Effect of Welding Methods on Mechanical Properties of Domex 700MC Steel

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Abstract. Recent years have seen a lot of research on modern steels with higher yield strengths. The study investigates the microstructure and mechanical properties of two different welding techniques - gas metal arc (GMA) and laser beam (LB). The result of this study showed a significant softening effect in the heat-affected zone (HAZ) for both welding techniques, the GMA and LB, resulting from formation of a coarse-grained microstructure during welding. The findings of this study increased understanding and added to the body of knowledge in the rapidly growing field of GMA and LB welding processes of HSLA steels.

Introduction

High mechanical properties and fine-grained microstructure of high-strength low-alloyed (HSLA) steels resulting from low carbon content and microalloying up to 0.15 wt.% by niobium, titanium, and vanadium are achieved by thermomechanical controlled treatment [1,2]. Domex 700MC steel is a high-strength, low-alloy steel that is widely used in bridge and crane construction. The welding procedure employed during fabrication can have marked impact on the mechanical properties. Gas metal arc welding (GMA) and laser beam welding (LB) are two of the most frequent welding processes used on Domex 700MC steel. Each of these techniques can generate different rates of heating and cooling, heat input and distortion, all of which can alter the mechanical properties of the steel [2,3]. The core problem is the formation of the coarse-grained microstructure in the HAZ during welding, after the rapid cooling from high temperatures. It is essential to conduct the behavior of these steels in the heat-affected zone during the welding process, especially in terms of safety.

Experimental Material and Methods

Experimental material. The 10 mm thick sheet of hot-rolled structural steel Domex 700MC produced by SSAB steelwork company was used to perform experimental part of the paper. An optical emission spectrometer (OES) was used to define the chemical composition of experimental material, and the obtained result is shown in Table 1.

Table 1. Chemical composition of Domex 700MC [wt.%]

C	Si	Mn	S	P	Al	Nb	V	Ti
0.12	0.09	1.99	0.07	0.014	0.02	0.05	0.104	0.07

For microhardness identification of base metal and the weld joint samples, the standard hardness testing method, and the procedure, specifically Vickers line microhardness testing (HV1), was used.

Welding procedures. Two welding techniques, GMA and the LB, have been applied to provide the experimental part. In accordance with the recommendations of the EN 10146-2 standard, low-alloy wire OK AristoRod 69 with a diameter of 1.2 mm was used as filler material for GMA welding. Welding conditions for GMA welding are described in Table 2. For the laser welding regime, the parameters are shown in Table 3.

Table 2. Specifications for the GMA welding procedure

	Electrode	**Diameter [mm]**	**Voltage [V]**	**Current [A]**	**Welding speed [mm/s]**
Root layer	OK AristoRod 69	1.2	23.3	164	4.8
Top layer			28.2	230	5

Table 3. Specifications for the LB welding procedure

Power [kW]	**Defocusing distance [mm]**	**Welding speed [mm/s]**
5	-4	7.5

The welding conditions for both methods were optimized to ensure complete material flow, proper formation of the weld root and weld bead, and also the absence of external or internal defects.

Microstructure. The microstructure was observed with an optical microscope. Experimental samples of base metal and HAZ were prepared and analyzed. Etching by 2% Nital ensured the reveal of ferrite grain boundaries.

Results and Discussion

Microhardness. The line measurements in the cross-sections of welded samples revealed distinctive changes in the final microhardness profiles, starting in the base metal, continuing in HAZ, and ending in the weld metal (mirrored results). The results of the GMA weld joint sample are shown in the left column of Fig. 1, and those of the LB weld joint sample in the right column.

Since GMA welding uses a wire electrode with a similar chemical composition to the base metal, the hardness results of base and weld metal are comparable. The laser beam is directed at the point of the weld, creating a small, highly concentrated heat-affected zone that melts the metal, creating a weld. The HAZ and weld metal width in the outcomes of the GMA and LB weld joints varied significantly, which is related to the heat input. The GMA welding process is a relatively low heat input process, while laser beam welding is a high heat input process which results in narrower welds as well as the HAZ. The width of the weld metal also varies depending on the measurement position of the individual measure lines A, B, and C. Sharp decrease in microhardness (softening phenomenon) is a result of the rapid coling rates from high temperatures and is associated with the formation of a coarse-grained microstructure. The formation of coarser grains occurs in a region referred to the coarse-grained HAZ (CGHAZ). In comparison to base metal, the microhardness of the CGHAZ decreased in GMA weld joint samples by 28.6% and in LB weld joint samples by 15.4%.

Microstructure. The microstructure of the base metal (Fig. 2) represents a very fine ferritic microstructure with uniformly dispersed very fine cementite particles and locally dispersed coarse TiC-based carbides.

