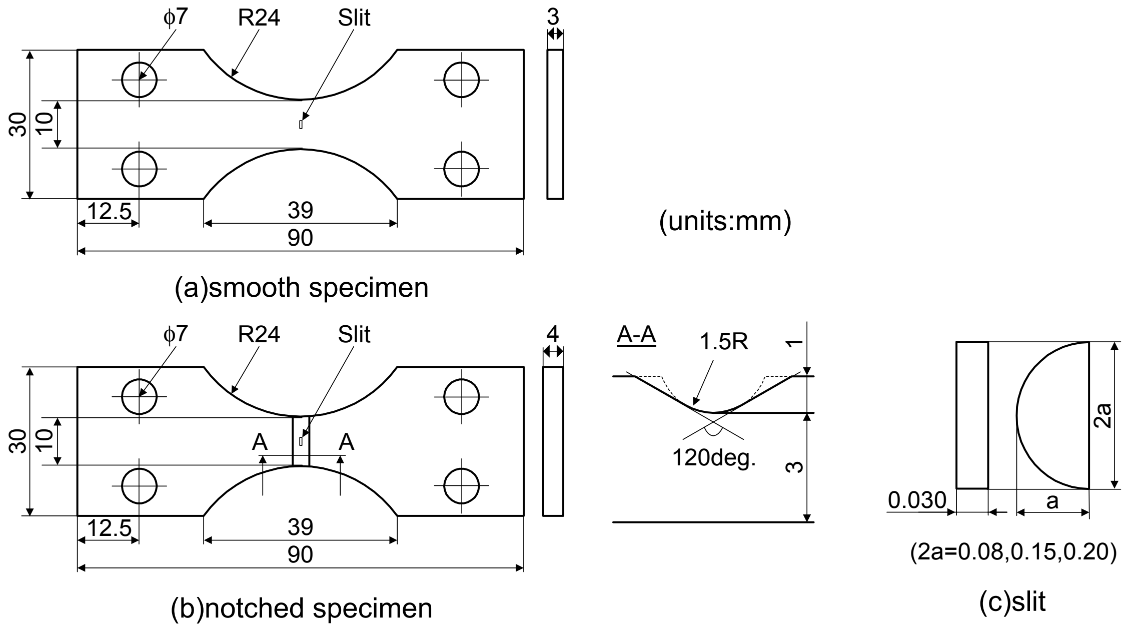


Fig. 2 Schematic illustration of specimens and slit

The CP method was adopted the atmospheric CP method, which was developed by Soyama, et al [H.Soyama, 2001]. The nozzle used for CP was a bipolar system as shown in Fig.3. High and low pressures water jets were ejected from the center and its surrounding nozzles, respectively. The conditions of CP are shown in Table1. Hereafter, the cavitation-peened specimen is called as CP specimen.

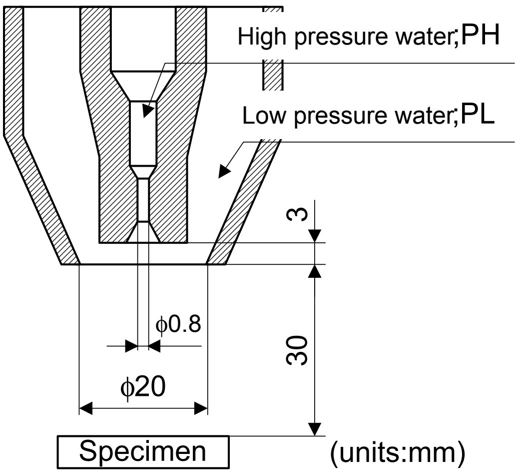


Fig. 3 Schematic diagram of the CP nozzle

Table 1 Cavitation Peening condition

Atmosphere		air
P_H	Nozzle diameter	ϕ 0.8mm
	Pressure	30MPa
P_L	Nozzle diameter	ϕ 20mm
	Pressure	0.21MPa
Standoff distance		30mm
Scanning speed		3.75mm/min, 1pass

Depth profiles of residual stress were investigated for the specimens. The X-ray conditions are: Cr-K_α beam X-ray spectrum and 1.0 mm X-ray beam injection diameter. The surface of specimen was masked with φ3mm window, and was polished to a specified depth using electrolytic polishing method.

