Fatigue properties of high strength steel treated by laser peening with handheld microchip lasers

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Abstract

Laser peening (LP) introduces compressive residual stresses (RSs) on the surface of metallic components covered with water by irradiating them with high intensity laser pulses [1-7]. The advantage of LP is the possibility of fine execution management and the capability to introduce deep compressive RS on the material surfaces. It is well known to be highly effective in inhibiting stress corrosion cracking and fatigue cracking on material surfaces [7]. In addition, LP has an excellent effect on improving the fatigue strength of welds, which compensates for the disadvantage of high strength steels when welded. LP has a high potential for enhancing material surface, but the high-power laser used requires clean room facilities, large equipment and severe operating conditions. Therefore, the application of the LP has been limited to the countermeasure against high cycle fatigue of jet engine fan blades and stress corrosion cracking of nuclear reactor structures. If microchip lasers, which are small and easy to handle, could be used as a light source for LP, it would be possible to apply them not only to production processes in factories but also to existing steel structures such as bridges, to which conventional lasers have been difficult to apply for the above reasons. Based on this idea, we have developed a compact mobile LP device and verified its performance. [8-9]

Keywords Laser peening, microchip laser, handheld laser, residual stress, fatigue

Introduction

In LP, peening intensity can be instantaneously controlled by adjusting process parameters such as laser pulse energy and irradiation density corresponding to "coverage" of shot peening. Furthermore, LP can be applied to objects with complicated surface structure by real-time control of the focal position of irradiated laser pulses. In this study, we prepared LP experiments with a pulse energy of about 8 mJ attainable by microchip lasers [10-13] and peened the welded joint samples of an HT780 high-strength steel to find a way to compensate for the drawback of high-strength steels when welded: First, HT780 base metal was laser-peened to confirm the conditions for introducing favorable compressive RSs. Next, LP was applied to fatigue samples cut out from HT780 butt-welded joints prepared by CO2 gas shield arc welding, and then followed by uniaxial fatigue experiments with a stress ratio of 0.1. The results showed that LP with a pulse energy of about 8 mJ imparted compressive RSs in a near-surface layer of HT780 to a depth of about 0.2 mm and improved fatigue properties to the same level attained by LP with a pulse energy of 200 mJ from a conventional laser.

Preparation of Fatigue samples (HT780)

Fatigue samples were cut out from a butt-welded joint of 9 mm thick HT780 high-strength steel plates. The V-groove was filled with solid wire for 780 MPa class steel by carbon dioxide gas shielded arc welding. The shape and dimensions of the fatigue samples are shown in Fig. 1.

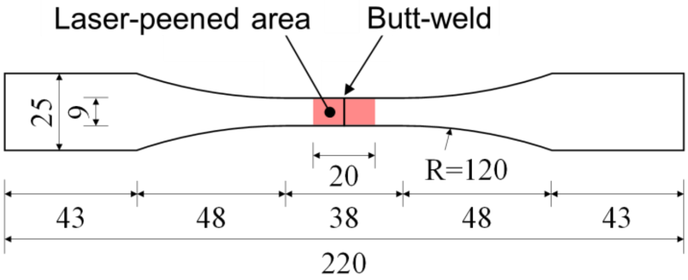

Fig. 1 HT780 butt-welded joint sample for fatigue testing.

LP was applied to both the front and back sides of the central part of the samples (shown in red in Fig. 1). A newly-developed compact LP device was used for the treatment. The LP conditions were 7.7 mJ pulse energy, 0.49 mm spot diameter, and 800 pulse/mm^2 irradiation density.

Effects on Surface Residual Stress of HT780

The effects on RSs were confirmed using an X-ray diffraction (XRD) device. The depth distribution of RSs was estimated by alternating electropolishing and XRD. The unpeened material was also subjected to the same procedure and the results were compared to evaluate the effect of LP. Fig. 2 shows the RS depth profile in the laser-peened and unpeened HT780 base metal. The depth of compression reaches about 0.2 mm from the surface. On the top surface of the peened material, the absolute value of RS is quite small compared to those just below the surface, which is probably due to the mill scale covering the base metal.

