

Effect of Heat Treatments on Microstructure and Mechanical Properties of Low Carbon Steel Pipes Welded by Induction Process

Zakaria Boumerzoug^{1,a*} and Lakhdar Lakhdari^{2,b}

¹Department of Mechanical Engineering, Biskra University, B.P. 145, Biskra-7000- Algeria.

²University of Adrar, Adrar, Algeria

* Corresponding author

^ae-mail: zboumerzoug@yahoo.fr ^be-mail : lakhdari_hit@yahoo.fr

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Abstract. In this work, the effect of isothermal heat treatments on microstructure evolution and mechanical properties after welding by induction of A37 pipeline steel have been studied by scanning electron microscopy, hardness measurements, and tensile tests. Microstructural evolution in welded joint was identified after isothermal annealing from 200 until 900 °C.

Introduction

Welding is a process of joining materials into one piece. Generally, welding is the preferred joining method and most common steels are weldable. Low carbon steels that have less than 0.25 % carbon display good welding, because they can be generally welded without special precautions using most of available processes. Induction welding is a form of welding that uses electromagnetic induction to heat the workpiece. Induction welding is used for long production runs and is a highly automated process, usually used for welding the seams of pipes. High frequency induction welding is widely employed for longitudinal seam welding of small scale tubes and pipes due to its relatively high processing speed and efficiency [1].

However, steel line pipes produced by high frequency induction welding can result in a low-toughness zone at the weld junction, even after a heat treatment which re-austenitises the affected region. It is found that the toughness is reduced primarily by the tendency for cleavage planes of ferrite crystals to align and hence create a macroscopic plane on which cleavage can propagate easily with little resistance from grain boundaries. This mechanism suggests that an appropriate heat treatment may alter the texture sufficiently to enhance the toughness of the zone concerned [2].

It is known that the welded thermal cycle in the heat-affected zone causes drastic microstructures changes in the engineered microstructure of the base metal [3,4]. Consequently, an annealing heat treatment subsequent to the welding operation can reduce these negative effects. As reported by Yan et al [5], the joint resulting from induction welding is quite narrow, with a central 2 mm wide region, but it represents a source of weakness, so welding is immediately followed by induction heat treatment.

The purpose of this present work was to study the effect of heat treatment on microstructures and mechanical properties after induction welding of A37 pipeline steel.

Experimental Procedure

The explored material was A37 steel with chemical composition Fe-0.11C-0.145Mn wt % with micro-alloying of Nb and V. Figure 1 presents the spectrum of analysis by EDAX of pipeline steel. Parameters of induction welding were : I= 25 A, V= 15 Kv and Frequency = 360 kHz , displacement rate = 50 m/min. Specimens were obtained from different stages of manufacturing process, i.e. the unaffected base metal and the pipe just after welding. In order to study the heat treatments effects on welded specimens of A37 pipeline steel, isothermal annealing were

performed in electrical furnace at different temperatures (200, 400, 600, 800 , and 900 °C) during 5 and 30 min. The tensile test of A37 pipeline steel was realized at room temperature on the universal testing machine UMIB 5005 SW. Tensile test specimens of size (gauge length 500 mm, width 35 mm and thickness 3 mm). Test results of tensile experiments were an average of three specimens. Cross-weld microhardness measurements were carried out on the as-welded samples and the samples after isothermal heat treatments by using a Leitz microhardness tester with a load of 500 g and dwell time 15s. The samples were analysed by scanning electron microscope after suitably polishing and etching the surface (using nital 2 %). Consequently, the microstructures of the base, weld and the heat affected zone were defined.

