Effect of FIB-processed sharp flaw on fatigue limit of shot peened medium carbon steel

J. Sakamoto[1,2], Y.S. Lee[1], S.K. Cheong[1]

1 Seoul National University of Science and Technology, Seoul, Republic of Korea
2 Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan

Abstract
Effect of surface flaw on fatigue limit of shot-peened medium-carbon steel was investigated. Fatigue tests were conducted by using the specimens containing an artificial flaw with focused ion beam technique. The fatigue limits were increased by shot peening. The non-damaging region of flaw size can be increased by shot peening. Considering the introduction of small cracks due to shot peening, the flaw which is smaller than the cracks seems not to affect fatigue limit. Shot peening is useful for materials with a surface flaw introduced after the treatment.

Keywords
Fatigue limit, Surface flaw, Focused ion beam

Introduction
Every structural material can have surface flaws introduced during the manufacturing process and the handling process of the structure. The flaws reduce the fatigue strength. Fortunately, some researchers reported that a surface flaw with a certain size can be rendered harmless by using shot peening (SP) [1-4]. On the other hand, surface flaws may also be introduced during the handling process of materials.
Therefore, in this study, the effect of surface flaw introduced after SP on the fatigue limit of medium-carbon steel was investigated. Fatigue tests were conducted. Artificial surface flaw was introduced by using focused ion beam (FIB) technique.

Experimental Procedure
The material used in this study was an annealed medium carbon steel with following chemical composition (in wt.%): C – 0.45, Si – 0.77, Mn – 0.54, S – 0.32, Al – 1.32, Cr – 0.15, Ni – 0.33, Cu – 0.23, and Fe-Balance. The steel was annealed at 845°C for 0.5 h in the air atmosphere. The average Vickers hardness was 184*HV*.
Figure 1 shows the shape and dimensions of fatigue specimen. After machining the specimen, the central part was polished using fine emery papers with grit sizes of up to #2000. Four kinds of specimens were used in this study: non-SP specimens, SP specimens, non-SP specimens with an FIB-processed flaw, SP specimens with an FIB-processed flaw. The machining process is shown in Figure 2. The FIB-processed flaws were introduced after all surface treatments. The surface length, depth, and $\sqrt{area}$ were 50, 50, and 50 μm, respectively. Here, $\sqrt{area}$ is the square root of the projected area of a flaw in the direction of the load. The FIB-processed flaws in this study were prepared by an FIB system. An acceleration voltage, a beam current, and machining time used in this study were 30 kV, 65 nA, and 30 min, respectively.
Fatigue tests were conducted under constant load using an Ono-type rotating bending machine in which the stress ratio was always -1. All specimens were rotated by the machine at room temperature in atmosphere environment.
Table 1 lists the SP conditions used in this study. In order to determine the Almen intensity which applied to fatigue specimens, authors had conducted fatigue tests. Figure 3 shows the results of fatigue tests [5]. The fatigue limit increased with increasing Almen intensity from 0.24 to 0.44 mm A. The fatigue limit of the specimens peened at an Almen intensity of 0.44 mm A was almost same as that of the specimens peened at an Almen intensity of 0.62 mm A. Therefore, we determined to use the Almen intensity of 0.44 mm A.

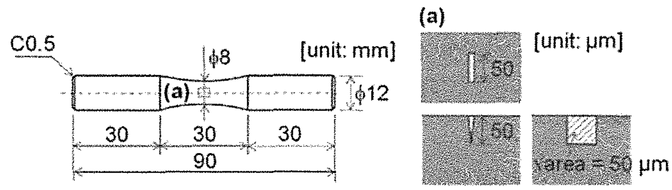

Figure 1. Shape and dimensions of fatigue specimen

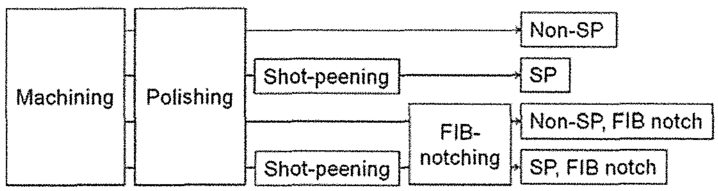

Figure 2. Flowchart of machining process of four kinds of specimens

Table 1 Shot peening condition

Peening machine		Impeller type
Shot ball	Material	Steel
	Diameter	0.8 mm
	Hardness	371HV
Shot velocity		30, 50, 70 m/s
Almen intensity		0.24, 0.44, 0.62 mmA
Coverage		Approximately 500%