The coarse-grained heat-affected zone (CGHAZ) and the fine-grained heat-affected zone (FGHAZ) were identified as the two primary regions of the HAZ in each weld (Fig. 3). The CGHAZ suffers a higher temperature during the welding process than the FGHAZ since it is situated nearer the weld metal.

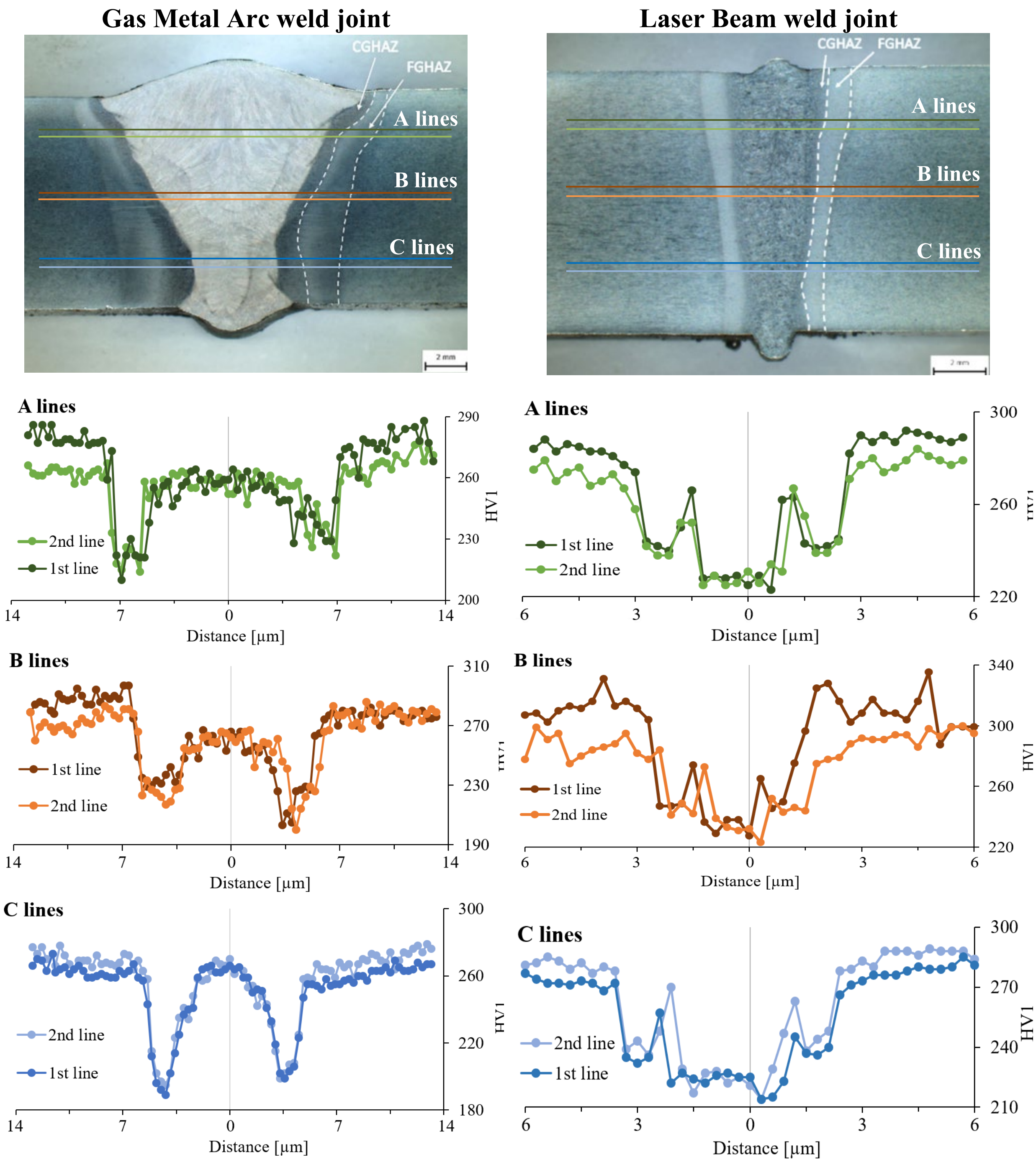

Fig.1. *Microhardness line measurements of: GMA weld joint sample (left column), and LB weld joint sample (right column).*

The high cooling rate and the large grain size of the CGHAZ result in a coarser microstructure. The grain size increases as a result of the recrystallization process, giving the material a coarser microstructure. On the contrary, the FGHAZ has a finer microstructure since it is farther away from the weld metal and receives a lower temperature during the welding process.