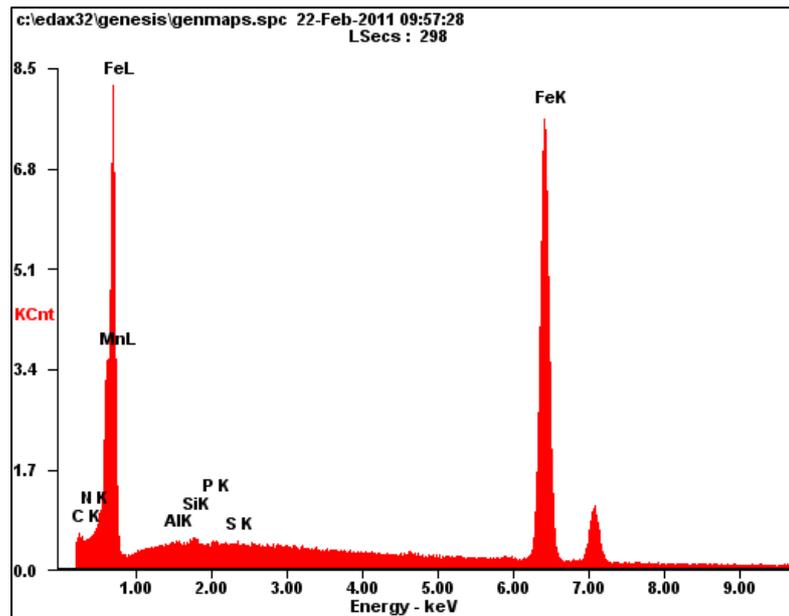


Fig.1 Spectrum of analysis by EDAX of pipeline A37 steel

Results and Discussions

SEM observations

Microstructures after welding

In order to clarify the effect of welding on the base metal, the microstructures of welded joints were inspected with a scanning electron microscope. Figure 2 shows the welded joint before heat treatments, it is clear that there is a difference between all regions. Generally, the metallurgy of the welded joint can be categorised into two major regions, the fusion zone (FZ) and the heat-affected zone (HAZ). It is known that the microstructure that evolved in the weld is heterogeneous due to the temperature gradients and the chemical gradients that evolve during the process [6].

However, in our case the center of weld metal (FZ) is characterized by a finer grains which is the result of the fastest cooling rates. It appears that this zone contains mainly ferrite and some colonies of pearlite. However, the HAZ has a typical microstructure of the base metal which is composed of grains of ferrite (α -Fe) and small regions of pearlite (α -Fe + Fe₃C) at grain boundaries edges and corners. Concerning the welded joint after induction welding, Yan et al have observed [5] a narrow central zone at the weld junction by induction welding with a coarse microstructure.

