LASER BEAM WELDING OF QUENCHED AND TEMPERED ASTM A 517 GR.B STEEL

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ABSTRACT

Quenched and tempered steels are required to combine high yield and tensile strengths with good notch toughness, ductility and weldability. However, toughness and soundness of these steels can be affected by welding operations, in particular Heat Affected Zone (HAZ) may undergo embrittlement and cracks through the heating cycles. In this paper, a preliminary investigation is done on welds of steel ASTM A 517 Gr.B, carried out by utilizing LBW process without any filler metal. Experimental work included metallographic examination and microhardness survey. The results show the formation of a mixed bainitic-martensitic structures in the Heat Affected Zone (HAZ), due the relatively high cooling rate of the re-austenitized region close to the melted zone. If compared to Shielded Metal Arc (SMAW) process, LBW technique gives rise to an advantageous reduction of areas of both fusion and heat affected zones, less distortion and residual stresses. The measured HAZ was about 0.40 mm wide, instead of about 1.50 mm as obtained with SMAW process. In spite of higher cooling rates typical of LBW process, hardness values are of the same order as with SMAW process.

KEYWORDS

Laser Beam Welding- Quenched/Tempered Steels – Weld Toughness- Weld Microhardness-Mechanical properties-Metallographic observations

INTRODUCTION

Quenched and tempered steels can combine high yield and tensile strengths with good notch toughness, ductility and weldability. These steels are commonly utilized on welded constructions and are particularly convenient whenever the increase of mechanical resistance gives rise to a proportional reduction of weight. Several studies have been carried out about characteristics of these welded joints [1,2,3]. As well known, toughness and soundness of these steels can be affected by welding operations, which induce metallurgical modifications in the HAZ consequent upon the heating cycles [4,5]. It is recognized that the slower is the cooling rate during welding operations, the wider is the alteration and the reduction of toughness; consequently welding process with controlled heat input are preferred. Laser Beam Welding (LBW) process, among others, offers low thermal input and is established as joining technique in several manufacturing sectors, such as in the automobile and in the shipbuilding industry [6,7]. The expected advantages of LBW technique are the improved mechanical properties due to reduced fusion zone and HAZ and the easy automation of welding operations.

1. MATERIALS

The material utilized in welding trials is the low-alloy steel ASTM A 517 Gr.B, in form of plates, 10 mm thick, supplied in the quenched and tempered condition. In Tables 1 and 2 are reported here-below the composition and the mechanical properties of the steel as-supplied.

HOME

Table 1- Composition of the steel (from Supplier Certificate)

Specification	C	Si	Mn	P	S	Cr	Mo	Ti	V	B
A 517 Gr B	0.20	0.26	0.90	0.015	0.006	0.54	0.23	0.03	0.06	0.003

Table 2- Mechanical properties of the steel as-supplied (from mechanical tests)

N. of samples	Yield strength (MPa)	Tensile strength (MPa)	Elongation %
4	821	881	18

The utilization of filler metal with LBW process would permit a favorable influence on formation of the fusion zone, in particular to avoid risks of martensitic transformation in the weld metal [9,10]. In the present case however, aiming to focus on the HAZ characteristics, no filler metal was used. Some bead-on-plate welds were carried out with the welding parameters as reported in Table 3 .

Table 3 – Laser Beam Welding parameters (LBW)

Power at the workpiece (kW)	1.5
Welding speed (cm/s)	2.0
Estimated net Heat Input (kJ/cm)	0.60
Distance Δz (mm)	0
Focal radius (μm)	600
Filler metal	None
Position	Flat (*)
Edge preparation	Squared
Preheat	None

(*) Plate on horizontal plane with laser beam on upper side.

In order to compare LBW and conventional Shielded Metal Arc Welding (SMAW) process, some bead-on-plate welds were carried out with this last technique, by using a suitable coated electrode the welding parameters reported in Table 4 .

Table 4 – Shielded Manual Arc Welding parameters (SMAW)

Specification of electrodes	ASTM E 11018-M
Diameter of electrodes (mm)	3.25
Current Intensity (A)	110...120
Voltage (V)	22
Arc travelling speed (cm/s)	0.7
Estimated net Heat Input (kJ/cm)	2.85
Preheat	None

2. EXPERIMENTAL WORK AND RESULTS

Cross sections of welds were submitted to visual examination, Vickers microhardness survey and metallurgical observations with optical microscope. Some optical micrographs are shown on Fig.1-3 for LBW process and on Fig.6 for SMAW process. The profiles of microhardness are reported on Fig.4 and 5 for the two processes.

