Mechanical Properties of High-strength Steel Affected by Laser Surface Treatment

Kyushu University Student member ○Shusen ZHUANG
Kyushu University Fellow member Shigenobu KAINUMA
Kyushu University Regular member Muye YANG
TOYOKOH Inc. Non-member Hou KAKU
West Nippon Expressway Company Regular member Takahiro ASANO

1. Introduction In steel structure maintenance fields, surface preparation is a common process before repainting. Abrasive blasting is a surface cleaning method wildly used in construction field.[1)] When dealing with corroded steel members, abrasive blasting lacking the capacity to clean compact rust and residual chloride derived from sea salt and antifreezing agent inside corrosion pits. To solve these problems, attention has been paid to laser treatment as an alternative surface preparation method. The mechanisms of laser beam on surface cleaning are based on combination of ablation and thermal effects. Research of Chen et al.[2)] indicated surface contaminants, including rust, paint, salt, crude oil, and grease can be efficiently removed by appropriate laser processing parameters. Although laser surface treatment has the potential to achieve desirable surface conditions, heat effects during laser irradiation may damage the material and influence the mechanical properties of steel members. Moreover, the input laser energy may also affect some components of steel structures, for example, the bolted connections and narrow positions. This study applied high-power continuous wave (CW) laser to irradiate the high-strength steel surface, and compared with non-thermal abrasive blasting method. The relationship between changes in mechanical properties and laser energy density is established using tensile test.

2. Specimen and surface treatment Steel coupons (JIS G3106 SM490YB) were manufactured based on JIS Z2201 for surface treatment and tensile test, as shown in Fig.1. All specimens were abrasive blasted according to ISO Sa 2.5 before laser irradiation to achieve identical surface condition, and the steel coupon only treated by abrasive blasting were also used as comparison to laser surface treatment. The laser irradiation was performed using a fiber laser operating at various power and scanning speed. The laser beam is focused to specimen surface through a lens, then the laser spot was rotated by a motor-driven prism as a fixed diameter laser ring. To ensure laser-cleaned steel plate reach complete surface treatment, the adjacent laser ring was overlapped in ring width, and each parallel laser path was overlapped in ring diameter. The output energy during laser treatment divided by irradiated area was defined as energy density. Two different laser energy densities of 2857 and 1282 J/cm^2 were adopted in the treatment procedure, and classified into LA and LD respectively. During tensile test, all specimens were subjected to universal tension machine under displacement control of 0.03 mm/s, a Ω extensometer was utilized to track the elongation.

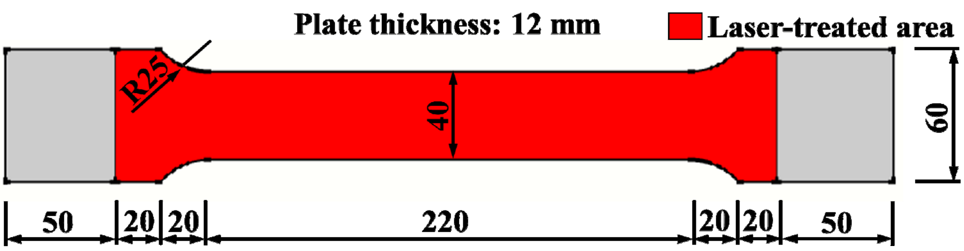

Fig.1 Configuration and dimensions of specimens

3. Test results Optic microscope (OM) photos of laser-treated and abrasive blasted steel surface are shown in Fig. 2. The micrograph clearly showed that surface morphologies of laser-treated specimens are different from abrasive blasted specimen, due to combination of thermal and plasma ablation effect. The surface of LA and LD specimens exhibited an obvious trace of scanning path, indicating distinct laser ablation effect of both laser conditions. For different laser energy density, higher energy used during laser irradiation resulted in a surface condition with metallic luster, and the lower energy contributes to a surface with blue color contained. Different compositions of iron oxide are expected to form on the steel surface under different laser conditions. These kinds of surface modification will change the electrochemical properties of laser-treated steel surface, which needs a more thorough study. On the other hand, the surface of laser-treated steel shows no obvious defect, thus stress concentration is less likely to take place during the tensile test. Besides, the surface morphologies confirmed laser parameters adopted in this study are suitable for surface preparation as a high-power treatment.

The nominal stress-strain curves of specimens at room temperature are illustrated in Fig. 3. It can be found in abrasive blasting and laser conditions that the curves are similar to each other. However, tensile results of LA specimens exhibited relatively smaller elongation, and slight increase in the plastic stress-strain curve compared with abrasive blasted specimens. From the nominal stress-strain curve of the abrasive blasted specimens, steel coupon deformed elastically until approximately 0.32% of the nominal strain in initial portion. From the stress-strain curve, the upper-yield and lower-yield point phenomena indicate a transition from elastic to plastic deformation. The deformation in the abrasive blasted steel coupon is distinctly inhomogeneous at this time, known as Lüders band. During this period the specimens are partially yielded, the Lüders band develops along with tensile process and eventually covered the whole area. The Lüders band of abrasive blasted specimen starts at 0.32% of strain from the gripped portion of the steel coupon where the stress is concentrated, and it covered gauge length at 2.00% of the strain level. The total strain from upper-yield point to lower-yield point is also known as Lüders strain. In case of abrasive blasted steel coupon, the Lüders strain is approximately 1.68%. From the stress-strain curve of LA specimens shown in Fig. 3, the upper-yield point appeared at 0.28% of strain, and the lower-yield point was reached until 1.73% of strain, showing a Lüders strain of 1.45%, which is smaller than abrasive blasted specimens. For LD condition, the upper-yield point appeared at 0.20% of strain, and the lower-yield point was reached until 1.94% of strain. A similar Lüders strain with abrasive blasted specimens about 1.74% is observed in steel coupon treated by LD condition, as a result of lower heat effects of laser irradiation. Besides, this difference in Lüders strain may change the cyclic and seismic performance of steel material to some extent.[3] The average mechanical properties of specimens extracted from tensile test are reported in Table 1. Results show that tensile strength slightly improved after laser irradiation, while the other mechanical properties remain steady state.

