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Effect of pulse frequency on microstructure and properties of welded joints for dual phase steel by pulsed laser welding

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ABSTRACT

This paper investigated the metallurgical phenomena of overlapping zone between two laser spots and related effects of pulse frequency (3–15 Hz) on properties of welded joints by pulsed laser welding for DP 590 steel sheets. The welded surfaces were not continuous at 3 and 5 Hz and shallow penetrations, but welded joints with full penetration were obtained at 8–15 Hz, caused by increasing average power. The microstructure evolution of fusion zone (FZ) with pulse frequency increasing was: lath martensite → lath martensite and bainite → bainite and grain boundary ferrite. When pulse frequency was 3–8 Hz, overlapping zone was divided into four areas (FZ of former spot, super-critically HAZ (SC-HAZ), inter-critically HAZ (IC-HAZ), sub-critically HAZ (*S*-CHAZ)) wherein the microstructure changed with the increase of heat input. Hardness distribution of welded surface (3–8 Hz) was in zig-zag pattern and hardness dropped in S-CHAZ and IC-HAZ owing to the different microstructures. An increasing pulse frequency led to a hardness decrease in the cross-sectional of welded joints. For the full penetration of welded joints, tensile test revealed that strength of FZ was superior compared with base metal, and Erichsen value of welded joints could reach to 80% of the base metal when pulse frequency increased to 10–15 Hz.

1. Introduction

At present, the automobile energy saving, emission reduction and light weight have been developed as a focus concern in the automobile industry. Dual phase (DP) steel is now widely used for fabricating automotive components such as frames, wheels, and bumpers as they offer a highly desirable combination of high strength and ductility [1–3]. The microstructure of DP steel is composed of ferrite (soft phase) and martensite (hard phase), which ensure the superior performance [4–6]. In order to satisfy the requirements of continuous innovation and development in the field of automobile manufacturing, the high efficiency and quality welding technology have been gradually of concern to researchers and manufacturing enterprises. As far as we know, the strength and toughness of welded joints are poor by traditional welding methods as CO_2 gas shielded arc welding owing to high heat input which will lead to the coarse microstructure in welded joints [7]. Laser welding as an advanced welding technology with the characteristics of high power, flexible beam delivery, low maintenance costs, high efficiency and compact size [8]has been used in automobile manufacturing area on DP steel continuous welding.

The pulsed laser welding as a kind of laser welding, with lower average power and higher peak power, is conducive to decrease the width of heat-affected zone and residual stress, and reduce the degree of softening [9–11]. However, different pulsed welding parameters will result in different effects on microstructure and properties. Some researchers have studied the welding parameters for pulsed laser welding and gain some significant conclusions [12–14]. For instance, Torkamany et al. [15] have investigated the effect of pulse peak power, pulse energy, and welding speed on welding mode with a 400 W Nd:YAG pulsed laser welding. The welded metal characteristics with pulse energy, pulse duration and welding speed changed in pulsed Nd:YAG laser welding have been studied by Malek Ghaini et al. [16], and the cumulative overlapping index was proposed to calculate the effective peak power. Also, Baghjari et al. [9] have studied the effect of pulsed Nd:YAG laser welding parameters such as voltage, laser beam diameter, frequency, pulse duration, and welding speed on the weld dimensions of AISI 420 stainless steel. Mirakhorli et al. [17] have investigated the microstructure of the weld metal of a duplex stainless steel made with Nd:YAG pulsed laser at different welding speeds and pulse frequencies. Sabbaghzadeha et al. [18] have studied the effect of process parameters on the melting ratio in pulsed laser welding on St14 carbon steel sheet. E. Biro et al. [19] have studied the effect of using oxygenated assist gases on the weldability and weld properties by Nd:YAG pulsed laser welding and gained some valuable achievements on effective absorptivity, etc.

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Table 1
Chemical compositions of DP590 steel (wt.%).

C	Mn	P	Si	S	Al	Fe
0.15	2.50	0.04	0.6	0.015	0.02	Balance

However, reports in the literature on metallurgical phenomena of overlapping zone between two laser spots and related effects on mechanical properties of welded joints by pulsed laser welding are limited for DP steel. Consequently, this paper will focus on cold-rolled DP 590 steel with a thickness of 1 mm as a study object, revealing the effect of pulse frequency on microstructure and properties of welded joints including overlapping zone using Nd:YAG 300 W pulsed laser.

2. Experimental procedure

2.1. Materials

A cold-rolled steel sheet used in this investigation was 1 mm thickness. The chemical composition was represented in Table 1. Fig.1 presented the microstructure of experimental steel. Ferrite (F) and a large number of block martensite (M) dispersing in ferrite boundary could be observed as shown at the arrows in Fig. 1a and b. According to statistical analysis, the volume fraction of martensite was ~20%, the grain size of ferrite was in 5–18 μm with the average size of ~10 μm, and the block martensite size was in 0.5–3 μm. A great deal of movable dislocation was induced in ferrite caused by volume expansion during martensite transformation (Fig. 1c and d), leading to the activation of the dislocation source due to the lower stress applied in the deformation process of the experimental steel, so the microstructure necessary for its characteristic low yield strength and continuous yielding was shown on the micrographs [20].