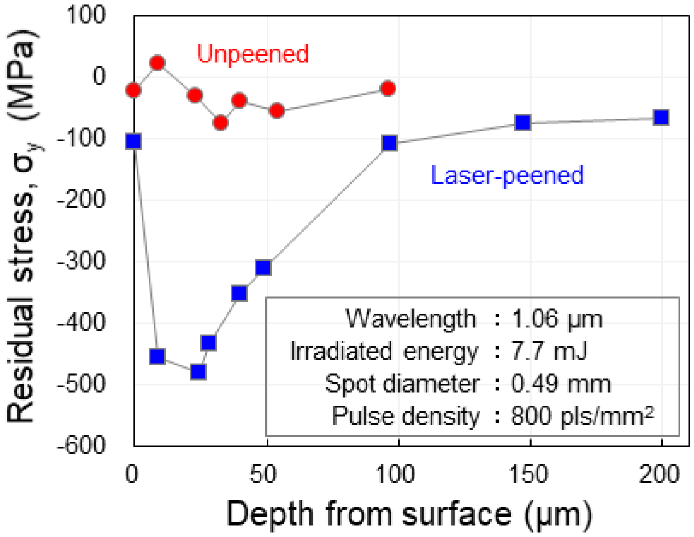

Fig. 2 Residual stress depth profiles of HT780

Effect on Fatigue Properties

A 100 kN uniaxial fatigue testing machine was used for fatigue loading with stress ranges ($\Delta\sigma$) of 200, 250, and 300 MPa. The stress ratio (R) was 0.1. The runout of the experiment was set to 10^7 cycles. For comparison, samples without LP were also subjected to fatigue testing. Fig 3 plots the fatigue test results in the form of the S-N curve.

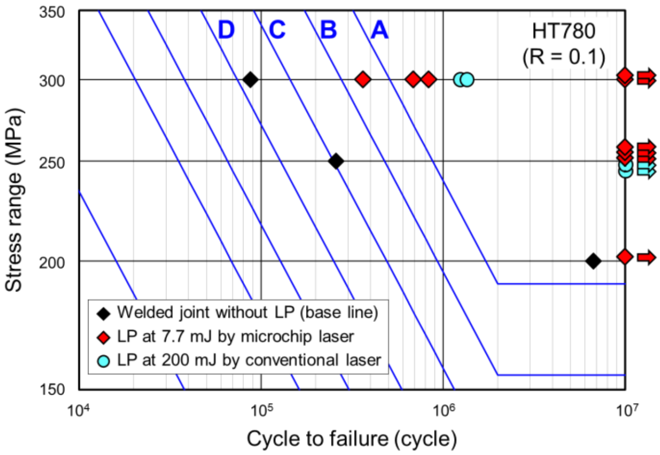

Fig. 3 Fatigue test results of HT780 butt-welded joint samples.

The blue lines indicated by A to D are the design curves for welded structural members specified by the Japan Society of Steel Construction. The design curve of the present samples is D. All the data are on the higher strength side than D, satisfying the standard.

The sample with $\Delta\sigma$ = 200 MPa, all three samples with $\Delta\sigma$ = 250 MPa, and two of the five samples with $\Delta\sigma$ = 300 MPa reached runout. Comparing with the results of the unpeened reference sample, it can be seen that the fatigue strength is significantly improved by LP with a pulse energy of 7.7 mJ, which may improve the category of the welded joint by two grade from D to B.

The fatigue data of the welded joint samples after LP using a conventional laser is also plotted in the figure. It seems that the average fatigue life extension effect is almost the same between the present results with a pulse energy of 7.7 mJ and the previous study using a 200 mJ pulse energy.

Conclusions

HT780 high-strength steel was subjected to LP using a newly-prototyped device with a compact robot arm and a thumb-sized microchip laser with a pulse energy of about 8 mJ. The results cleared that RSs and fatigue properties were significantly improved by LP despite that the pulse energy was orders of magnitude smaller than those of the conventional LP devices.

Acknowledgments

This work was partially supported by the JST-MIRAI Program (grant number JPMJMI17A1), the Supporting Industry Program of the Small and Medium Enterprise Agency (grant number 20334933), the Amada Foundation (grant number AF-2020239-C2), and the Impulsing Paradigm Change through Disruptive Technologies Program (ImPACT) of the Council for Science, Technology and Innovation.

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