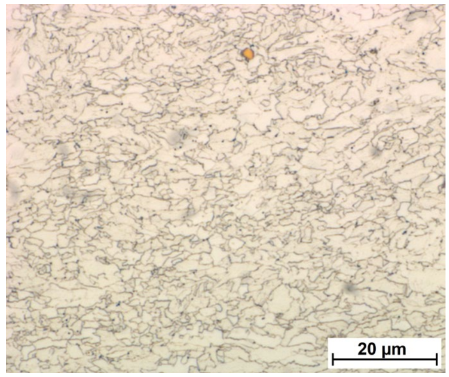

Fig.2. *Microstructure of the base metal Domex 700MC.*

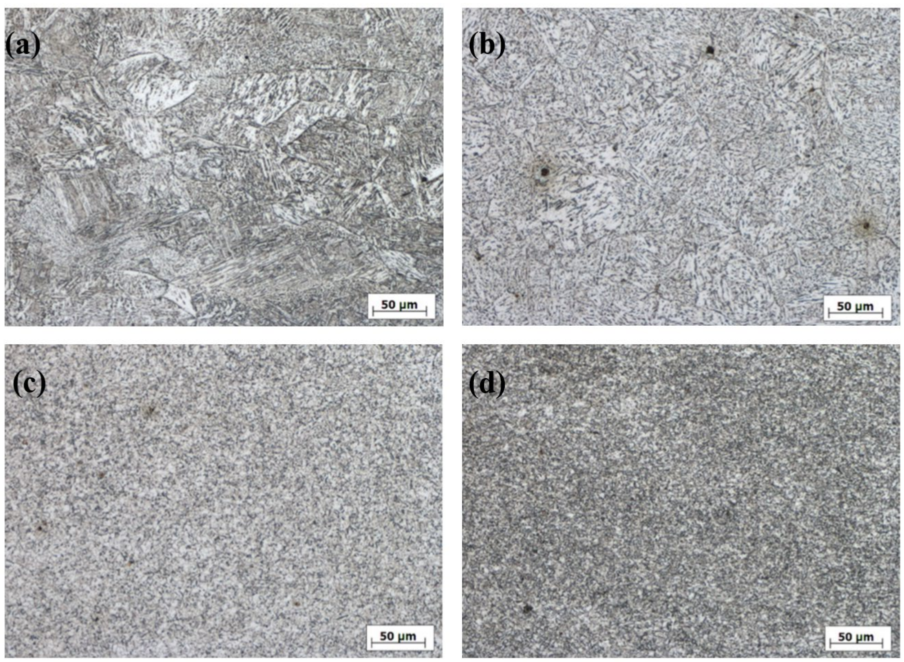

Fig.3. *The HAZ microstructure analysis:*
(a) CGHAZ of the GMA weld joint sample; (b) CGHAZ of the LB weld joint sample;
(c) FGHAZ of the GMA weld joint sample; (d) FGHAZ of the LB weld joint sample.

Conclusions

The following can be concluded from the testing and analysis that were conducted:

- The character of the microhardness profiles varies as a result of the application of specific welding techniques.
- In both cases, despite the difference in the welding methods used, softening occurs in the HAZ.
- GMA welded joints promoted a larger decrease in microhardness in the HAZ than LB welded joints. Microhardness results showed a decrease of 15.4% in the HAZ for samples welded using the LB method and a decrease of 28.6% for samples welded using the GMA method.

- The LB welding method has greater impact on the microstructural changes and mechanical properties than GMA welding method.
- The base metal has a very fine-grained ferritic microstructure with uniformly dispersed fine cementite particles. Two primary regions in the HAZ were identified in samples of both welding methods, CGHAZ and FGHAZ.
- A problematic CGHAZ region is represented by microstructure with coarse grains resulting from the recrystallization process.

It may be concluded that the most critical part of the weld join is the HAZ, especially the CGHAZ region, indicating the degradation of mechanical properties due to the formation of a coarse-grained microstructure.

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References
[1] P. Kopas et al. Comparison of the mechanical properties and microstructural evolution in the HAZ of HSLA DOMEX 700MC welded by gas metal arc welding and electron beam welding, MATEC Web of Conf. 244 (2018) art.01009. https://doi.org/10.1051/matecconf/201824401009

[2] M. Mazur et al. The Structure and Mechanical Properties of Domex 700 MC Steel, Commun. – Sci. Lett. Univ. Zilina 15 (2013) 54-57. https://doi.org/10.26552/com.C.2013.4.54-57

[3] Y.A. Takahashi et al. Influence of Roughness on Corrosion Resistance of Carbon Steel SAE 1020 and DOMEX 700 MC Steel, Mater. Sci. Forum 1012 (2020) 441-446. https://doi.org/10.4028/www.scientific.net/MSF.1012.441