The loaded conditions for the bending fatigue tests were: stress ratio(R)=-1, frequency=20Hz, stress wave=sine wave. The fatigue limit was defined for 10^7 cycles.

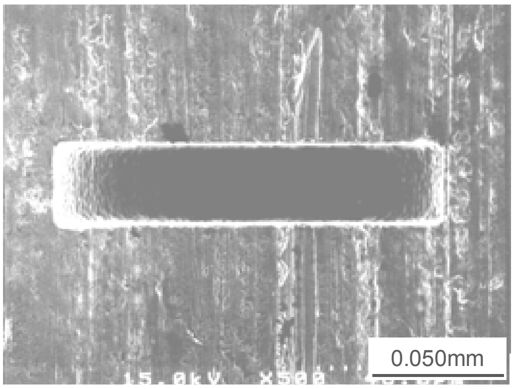
The definitions of acceptable defect were: a) the fatigue limit of the slit specimens is more than that of the non-slit and unpeened specimens. b) The initiation of the fatigue fracture is an area excluding the slit.

RESULTS and CONSIDERATIONS

Figure 4 shows SEM images of the slit on a smooth specimen surface and the surface roughness before and after being CP. From this, it is said that the appearance of surface and surface roughness are hardly changed by CP.

The depth profiles of residual stress are shown in Fig.5. The residual stress of the unpeened specimen was almost zero MPa. On the other hand, the surface compressive residual stress of the smooth CP and that of the notched CP specimens were approx. 750 and 1050MPa, respectively. The depth from the surface to the crossing point, where the residual stress is zero MPa, of each specimen were 0.05 and 0.09mm, respectively.

Slit diameter (2a) =0.15mm



	unpeened	CP
Ra	0.067μm	0.097μm
Rz	0.221μm	0.361μm

Fig. 4 SEM image of slit after CP and surface roughness on specimens

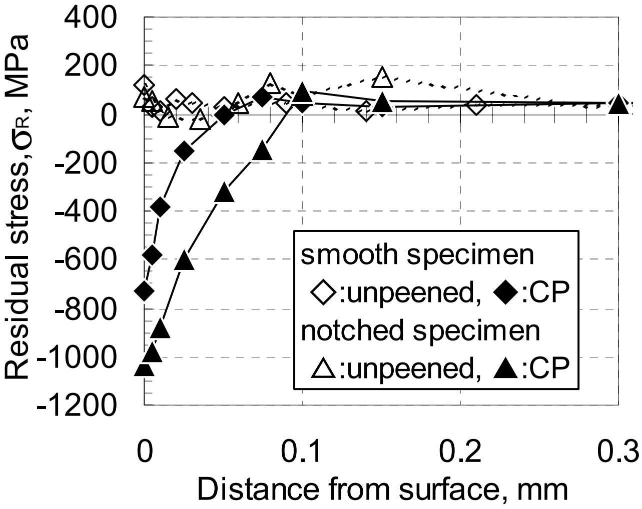


Fig. 5 Distribution of residual stress

Figure 6 shows the fatigue limit ratio of the slit specimens to that of non-slit specimens. In the case of the smooth and non-slit specimens, the fatigue limit of the CP specimens was 33% higher than that of the unpeened. In the case of the notched and non-slit specimens, the fatigue limit of the CP specimens was 25% higher than that of the unpeened. In the case of the notched and slit diameter (2a)=0.15mm specimens, the fatigue limit of the CP specimen was 107% higher than that of the unpeened.

In the case of the smooth unpeened specimens, the fatigue limits of the specimens with the slit diameter(2a)=0.08 and 0.15mm were 11 and 55% lower than that of the non-slit specimens. In the case of the smooth CP specimens, the fatigue limit of the specimens with 2a=0.15mm was less than that of non-slit specimens. Therefore, it is considered that the slit diameter(2a) of the acceptable defect in the smooth CP specimen is 0.08mm.

The fatigue limit of the notched CP specimens with the slit diameter(2a)=0.15mm was 13% more than that of the non-slit specimens. The fatigue limit of the notched CP specimens with the slit diameter(2a)=0.20mm less than that of the non-slit specimens. Fig.7 shows the relation between the slit diameter (2a) and the stress amplitude of the bending fatigue tests. The solid and open marks in the figure are represented the not fractured and fractured specimens, respectively. The maximum stress amplitude of open marks specimens is the fatigue limit. In the case of the notched CP specimens with the slit diameter(2a)=0.15mm, the cracks of some specimens began to propagate from outside the surface of the slit. Therefore, it is considered that the slit diameter(2a) of the acceptable defect in the notched CP specimen is 0.15mm.