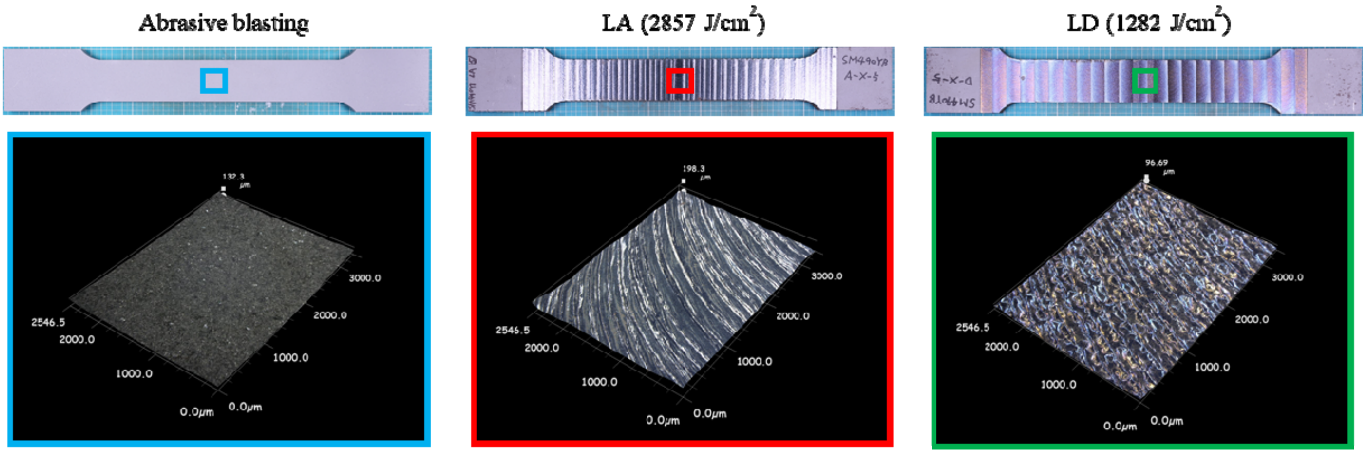

Fig.2 OM photos of laser-treated and abrasive blasted steel surfaces

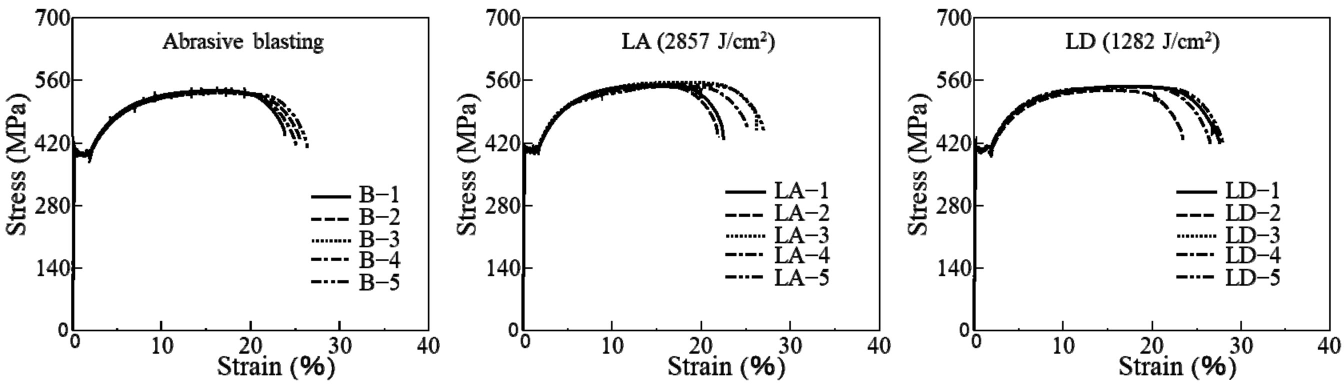

Fig.3 Nominal stress-strain curves of specimens

Table 1 Tensile test results

Specimens	Tensile strength (MPa)	Yield strength (MPa)	Young's modulus (GPa)	Poisson's ratio	Elongation (%)
Abrasive blasting	534	395	211	0.274	25.1
LA	550	404	196	0.250	24.0
LD	544	406	204	0.265	25.8

4. Summary 1) The surface morphology of laser-treated specimens exhibited different features from abrasive blasted specimens. No obvious defect on the laser-treated specimens is observed. 2) Tensile test results indicated that laser surface treatment has no distinct effects on the mechanical properties of high-strength steel.

Reference 1) S. Kainuma, A. Kim, T. Ikeda and T. Kotera: Effect of abrasive material and blasting conditions on characteristics of steel surface and the residual degree. Rust Prevention & Control, Vol.63, pp.285-300, 2019. 2) G. X. Chen, T. J. Kwee, K. P. Tan, Y. S. Choo and M. H. Hong: High-power fibre laser cleaning for green shipbuilding, Journal of Laser Micro/Nanoengineering, Vol.7, pp.249-254, 2012. 3) F. Hu, G. Shi: Constitutive model for full-range cyclic behavior of high strength steels without yield plateau. Construction and Building Materials, Vol.162, pp.596-607, 2018.