Materials Science & Engineering A 578 (2013) 125–133

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

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

Induction-assisted laser beam welding of a thermomechanically rolled HSLA S500MC steel: A microstructure and residual stress assessment

R.S. Coelho [a,b], M. Corpas [b], J.A. Moreto [d], A. Jahn [c], J. Standfuß [c], A. Kaysser-Pyzalla [a,b], H. Pinto [b,d,*]

[a] Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Straße 15, 12489 Berlin, Germany
[b] Former at Max-Planck Institut für Eisenforschung GmbH, Max-Planck-Str. 1, 40237 Düsseldorf, Germany
[c] Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS, Winterbergstr. 28, 01277 Dresden, Germany
[d] Universidade de São Paulo, Escola de Engenharia de São Carlos, CEP 13566-590 São Carlos, SP, Brazil

ARTICLE INFO

Article history:
Received 13 January 2013
Received in revised form
7 April 2013
Accepted 8 April 2013
Available online 17 April 2013

Keywords:
Laser welding
Induction heating
HSLA steel
Microstructure
Residual stress

ABSTRACT

The present work deals with the effect of different combinations of induction heating and autogenous CO_2 laser welding on the gradients of microstructure, microhardness and residual stresses in butt-joints of thermomechanically processed S500MC steel grade. Five strategies were pursued by varying the inductor position with respect to the laser beam. This enabled in-line pre-, post-, and simultaneous pre- and post-heating as well as annealing of the fusion and heat-affected zones. The induction-assisted CO_2 laser welding strategies were compared to individual CO_2 and Nd:YAG fiber welding procedures. The results demonstrate that induction heating can be combined to laser welding in order to effectively increase the cooling times. Martensite formation could be suppressed within the fusion and heat-affected zones and smooth hardness distributions were obtained by pre-heating and combined pre- and post-heating. The tensile residual stresses are, however, still of significance because of the high transformation temperatures ($>500\,^{\circ}C$) observed for the S500MC steel. This allowed for extensive thermal contraction after exhaustion of the austenite to ferrite transformation.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Thermomechanically processed (TMP) high-strength low-alloyed (HSLA) steels are high potential materials for light structures where considerable strength is required [1–4]. The combination of strength, toughness and formability enables construction engineers to realize light-weight structures in commercial vehicles and offer further new possibilities for designing engineers [5]. However, when submitted to welding processes, the mechanical performance of such steel grades can be easily modified. The thermo-cycle imposed by welding leads to microstructure changes in the fusion zone (FZ) and in the heat-affected zone (HAZ), which can support cold cracking due to the strong hardening of the weld seam during cooling [6–9]. In addition, uncontrolled tempering of the HAZ can lead to precipitation and grain coarsening which can increase hardness as well as diminish toughness and fatigue strength [9–12].

In this scenario, an increasing search for appropriate welding procedures to join HSLA steels has been observed [13–18]. Among many welding processes, laser beam welding (LBW) is particularly attractive for innovative and cost-effective applications. The concentrated heat source allows for narrow and deep weld seams as well as for fast welding speeds with low heat input. However, the application of LBW to HSLA steels is still challenging due to the short cooling times after welding [16,19]. Conventionally, the control of the cooling time is possible by changing the heat input or by heating the metal plates prior to welding. Recently, a novel approach, which combines in-line induction heating with LBW, was developed by the Fraunhofer Institute for Materials and Beam Technology (IWS) [22] within the framework of the EU-project INDUCWELD funded by the 'Research Funds for Coal and Steel' (RFCS). This innovative technology has shown potential to reduce the risk of hydrogen-induced cracking and improve the hardness distribution in the FZ and HAZ [20–22].

In this work, the weldability of commercial TMP S500MC steel plates [23] was investigated using a CO_2 LBW system equipped with induction coils, which allowed for the in-line application of different heat treatments to the welded regions. The study aimed at assessing the influence of different induction-assisted LBW strategies on the microstructure, hardness distribution and residual stress formation during welding. Five different procedures were defined by varying the position of the induction coils with respect to the laser beam, thus subjecting the welds to different in-line pre- and/or post-heating treatments. The induction-assisted

* Corresponding author at: Universidade de São Paulo, Escola de Engenharia de São Carlos, Departamento de Engenharia de Materiais, Av. Trabalhador Sãocarlense 400, 13566-590 São Carlos, SP, Brazil. Tel.: +55 16 3373 8290; fax: +55 16 3373 9590.
E-mail addresses: haroldo@sc.usp.br, haroldopinto@yahoo.com.br (H. Pinto).

0921-5093/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msea.2013.04.039

strategies were compared to simple CO_2 and Nd:YAG LBW processes.

2. Experimental details

2.1. Material

Commercial TMP S500MC steel plates with dimensions of 6.8 mm × 100 mm × 300 mm were selected for this study. Its nominal chemical composition is listed in Table 1. The equivalent carbon content (CE) for this steel grade amounts to about 0.22 according to SS-EN1011-2 [24], indicating a relatively high hardenability. Its parent microstructure is predominantly ferritic with a low fraction of fine pearlite colonies located at the grain boundaries.

