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EFFECT OF HEAT TREATMENT ON THE MICROSTRUCTURAL EVOLUTION IN WELD REGION OF 304L PIPELINE STEEL

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ABSTRACT
In this work, the effect of isothermal heat treatments at 300 °C on microstructure evolution after welding by Tungsten Inert Gas (TIG) welding technique of 304L pipeline steel have been studied. Microstructures of the weldments were investigated using scanning electron microscopy (SEM), X-ray diffraction analysis (XRD), and hardness measurements. Microstructural evolution in welded joint was identified. Results indicated that the microstructure of fusion zones exhibited dendritic structure. The applied heat treatments affected the microstructure of the welded joint. However some defects have been observed in weld joint.

INTRODUCTION
Stainless steels are an important class of engineering materials that have been used widely in a variety of industries and environments due to their high corrosion and oxidation resistance [1]. Austenitic stainless steels are a group of steels that contain nominally 19% chromium and 9% nickel. As implied by the name, austenite is the predominant microstructural phase in these steels at room temperature [2]. Among the many 300 series austenitic stainless steel grades, AISI 304L stainless steels are extensively used in industries due to their superior low temperature toughness and high corrosion resistance [3].

In the fabrication of equipment made from stainless steels such as pipe, automotive exhaust gas system, chemical industrial equipment, etc., arc welding using shielding gas is often used [4]. Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is the most reliable method for welding stainless steels due to its significant advantages like relative cleanliness, ability of welding complicated shapes with large and small dimensions and availability of a wide range of materials[5].

The previous work on welding of 304L stainless steel were focused on Microstructure and corrosion behavior of welded material [1,9-11]. However, there are no literatures available concerning the effect of the heat treatments on microstructure evolution of welded 304L stainless steel. This type of heat treatment is called 'post weld heat treatment'. It can affect the strength and toughness of a welded joint, its corrosion resistance and the level of residual stress. Consequently, this work deals with isothermal heat treatment effect on 304L stainless steel welded by Tungsten Inert Gas (TIG) welding technique.

EXPERIMENTAL PROCEDURE

AISI 304L Austenitic stainless steel is used for transport gas pipeline applications. The chemical composition of 304L steel is presented in Table 1. The most element are obtained by EDS technique (Fig.1).

Table 1 Chemical composition of the base metal AISI 304L austenitic stainless steel (Wt.%).

Fe	C	Mn	Si	P	S	Ni	Cr
Base	0.026	1 .07	0.40	0.038	0.001	8.11	18.50

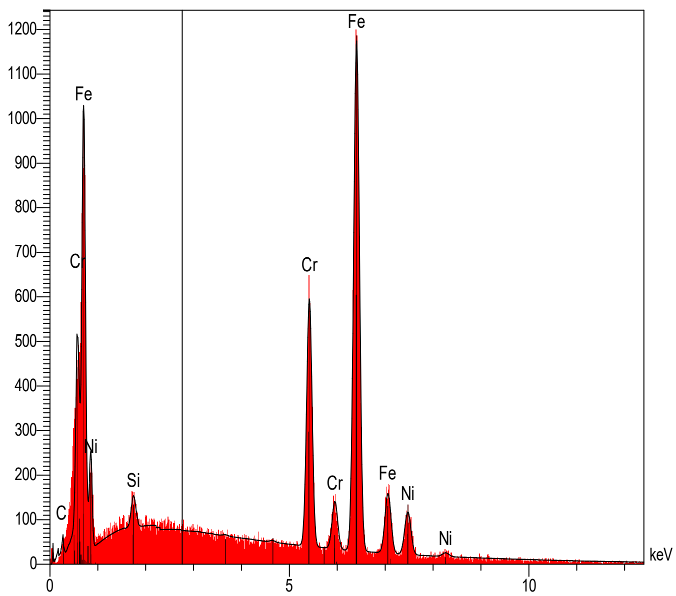

Figure 1. EDS spectrum of the base metal austenitic stainless steel AISI 304L.

V-shaped butt welds were prepared using a single-pass gas tungsten arc welding (GTAW) method. In order to study the heat treatments effects on welded specimens of 304L pipeline steel, isothermal annealing were performed in electrical furnace at 300°C during 60 min. Detailed microstructural observations were carried out in the fusion zone (FZ), heat-affected zone (HAZ) and base metal (BM) region. These zones were analyzed by scanning electron microscope after suitably polishing with SiC paper up to grade 4000 and with 0.5 µm diamond paste afterwards and etched with (HNO_3 + 30 % HF 30 % + 40 % H_2O). Electron microscopy (SEM) combined with energy dispersive spectroscopy analysis (EDS) were used. X-ray diffraction analysis was used by applying CuKα radiation in the range 20°≤ 2Θ≤ 80°. Microhardness measurements were carried out on the as-welded samples and the samples after isothermal heat treatments by using a Leco M-400-A Hardness Tester with a load of 300 g and dwell time 15s. The hardness measure is done at different zones of weldment namely base metal, HAZ and fusion zone (FZ).

RESULTS AND DISCUSSION

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. Generally, the metallurgy of the welded joint can be categorized 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. For example, Sarkar et al [12] simulated the temperature profiles in submerged arc welding of an austenitic stainless steel. They found that the distances between the center of welding line and the location where the peak temperature occurs increases slightly as the current is increased, and decrease with the increase of the welding speed. Fig. 2 presents SEM observations of BM, HAZ and FZ. It is well known that the microstructure of austenitic stainless steel is mainly composed of austenite under the condition of equilibrium solidification (Fig.2a).