HOME

3. DISCUSSION

The investigation on properties of these welds should start from evaluation of metallurgical transformations evaluated on Isothermal Transformation diagram, available for this class of steel [11]. This steel has some significant features, such as the long duration of time passed before transformation of austenite to ferrite-pearlite begins in the temperature range 550-650°C. Lower bainite and martensite structures, instead of mixed structures of ferrite-pearlite-upper bainite, are easily achieved, reaching good toughness and homogeneity, particularly after tempering. Martensite begins to form at a relatively high temperature (about 400°C), thus providing a good resistance to quenching cracks and some degree of self-tempering. Another beneficial feature is related to secondary hardening from precipitation of vanadium carbides at the tempering temperature of 570°C, applied by the steel manufacturer. The steel *as-supplied* consists of tempered martensite with fine carbides.

Welding heat melts the fusion zone and raises the temperature of the region close to fusion line at over a temperature high enough to make complete the transformation ferrite→ austenite. Microstructural changes occurring in the HAZ depend on the kinetics of formation of austenite and its grain size. The closer the distance to the fusion line, the higher is the peak temperature and the hold time at elevated temperature. Accordingly, microscope observations revealed the formation of the following zones:

a) Fusion Zone, rapidly solidified and cooled, with a structure that is likely to consist of martensite (white) mixed to bainite (dark) (Fig.1,2) with hardness HV 450..500.

b) HAZ- subzone 1, about 0.30 mm wide, where the austenite developed during heating over the point A3 (about 820°C), which marks for this steel the complete transformation of ferrite to austenite, gives rise to a mixed martensite-bainite structure, (Fig.1) with a peak microhardness of HV≅ 520;

c) HAZ- subzone 2, 0.10 mm wide, where the temperature is ranging between A3 and A1 (about 720°C, where austenitic transformation starts), with partial austenitization and formation during cooling of a mixture of transformation structures of prior austenite and untransformed ferrite.

d) untransformed Base Metal, which reached temperature less than 720°C, with hardness equal to the initial one (HV=260..280).

It is interesting to compare structures and hardness achieved with SMAW process. In spite of higher cooling rates typical of LBW process, the peak hardness(Fig.5) is of the same order (HV=530) and the structures (Fig.6) are similar to those as above described for LBW. However, due to the higher heat input utilized, a wider HAZ (about 1.5 mm) was obtained. It is confirmed that LBW technique allows an advantageous reduction of areas of both fusion and heat affected zones, if compared to SMAW process, thus giving rise to less distortion and residual stresses.

4. CONCLUSIONS

The results show the formation of a mixed bainitic-martensitic structures in the HAZ single-pass welded joint, due the relatively high cooling rate of the re-austenitized region close to the melted zone. The HAZ, due to the presence of martensitic structure, undergoes hardening and loss of toughness. In the case of conventional arc welding, the width of HAZ is usually greater (as in the studied case) than in LBW. Moreover, residual stresses generally increase as weld zone area increases. Therefore high energy density LBW allows to reduce effectively residual stresses.

With conventional SMAW process, since the zone subject to loss of toughness and to tensile residual stresses is quite larger than zone achieved with LBW process, possible cracks formed after welding are more likely to grow and propagate through brittle fracture and fatigue mechanisms.

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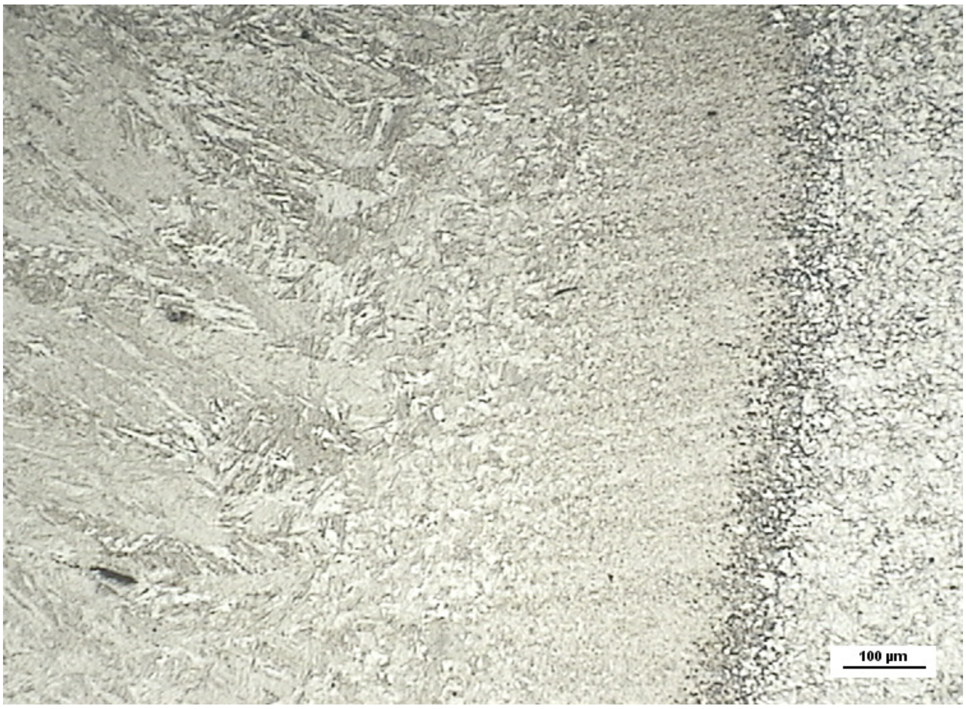

