Applied Surface Science 273 (2013) 128–134

Contents lists available at SciVerse ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Tensile property of low carbon steel with gridding units

Chuanwei Wang[a], Hong Zhou[a,*], Zhihui Zhang[b], Zhengjun Jing[a], Dalong Cong[a], Chao Meng[a], Luquan Ren[b]

[a] *The Key Lab of Automobile Materials, The Ministry of Education, Jilin University, Changchun 130025, PR China*
[b] *The Key Lab of Terrain Machinery Bionics Engineering, The Ministry of Education, Jilin University, Changchun 130025, PR China*

ARTICLE INFO

Article history:
Received 6 November 2012
Received in revised form 29 January 2013
Accepted 30 January 2013
Available online 8 February 2013

Keywords:
Tensile properties
Biomimetic
Laser remelting
Low carbon steel

ABSTRACT

Although much effort has been devoted to the mechanical properties of biomimetic coupled laser remelting (BCLR) processed steels, our understanding to the strengthening and toughening mechanisms of it has still remained unclear. To address it, here we studied the roles played by the gridding units of BCLR steels. Tensile tests show that the gridding units have a significant influence on the tensile properties. Interestingly, such an influence is essentially decided by the unit distance of gridding units. The strength increases with the unit distance narrowing while the ductility first increases with it up to a maximum then decreases. The mechanism behind these changes is attributed to the combined effects of the microstructure changes in the units and the stress transition throughout the BCLR samples.

1. Introduction

Low carbon steels are preferred structural materials for mechanical components of vehicles, bridges, ships, edifices and so on. Their major advantages are good ductility [1], good weldability [2] and excellent forgeability [3]. A major shortcoming is its low strength, which places a limit on its service life [4]. Many efforts have been made to improve its properties. Inspired by the excellent biomechanical properties of some biological materials, Zhang et al. abstracted the key feature of biological structure to a simple model with characteristics of alternate unit and matrix and fabricated a series of biomimetic units in the surface layers of carbon steels using laser remelting [5]. It was found that utilization of biomimetic coupled laser remelting (BCLR) had a beneficial effect on increasing the strength without impairing good ductility. Due to this, BCLR steels displayed a superior resistance to thermal fatigue and their thermal service life could be improved efficiently. Zhou et al. examined the wear properties of BCLR steels processed under different mediums (air or water film) [6]. Results showed that the BCLR specimens had higher strength and better wear resistance than the untreated specimens. More importantly, BCLR enhanced the mechanical properties but without changing the special properties of substrate materials, such as good machinability, the ability to resist galling and excellent vibration damping. More recently, biomimetic units with varied shapes (including 'striation' shape, 'spot' shape and 'gridding' shape) were designed and fabricated using this method [7]. With the same area ratio of biomimetic units, gridding-shaped BCLR samples exhibited the most desirable improvement in tensile properties, showing an improvement in the strength and ductility simultaneously. However, the strengthening and toughening mechanisms of BCLR steel still have not been systematically studied. In addition, according to the principles of bionics [8], biomimetic structural features (such as shape, size, distance and etc. of biomimetic units) are very important factors in determining the properties of biomimetic materials. Nevertheless, the influence of unit distance on mechanical properties of BCLR steels was ignored in previous papers.

This work focused on the strengthening and toughening mechanisms of BCLR steels with gridding units. In addition, the effect of unit distance on the tensile properties of biomimetic materials was also discussed.

2. Experimental details

As a structural material, a low carbon steel codenamed S355 (the designation of structural steel in the German standard), the chemical composition of which is similar to that of ASTM A529M steel, was applied in this work. The chemical compositions (wt.%) and mechanical properties of the steel are shown in Tables 1 and 2, respectively.

Flat tensile specimens with 24 mm gauge length, 1.7 mm gauge thickness and 10 mm gauge width were cut by electric spark machine (Huadong Group, DK77, China). Gridding units were fabricated in both surface layers of the specimen by laser beam. The

---

[*] Corresponding author. Tel.: +86 431 8509 4427; fax: +86 431 8509 5592.
E-mail address: jzj_1987@sina.cn (H. Zhou).

0169-4332/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.apsusc.2013.01.206

Table 1
Chemical compositions of experimental steel (wt.%).

C	Si	Mn	Cu	P	S	Mo	Fe
0.14	0.23	1.50	0.035	0.014	<0.01	<0.01	Bal.

Table 2
Mechanical properties of experimental steel.

Yield strength, MPa	Tensile strength, MPa	Total elongation, %	Average hardness (HV)	Substrate
412	506	23.2	170	Ferrite + Pearlite

Table 3
Various unit distances of the gridding units.

Specimen groups	Specimen No.	Unit distance	
		D_1 (mm)	D_2 (mm)
A	A-1	9	3
	A-2	7	3
	A-3	5	3
	A-4	3	3
	A-5	1	3
B	B-1	3	9
	B-2	3	7
	B-3	3	5
	B-4	3	3
	B-5	3	1

geometry of the specimen and gridding unit is shown in Fig. 1, and the only difference of these samples in this paper is the lateral distance (D_1 in Fig. 1) and longitudinal distance (D_2 in Fig. 1) of the units (listed in Table 3).