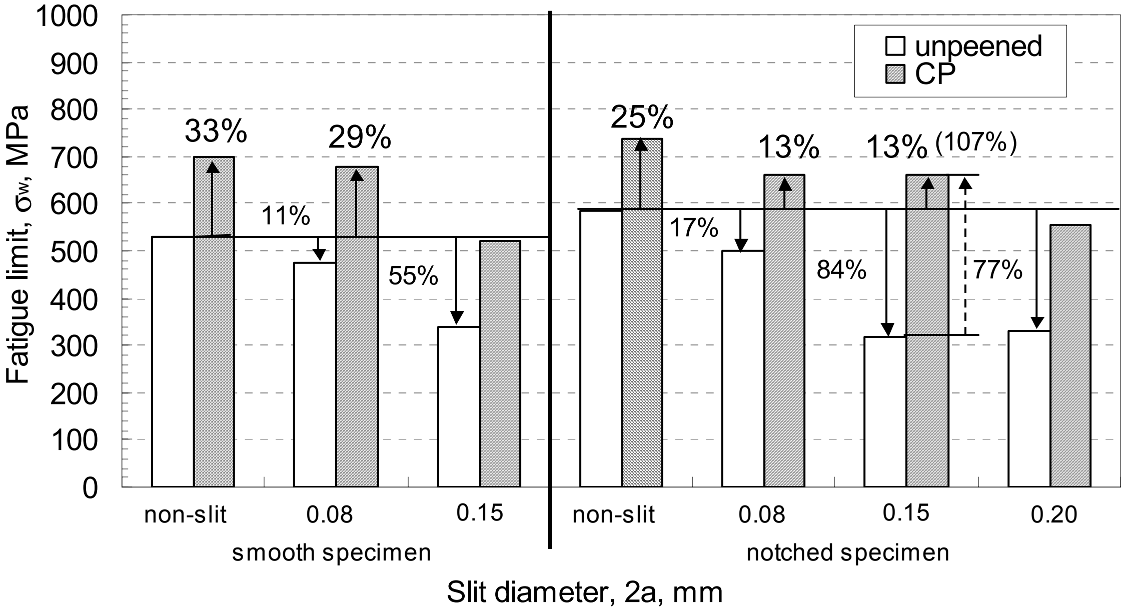


Fig. 6 Improvement ratio of fatigue limit

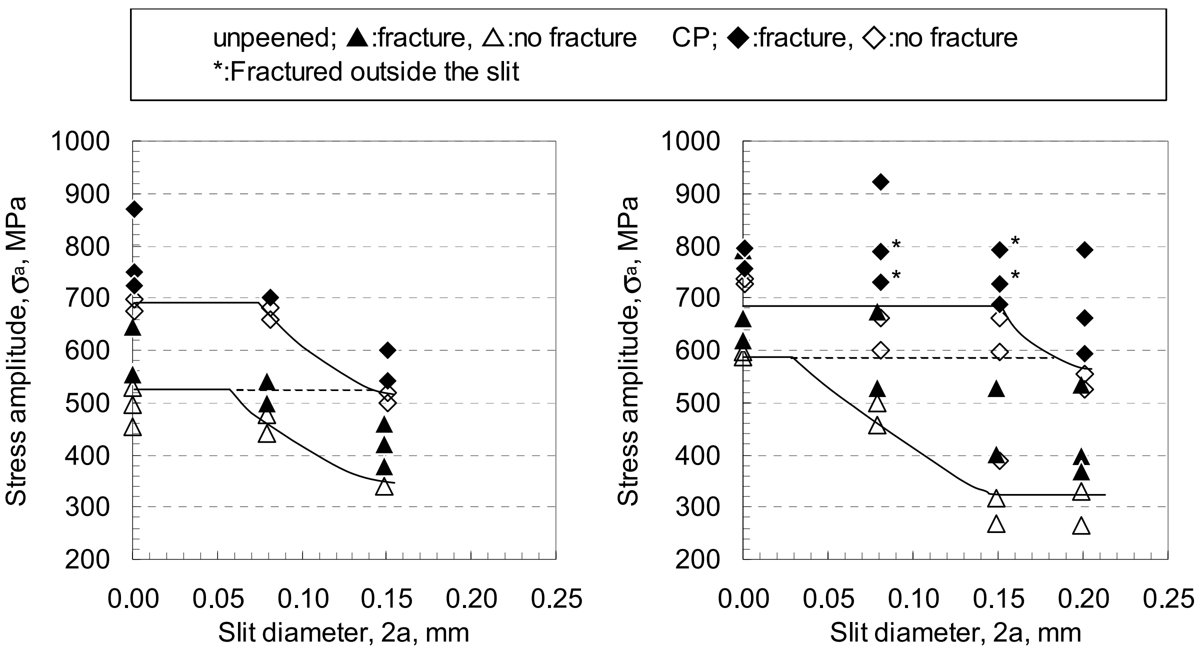


Fig. 7 Relationship between stress amplitude and diameter of semi-circular slit

It was assumed that some non-propagating cracks remained under the surface when the stress of the fatigue limit had been loaded and the specimen was not fractured. Then, the specimens after fatigue test were heated to color the non-propagating cracks and then were fractured by higher cyclic stress than the fatigue limit. The specimens were heated for 1hr at 553K. Fig.8 shows SEM image of the non-propagating crack of the notched CP specimen with the slit diameter(2a)=0.15mm. The non-propagating crack was observed around the slit. The crack width was 0.215mm and the crack depth was 0.078mm. Therefore, it was estimated that the maximum size of the surface defect acceptable was the slit diameter(2a)=0.156mm.