2.2. Welding procedure

The samples were produced in a butt-joint configuration at the Fraunhofer IWS, Dresden, Germany, using a CO_2 LBW system equipped with induction coils which allows for the in-line integration of different pre- and post-heating treatments. Prior to welding, the edges of the 6.8 mm thick steel plates were milled and the surface grit-blasted in order to remove any surface contamination. The welds were produced without filler addition and helium was applied as shielding gas. The laser power was 3.5 kW. The focal point of the laser beam was set to 0 mm. The welding speed was 1.0 m/min.

The inductors consisted of linear coils with 60 mm length, which were placed near the welding thermal source and positioned 2 mm above the sample surface. They were aligned with the welding path and moved together with the laser beam at a fixed separation distance. For each welding setup the separation between the induction coil(s) and the laser beam as well as the induction parameters were defined so as to produce a maximum temperature of 700 °C on the top of the weld seam, thus avoiding microstructure transformation during induction heating. The temperature cycles were measured on the top and bottom sides using a thermo-camera VarioTherm and a color pyrometer Maurer respectively.

Table 2 describes in detail the applied welding conditions. The following sample designations were defined according to the CO_2 LBW strategy: without induction heating (A); and subjected to pre-heating (B); post-heating (C); combined pre- and post-heating (D); and induction annealing after cooling the weld seam (E).

In order to compare the suitability of induction-assisted CO_2 laser welding for joining TMP steel grades with another LBW approach using a minimum heat input, a sample (F) was additionally produced without induction heating applying a Nd:YAG fiber laser. In this case the laser power was 4 kW and the welding speed was increased to 1.5 m/min.

Table 1
Chemical composition of the rolled TMP-HSLA-S500MC steel selected for this study (wt%) [25].

Element	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Al (%)	Ti (%)
Composition	0.12	1.5	1.7	0.025	0.015	0.015	0.15

2.3. Microstructure assessment

Microstructure characterization was carried out by optical microscopy (OM), scanning electron microscopy (SEM) and electron backscattering diffraction (EBSD). The SEM–EBSD analyses were performed using a Jeol JSM-6490 SEM equipped with a tungsten filament and a Pegasus EDAX/TSL EBSD system. The microstructure inspection was conducted on the butt-joint cross sections covering all relevant regions: base material (BM), heat-affected zone (HAZ) and fusion zone (FZ).

The samples were extracted from the butt-joints by spark erosion and subjected to standard metallographic grinding and polishing. The OM specimens were finally etched for 1 min in a 1% Nital solution for revealing the welded microstructure. The samples for the EBSD investigations were subjected to a final chemical polishing for 3 min using a solution of 10 mL HF and 100 mL H_2O_2. The OM characterization focused on the qualitative microstructure assessment, whereas the EBSD-analyses were applied to quantify the microstructure constituents.

The EBSD measurements were carried out using step sizes between 0.08 and 0.15 μm for the high resolution maps and 1.5 μm to record the overviews of the welded regions. The results were analyzed applying a procedure based on the grain average values of the image quality (IQ) and the distribution of the boundary misorientations [26,27,31,32]. The grain average IQ is associated with the sharpness of the Kikuchi patterns, which can be correlated to the local average level of lattice distortion of each grain caused by crystal defects (e.g. dislocations and grain boundaries) [27,28]. This parameter is suitable for quantifying multiphase low-alloyed steel microstructures, since the morphological BCC constituents (ferrite, bainite and martensite) exhibit different dislocation densities and sub-grain structures [29,30]. As a result, partitions with low average IQ values can be assigned to martensite, with intermediate values to bainite and with high IQs to ferrite. Thus, the formation of multiphase microstructures within the characteristic regions of the welded cross-sections causes multimodal distributions of grain average IQ. The deconvolution of the IQ distributions can be carried out by applying Gaussian populations to describe each constituent [31,32].

However, the grain boundary regions reveal low IQ values such as those of the martensitic structure. They therefore need to be filtered out of the data before applying such evaluation. Hence,

Table 2
Welding conditions applied to each sample.

Sample nomenclature	Laser sources	Welding conditions
A	CO_2	Reference sample: produced without any induction heat treatment
B	CO_2	Pre-heated sample: produced only with an inductor power of 11 kW and frequency of 6 kHz positioned 10 mm in front of the laser beam
C	CO_2	Post-heated sample: produced only with an inductor power of 5 kW and frequency of 6 kHz positioned 24 mm behind the laser beam
D	CO_2	Pre- and post-heated sample: produced simultaneously with an inductor power of 11 kW and frequency of 18 kHz positioned 21 mm in front of the laser beam and with an inductor power of 4 kW and frequency of 6 kHz positioned 180 mm behind the laser beam
E	CO_2	Annealed sample: produced discontinuously. The sample was welded, cooled down to room temperature and then annealed using an inductor power of 9 kW and frequency of 6 kHz
F	Nd:YAG	Produced to investigate the consequences of minimum heat input in comparison to the CO_2 welding strategies with and without induction heating

Download English Version:

https://daneshyari.com/en/article/1576095

Download Persian Version:

https://daneshyari.com/article/1576095

Daneshyari.com