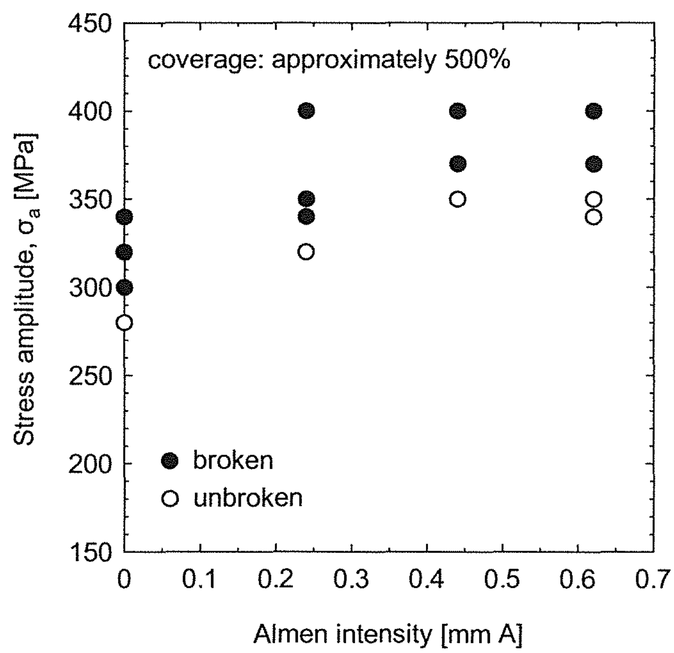

Figure 3. Relation between stress amplitude and Almen intensity [5]

Results and Discussion

Figure 4 shows the surface state of SP specimen. Some cracks were observed in the specimen. Figure 5 shows the relation between stress amplitude and flaw size using the previous results of fatigue tests [6]. The line calculated by using Equation 1 suggested by Murakami and Endo [7] are also shown in Figure 5.

$\sigma_w = 1.43(HV+120)/(\sqrt{area})^{1/6}$ (1)

where σ_w [MPa] is fatigue limit of non-peened material with a surface flaw at a stress ratio of -1. *HV* is Vickers hardness. $\sqrt{area}$ [μm] is the square root of the projected area of a flaw in the direction of the load.

The fatigue limits were increased by SP. Moreover, the non-damaging region of flaw size can be increased by SP. The result shows that SP is also useful for materials with a surface flaw introduced after the treatment. Considering the introduction of small cracks due to SP, the flaw which is smaller than the cracks seems not to affect fatigue strength.