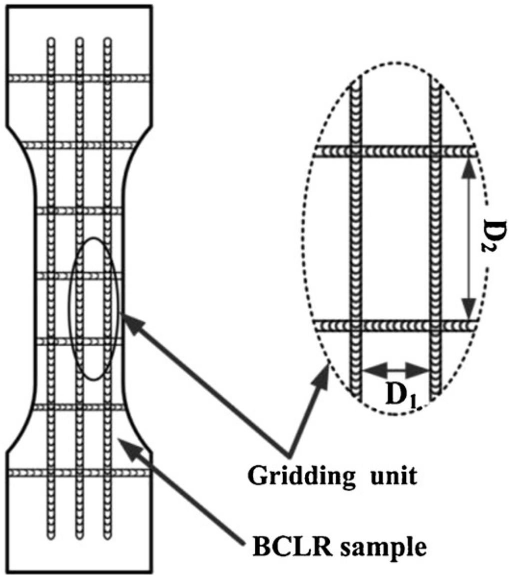

Fig. 1. A sketch of the specimen and gridding unit.

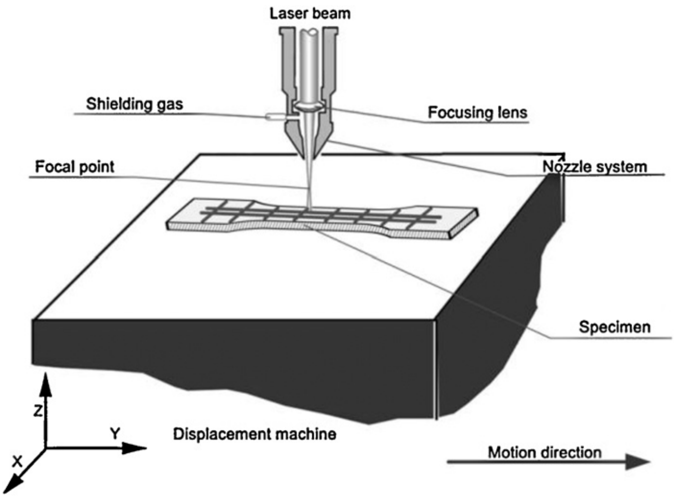

Fig. 2. A schematic of the setup used for BCLR of gridding specimens.

Fig. 2 is a schematic diagram of the setup used for the manufacturing process. A pulsed Nd:YAG laser of 1064 nm wavelength and maximum power of 300 W was employed here to process the gridding units at room temperature, using the parameters of laser pulse duration 5.0 ms, frequency 3 Hz, laser input energy 140 J/cm^2 and a circular spot size 0.5 mm in diameter on the specimen surface. During the laser process, the samples were placed on the displacement machine. Movement along X and Y axes was used to process the units with desired unit distance and scanning speed (0.5 mm/s), while that along Z-axis was to adjust the defocusing amount (5 mm). Pure argon gas with flow rate of 10 L/min was used for shielding, delivered to the sample via a convergent nozzle with 3.5 mm diameter.

After the laser processing, cross sections of the units were cut parallel to the laser direction and standard methods of metallography were followed. An optical microscope (Zeiss, Axio Imager A2m, Germany) was used to study the details of the unit. Microstructure analysis was carried out by means of Zeiss-Evo18 scanning electronic microscope (SEM) and JEM-2100F transmission electron microscopy (TEM). The grain size of the steel is determined by the conventional linear intercept method using SEM micrographs [9]. Phase compositions of the unit and matrix were identified by D/max-RC X-ray diffraction (XRD) with Cu Kα radiation operated at 40 kV with a current of 40 mA and a scanning rate of 4° min^{-1}. Microhardness measurements of the laser treated surface layer (along the depth in the longitudinal section) were carried out using a Vickers microhardness tester (Buehler, 5104, USA) with the applied load 25 g and the loading time 10 s. Tensile experiment was performed on a material testing system (MTS 810, USA) at room temperature (22 °C). The strain rate used was $3.5 \times 10^{-4}\,\mathrm{s}^{-1}$.

In order to have a better insight into the tensile behavior of untreated and gridding samples, we examined localized plastic deformation in different regions of these samples. Square lattices were marked on the surface of tensile specimens before tensile tests (Fig. 3). Longitudinal dimension of each lattice was measured by optical microscope before and after tensile testing respectively. Accordingly, the longitudinal strain (LS) in different regions can be calculated as:

$$\mathrm{LS} = \frac{L_2 - L_1}{L_1} 100\%,$$

where L_1 represents the longitudinal dimension of a single lattice before the tensile test, as shown in Fig. 3; L_2 is the corresponding longitudinal dimension after failure.

3. Results

Fig. 4 shows the cross-section and surface morphology of gridding unit. It can be seen that the laser-affected layer consists of the following zones: semicircular laser remelted zone and parabolic heat-affected zone (HAZ). By the measurement, the width of remelted zone is around 530 μm, while the corresponding depth is 190 μm and the depth of HAZ is nearly 50 μm. It is also clear that