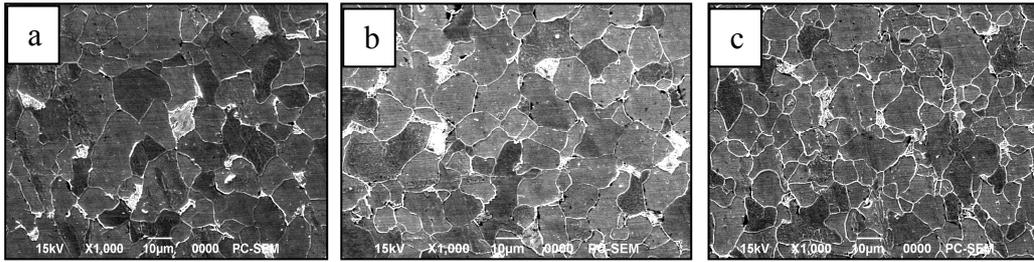
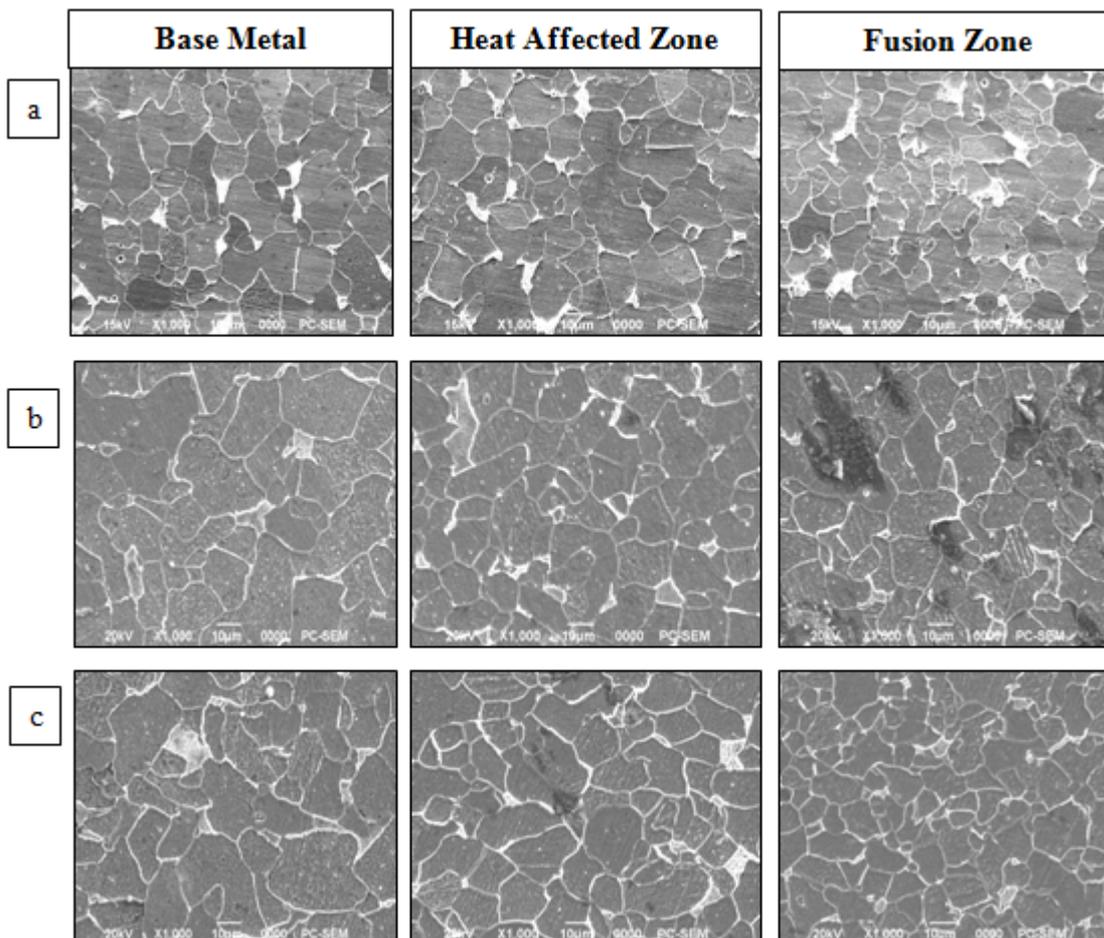


Fig. 2 Microstructures of welded joint of A37 steel (a) base metal, (b) Heat Affected Zone and (c) Fusion Zone.

Microstructures evolution of heat treated welded steel

Figure 3 presents the microstructural evolution of the welded joint after isothermal heat treatments from 200 until 900°C. Heat treating of welded joints at 200°C for 30 minutes is considered as temper after the severe heat treatment caused by the welding process. This treatment does not change the microstructures of welded joint, but the heat treatments at 400°C or at 600°C induce a slight grain growth in all three regions (HAZ and FZ). However, the heat treatment at 800 °C provokes the grain growth of ferritic phase. Contrary to other isothermal annealing, heat treatment of welded joint at 900 °C induces the refinement reaction of grains of ferrite. In this last case, the grain-refinement region is subject to a peak temperature just above the effective upper critical temperature AC_3 , thus allowing austenite grains to nucleate. Such austenite grains decompose into small pearlite and ferrite grains during subsequent cooling [5].