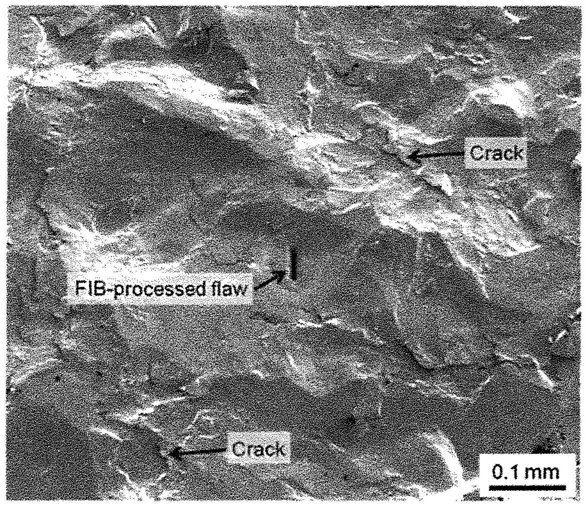

Figure 4. Scanning ion microscopic image of surface of SP specimen

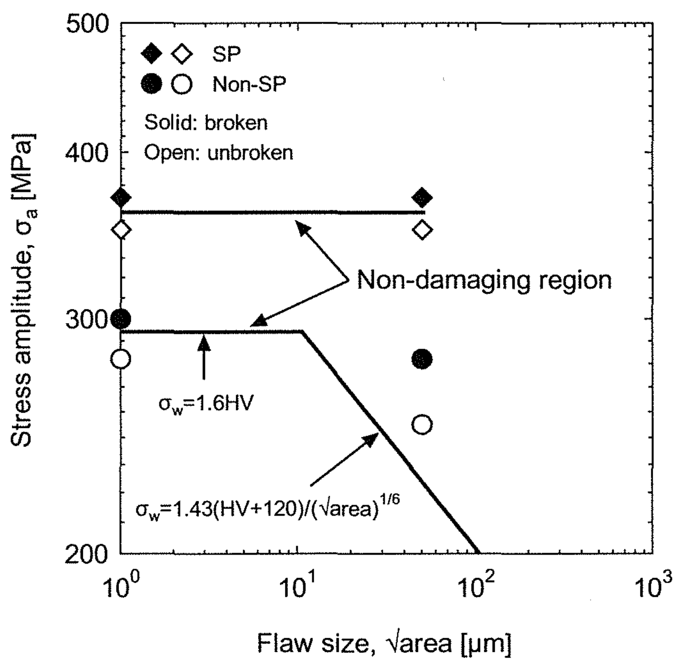

Figure 5. Relation between stress amplitude and flaw size.

Conclusions

In order to investigate the effect of surface flaw on fatigue limit of shot-peened medium-carbon steel, fatigue tests were conducted by using the specimens containing an artificial flaw with focused ion beam technique.

(1) The fatigue limits were increased by SP.
(2) The non-damaging region of flaw size can be increased by SP.
(3) Considering the introduction of small cracks due to SP, the flaw which is smaller than the cracks apparently, does not affect the fatigue limit.

References

[1] K. Takahashi, T. Amano, K. Ando, and F. Takahashi. *Improvement of fatigue limit by shot peening for high-strength steel containing a crack-like surface defect*. International Journal of Structural Integrity, Vol. 2-3 (2011), pp 281-292.

[2] F. Takahashi, A. Tange, K. Ando, *Effect of shot peening on fatigue limit of surface flawed samples*. Fatigue & Fracture of Engineering Materials & Structures, Vol. 31 (2008), pp 242-250.

[3] K. Takahashi, K. Ando, T. Amano, T. Miyamoto, F. Takahashi, A. Tange, H. Okada, Y. Ono. *Improvement of bending fatigue limit by shot peening for spring steel specimens containing an artificial surface defect*. Proceedings of 10th International Conference on Shot Peening, Tokyo, Japan, 2008.

[4] H. Okada, K. Ando, K. Takahashi, Y. Abe, T. Nakano, K. Kawagoshi. *Effect of shot peening on bending fatigue strength of spring steel specimens containing an artificial surface defects*. Proceedings of 10th International Conference on Shot Peening, Tokyo, Japan, 2008.

[5] J. Sakamoto, Y.S. Lee, S.K. Cheong. *Optimum shot peening condition for improvement of fatigue limit of annealed carbon steel based on Almen intensity*. Proceedings of Conference of Korean Society for Precision Engineering, Busan, Republic of Korea, 2013.

[6] J. Sakamoto, Y.S. Lee, S.K. Cheong. *Effect of surface flaw on fatigue strength of shot-peened medium carbon steel*. Under review in, Engineering Fracture Mechanics; 2014.

[7] Y. Murakami, T. Endo. *Effects of small defects on fatigue strength of metals*. International Journal of Fatigue, Vol. 2-1 (1980), pp 22-30.