Fig.1 – Overall view of the microstructures, from left to right: fusion zone, HAZ and base metal

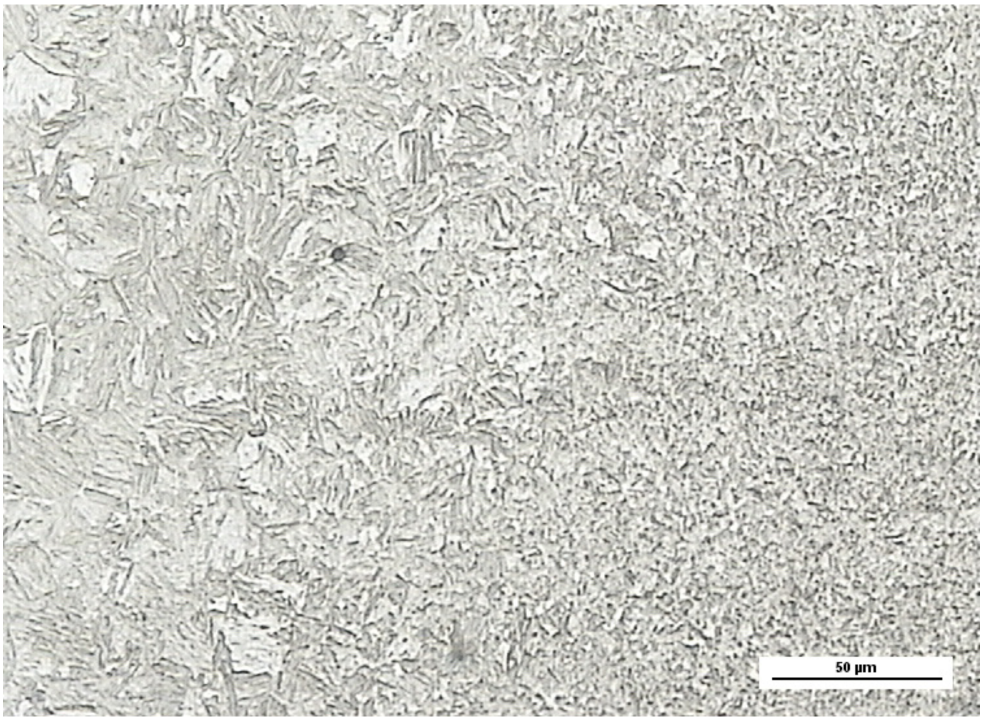

Fig.2 – Detail of interface between fusion zone (left) and HAZ (right)