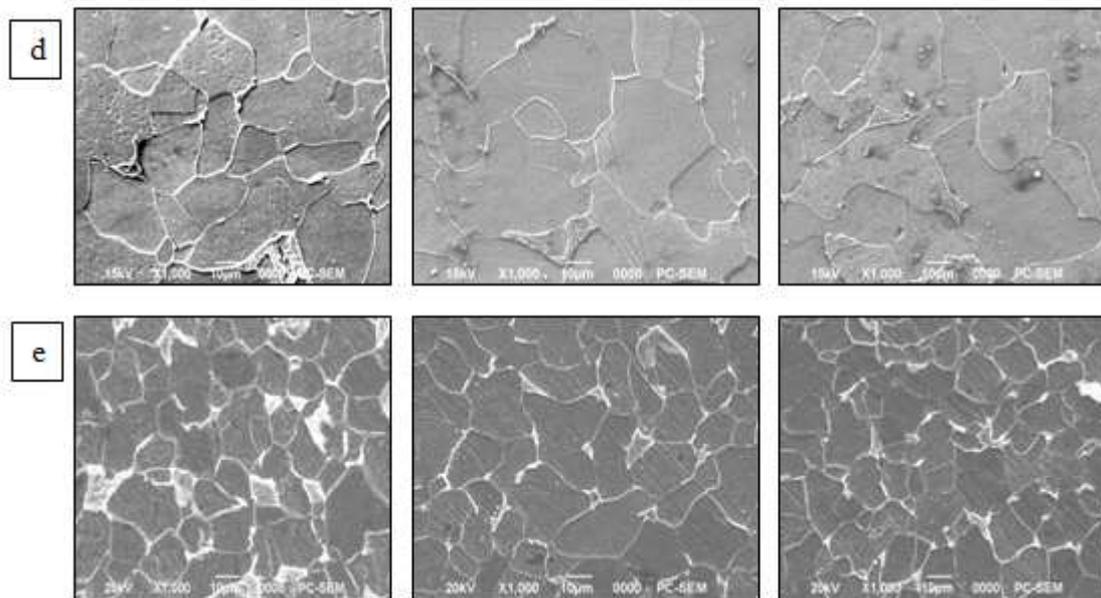


Fig.3 Microstructures evolution of welded joint of A37 steel after heat treatments during 30 min at (a) 200°C, (b) 400°C, (c) 600°C, (d)800°C and (e)900 °C.

Hardness Measurements

It was reported that a hardness testing is the usual approach in delineating the properties of these various zones, but the information obtained is very limited [2]. For other researchers, a simple rapid way to obtain important information is by hardness testing [8]. Concerning our material, the hardness distribution in different zones of welded joint of A37 steel before and after different isothermal heat treatments is shown in figure 4. The maximum hardness values of 180-205 HV are observed in welded sample at location within 3 mm which contains the fusion and the heat affected zone. Our hardness results are in good agreement with literature. Because, Gul et al [9], have found that maximum hardness values are measured in the area of weld metal (WM). The variation in properties across the weld can be attributed to several factors, mainly to residual stresses just after welding. On the other hand, other factors can contribute to this hardening like grain size, phase composition, metallic inclusions.

However, after isothermal heat treatments, only the FZ hardness is really affected by the heat treatments, but the BM hardness is also slightly decreased. As expected, heat treatment at 200°C decreases the FZ hardness much more than other isothermal heat treatments. In general, these isothermal heat treatments induce a homogenisation of hardness values between FZ, HAZ and base metal, with an average hardness value around 100-120 Hv which confirms the results of SEM observations.