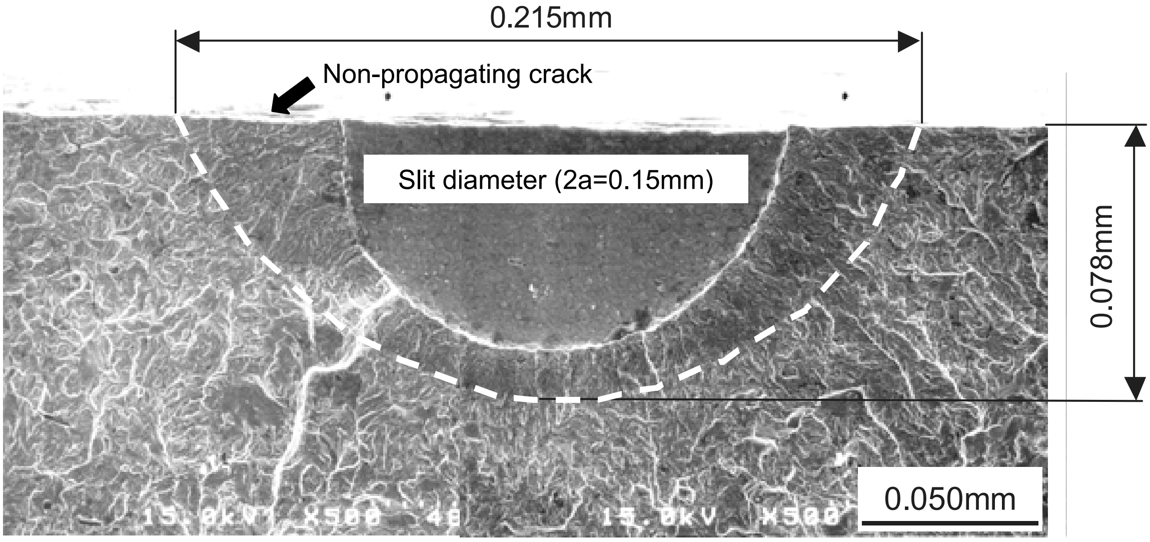


Fig. 8 SEM image of the fracture surface after heat tint

CONCLUSIONS

Semi-circular artificial defects were introduced into the specimens and their specimens were cavitation peened. Then, the bending fatigue limits of their specimens were evaluated. As the result, the following conclusion was obtained.

(1) In the case of the smooth specimens, the slit diameter (2a) of the acceptable defect was 0.08mm by Cavitation Peening.
(2) In the case of the notched specimens, the slit diameter (2a) of the acceptable defect was 0.15mm by Cavitation Peening.
(3) The acceptable defect slit diameter of the notched specimens was 1.9 times that of the smooth specimens.
(4) Non-propagating cracks were observed around the slits.

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