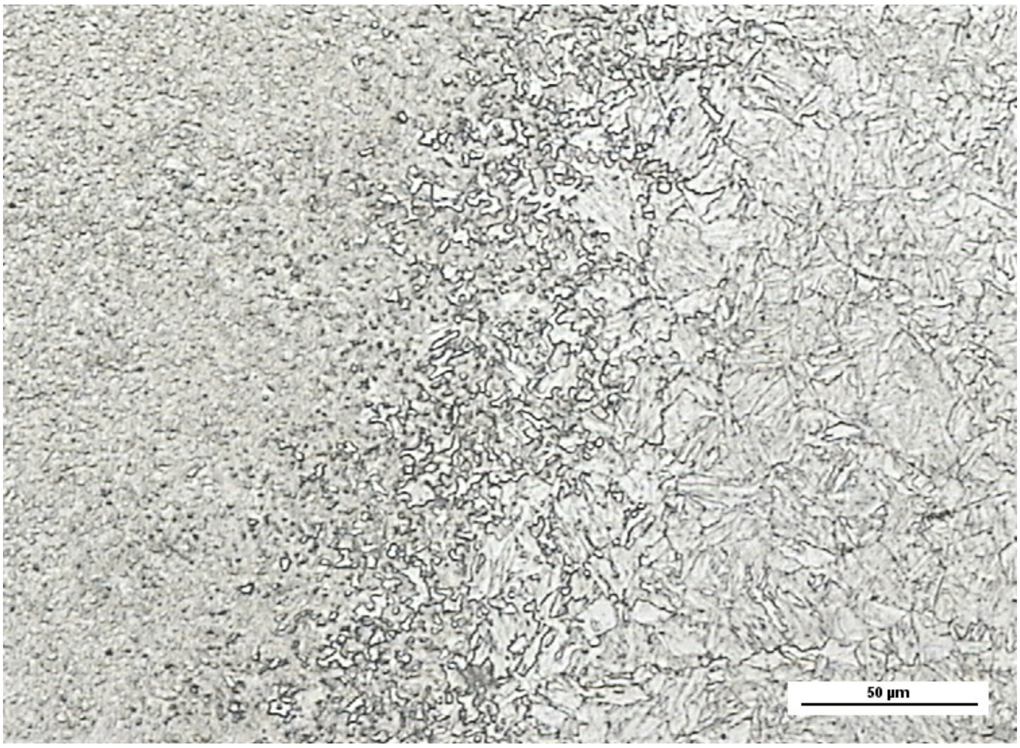

Fig.3 – Detail of transition from HAZ (left) to the base metal (right)

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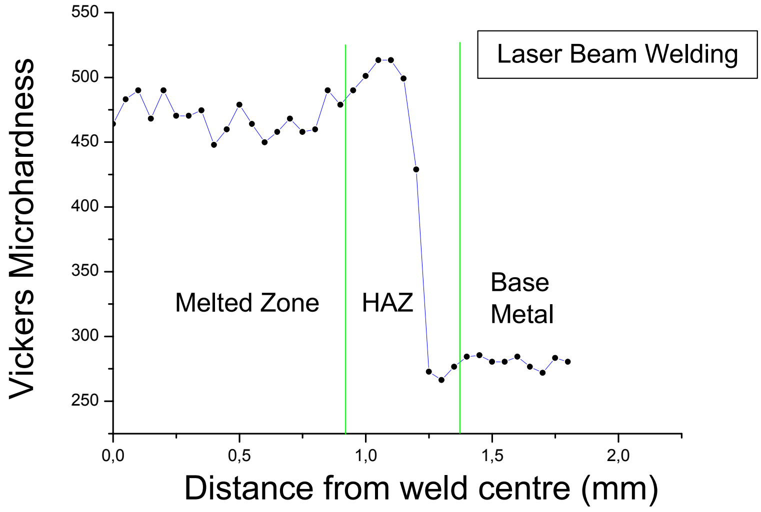

Fig.4 – Microhardness survey along cross section of LBW joint

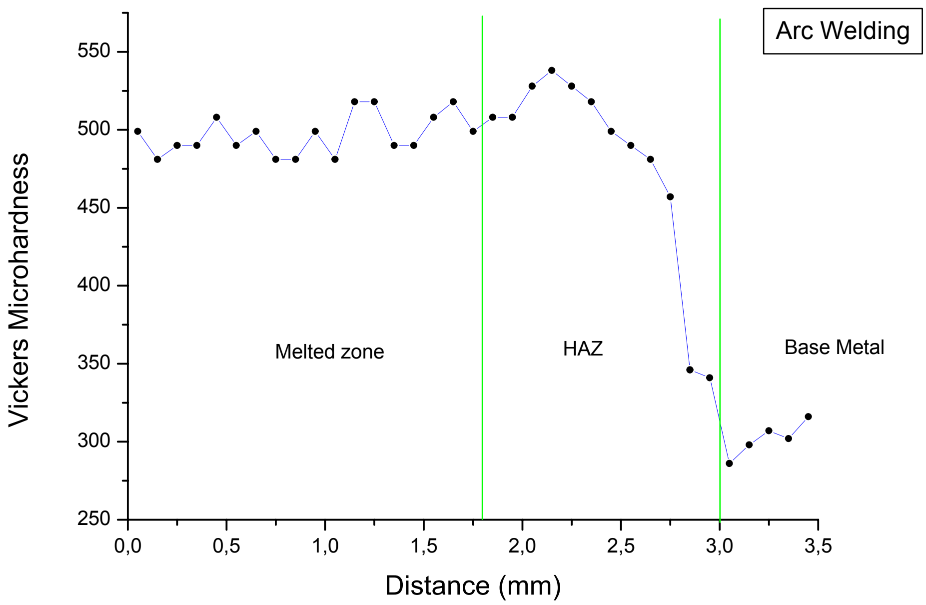

Fig.5 – Microhardness survey along cross section of SMAW joint

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Fig.6 – SMAW joint- Overall view of microstructures.
From left-high to right-low: fusion zone, HAZ and base metal