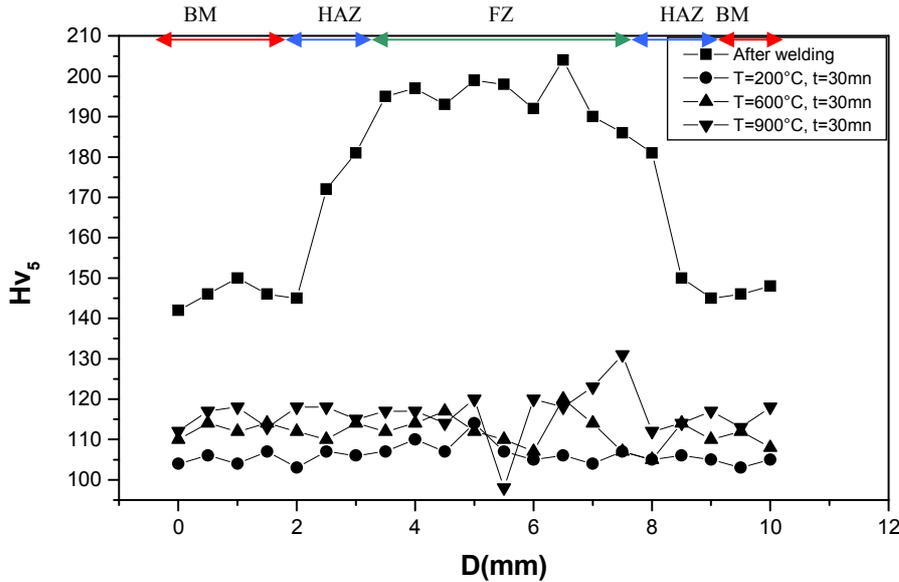


Fig. 4 Microhardness curves the base metal across the weld metal of A37 pipeline steel before and after isothermal heat treatment from 200 until 900°C during 30 min.

Tensile tests

Figure 5 presents tensile strength Rm variation after isothermal heat treatments at 200, 600 and 800 °C during 5 and 30 min. The highest strength (520-540 MPa) is obtained for the heat treated material at 200° C which corresponds to the appropriate value for such welded steel.

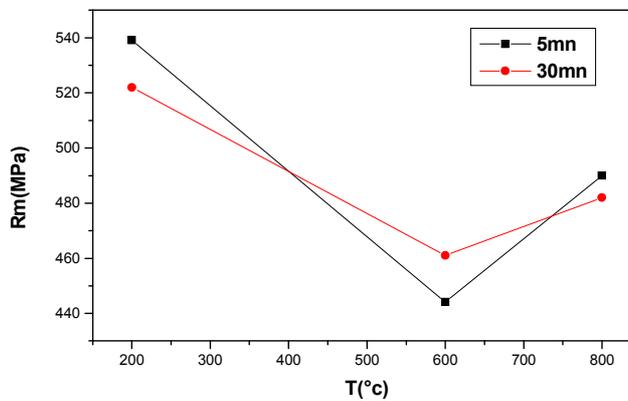


Fig. 5 Tensile strength Rm variation at different temperatures of welded A37 pipeline steel.

In order to understand the fracture mechanism of this material, fractured samples by tensile test were analyzed by a SEM. Figure 6 presents SEM observation of the rupture surface after tensile tests. Observation of all fractured samples presented characteristics of a quasi-cleavage fracture (QC). According to Yajiang et al [10], the fracture appeared as cleavage fracture along {100} surface of ferrite where some inclusions are precipitated on the {100} cleavage surface.

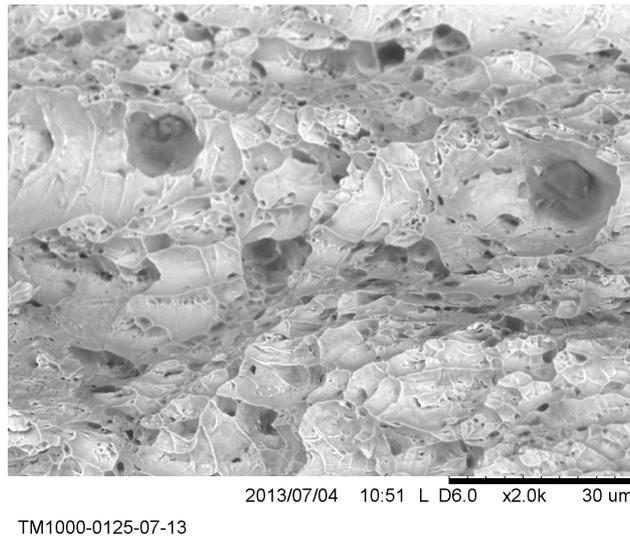


Fig. 6 SEM observations of the cross-section of the fractured welded steel by tensile tests.

Conclusion

In summary, the effect of isothermal heat treatments on microstructure evolution and mechanical properties after welding by induction of A37 pipeline steel have been studied by using optical microscopy, SEM, microhardness measurements, and tensile tests. Microstructures of heat-affected zone and fusion zone are identified after welding and also after isothermal annealing. The hardness measurements have confirmed the optical observation. Maximum hardness values were found in the area of weld metal. The isothermal heat treatment at 200°C homogenizes the hardness values across the welded joint and it gives the highest strength to the material.

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