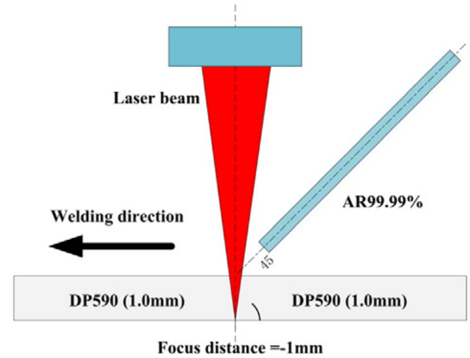

Fig. 2. Diagram of laser welding process.

2.2. Experimental methods

The welding samples with a size of 80 mm × 80 mm were selected by DK7732 numerical control wire cutting mechanism. The interface sides of samples were carefully mechanically polished by emery papers, and then cleaned by HQD-200 ultrasonic cleaning machine. The welding was performed by Nd:YAG 300 W pulsed laser which was capable of up to 150 W mean power, a focus lens of 75 mm, a wavelength of 1064 nm, a pulse duration of 5.5 ms, and a defocusing distance of −1 mm (the work piece surface was located 1 mm higher than the laser focal point), and the optical was set up to have a minimum laser beam spot diameter of 0.20 mm on the work piece. The welding speed was 3 mm/s. Pure argon gas was selected for shielding at 10 L/min flow rate. The pulse frequencies were performed at 3, 5, 8, 10, 12 and 15 Hz separately. Three repeated experiments were implemented for each pulse frequency to ensure the accuracy of the experimental data. The diagram of pulsed laser welding was presented in Fig. 2.

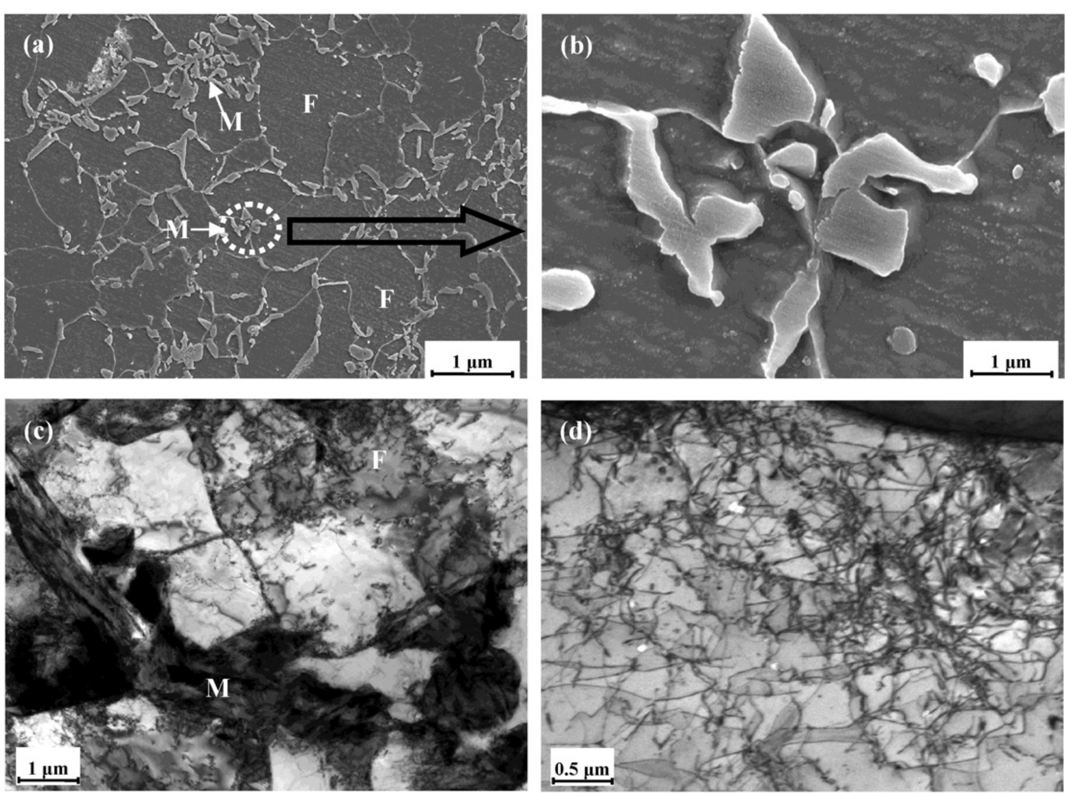

Fig. 1. Microstructure of DP590 steel. (a)–(b) scanning electron microscope image and (c)–(d) transmission electron microscope image.