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Laser softening of ultra-high-strength steel for a self-piercing riveting process

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Abstract

Ultra-high-strength steels have recently attracted attention in the automotive industry because they can be used to fabricate lightweight structures and can improve crash test results. However, due to the poor formability of these steels, their application to car bodies is limited. A possible solution to this limitation is a localized heat treatment using a laser softening process. Here, a laser heat treatment was conducted using a 2.5 kW high-power diode laser. The output power was controlled to achieve a constant temperature. As a result, the transformation of cementite in martensite was observed by non-isothermal tempering below a temperature of 500 ℃. In the end, a self-piercing riveting process which is capable of attaching laser-heat-treated ultra-high-strength steels to an aluminum plate was successfully realized. This outcome shows that non-isothermal tempering by means of a laser heat treatment can improve the formability of ultra-high-strength steels.

Keywords: Heat treatment; laser softening; ultra-high-strength steels; self-piercing riveting; high-power diode laser; non-isothermal tempering

1. Motivation

New requirements in the automotive industry, which combines fuel savings with vehicle safety enhancements, have led to the development of UHSS (Ultra-High-Strength Steel). The high yield and tensile strength of these types of steel can help maintain or improve crash tests outcomes while reducing sheet

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thicknesses. The disadvantage of UHSS, however, is that the formability is reduced compared to normal steels. This reduces the degree of deformation and increases spring back as well as tool wear. A proper heat treatment of the sheet improves the formability, but the high strength will be lost. In relation to this, Reimund et al. showed that a laser heat treatment has the potential to improve the formability of UHSS (Reimund et al., 2009). However, the laser heat treatment process does not yet guarantee the productivity levels required in the automobile industry and is therefore not applied regularly. In this paper, we introduce a non-isothermal tempering method which softens UHSS by means of a short laser irradiation process and verify the feasibility of rapid tempering for SPR (self-piercing riveting). The non-isothermal tempering method involves rapid heating (>2000 K/s) with a negligible holding time (milliseconds) at the peak temperature, followed by fast cooling (60 K/s) to room temperature, while general isothermal tempering is carried out in a muffle furnace with very low heating rate (0.5 K/s), followed by longer holding times (t = 5300 and 5400 seconds) at 923 K (650 ℃) and cooling from the peak to room temperature at around 10 seconds by air cooling (Hernandez et al., 2011)

2. Experimental setup

In the experiment conducted here, we attempted to soften martensite-based UHSS (tensile strength: 1470 MPa, thickness: 1.2 mm) using the non-isothermal tempering process as introduced above. The experimental setup employed for the non-isothermal tempering process is shown in Fig. 1. The applied laser source is a HPDL (Laserline, LDF 1000-2500) with 2.5 kW of power and NIR (910 nm, 980 nm) radiation. The laser beam travels through optical fiber and an optics module, where it is then irradiated on the surface of the workpiece with a spot size of 17 mm. A pyrometer (Lascon, QP003) was installed to measure the temperature of the material and to control the laser power in the range of 300 °C – 1400 °C.

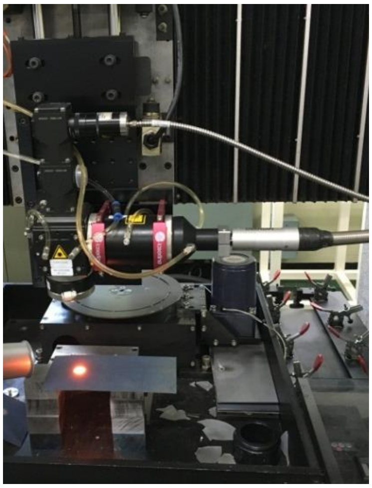


Fig. 1. Experimental setup for laser softening

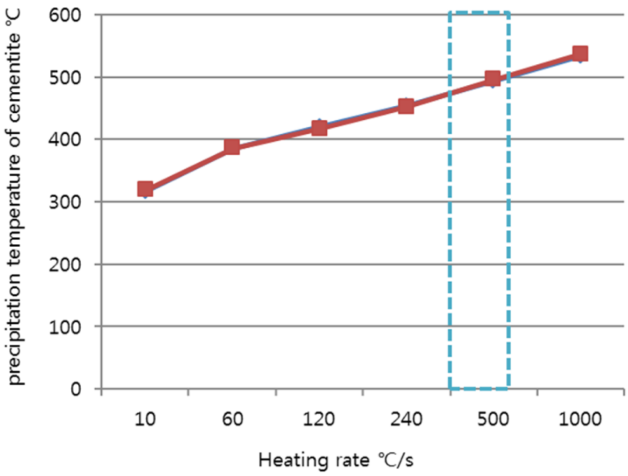


Fig. 2. Precipitation temperature of cementite with an increase in the heating rate

Prior to the experiment, the commercial software JMatPro® was used to set process variables such as the laser power, heating rate and heating temperature. Figure 2 shows the precipitation temperature of cementite with an increase in the heating rate. This figure demonstrates that the precipitation temperature of cementite increases in proportion to the heating rate.

Hernandez et al. showed a non-isothermal temperature introduced by this method of 650 ℃ at a heating rate of 2000 ℃/sec based on resistance welding. However, in this experiment, the heating rate of the laser heat treatment is lower than that in resistance welding, and the heating temperature should be adjusted accordingly (Hernandez et al., 2011). We found that the heating rate for the 2.5 kW laser output with a beam size of 17 mm is approximately 500 ℃/s. Thus, the heating temperature at which the cementite precipitates is 470 ℃, as shown in Fig. 2.

3. Results and Discussion

We determined the heat treatment conditions of the martensite-based UHSS through simulations and preliminary experiments and present the results of the SPR process after the heat treatment and hardness measurements of the martensite-based UHSS using the heat treatment conditions derived above. Figure 3 shows the hardness measurement value of the cross-section after laser softening considering the distance from the center to the edge. The difference in the hardness between the upper and lower parts was almost nonexistent, the hardness at the center area was reduced by 40 %, and the diameter of the heat-treated region was approximately 20 mm.

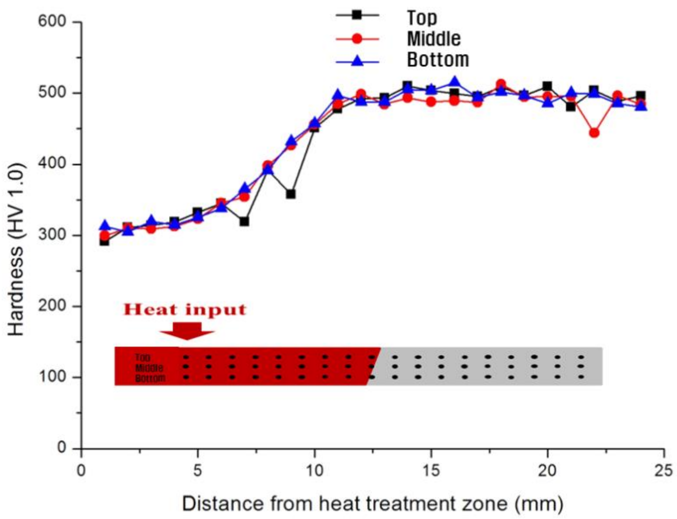
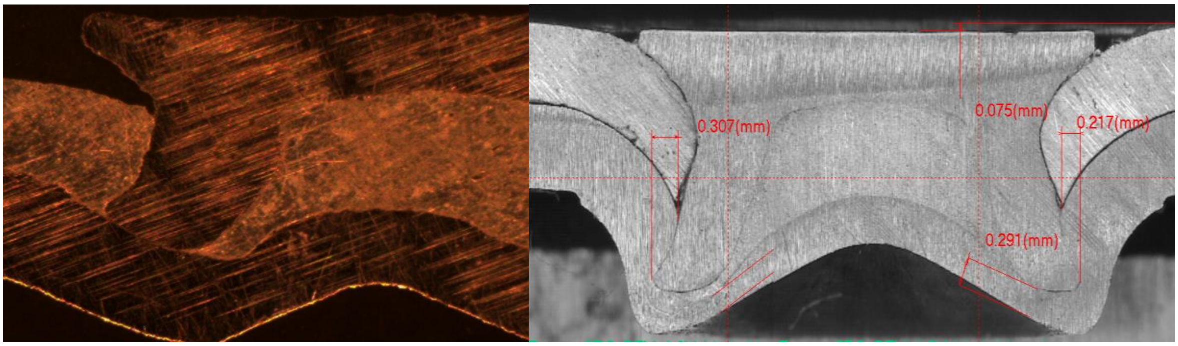


Fig. 3. Hardness distribution of UHSS after the laser softening process

Subsequently, a riveting process between the softened UHSS and aluminum was performed. The aluminum (AL5056) used as a top plate and the softened UHSS used as a bottom plate are both 1.2 mm thick. The rivet used is SM45C steel with a hardness value of 550 Hv and a diameter of 5 mm. Figure 4(a) shows the result of the riveting process using UHSS before the laser softening step, and Figure 4(b) shows the result of riveting using UHSS after laser softening. In Fig. 4(b), plastic deformation of the lower plate is smooth and the interlock of the rivet is established such that a stable connection is achieved. On the other hand, when laser softening was not conducted, the fastening was not feasible, as shown in Fig. 4(a). In addition, lapshear tests were carried out to ensure that the rivets were correctly fastened. In these tests, a fracture occurred in the upper aluminum part at loads of 4kN or more. This indicates that martensitic UHSS can be locally and feasibly softened for riveting by a laser heat treatment.



(a) (b)

Fig. 4. (a) The result of riveting with UHSS before laser softening and (b) the result of riveting using UHSS after laser softening

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