The microstructure of HAZ is different to the base metal (Fig.2b). HAZ is generally comprised of an austenite matrix and interspersed ferrite precipitates, because, during the non-equilibrium rapid solidification conditions, such as in welding, the high cooling rate will result in incomplete $\gamma \rightarrow \delta$ transformation and small amounts of δ-ferrite should be remained unavoidably in the weld microstructure at room temperature. The retained δ-ferrite is known to prevent solidification and hot cracking and to improve ductility, toughness and corrosion resistance. However, it is also reported that excess δ -ferrite (usually more than 10 vol. %) can decrease the hot workability [13]. The microstructure of FZ is characterized by a lamellar morphology (Fig. 2c and 3). Because of the rapid cooling rates encountered during welding, it is convenient to consider the FZ as a minicasting. During growth of the solid in the weld pool, the shape of the solid-liquid interface controls the development of microstructural features [14].

It was reported that a hardness testing is the usual approach to evaluate the mechanical properties of these various zones. For other researchers, a simple rapid way to obtain important information is by hardness testing [15]. Concerning our material, the highest value of hardness is obtained in HAZ (185Hv) and the lowest value is measured in BM. We notice that the Heat-Affected Zone (HAZ) is a part of a base metal which, while not melted still, has had its chemical properties altered by high temperature heat.

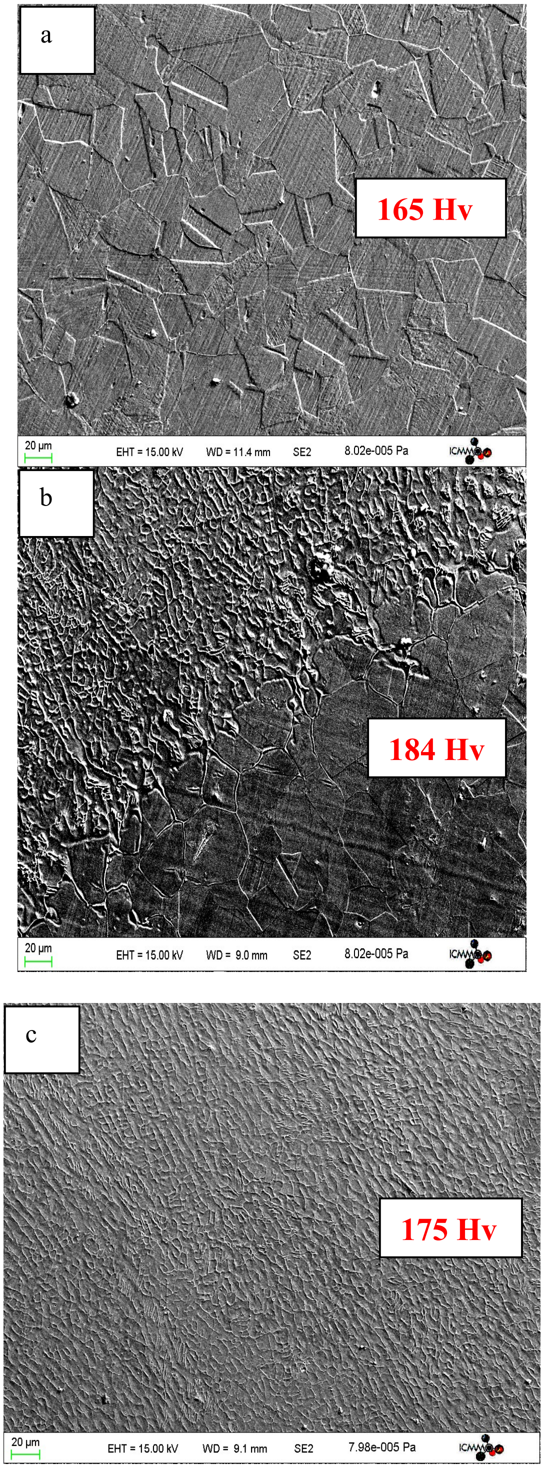

Figure 2. SEM observations of the base metal (BM), (b) the heat affected zone (HAZ) ,and (c) the fusion zone (FZ) OF austenitic stainless steel AISI 304L after welding.

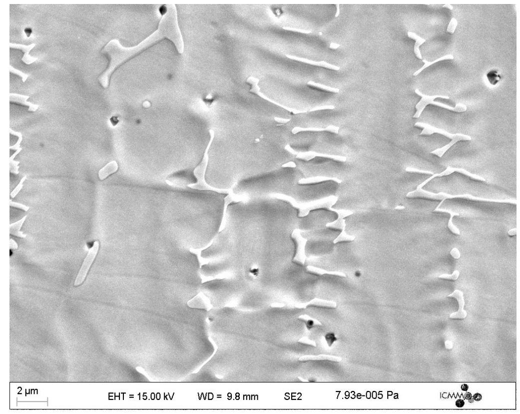

Figure 3. High magnification of fusion zone of austenitic stainless steel AISI 304L after welding.

In order to determine the main phases in the different zones of welded joints (BM, HAZ, and FZ), X-Ray diffraction was applied particularly in these specific regions (Fig.4). As can be seen, only austenite peaks were observed in the base metal. However, both austenite and ferrite delta peaks were observed in FZ and HAZ. It has been found that the delta ferrite may form during solidification of steels and welds. In addition, with increasing rate of solidification and following fast cooling the delta ferrite content of austenitic ferritic welds increases [16].

It is known that several types of discontinuities may occur in welds or heat affected zones. Welds may contain porosity, slag inclusions or cracks. In our welded steel, some cracks were observed in welded zone (Fig. 5). For our case, this crack can be acceptable as defect because it has a limited size. This cracking is the result of solidification, cooling, and the stresses that develop due to weld shrinkage [17]. Two general forms of cracking have been observed to occur in welded austenitic stainless steels. They are:

1) In the weld metal during or immediately after welding.
2) In the base metal near a weld joint [18].

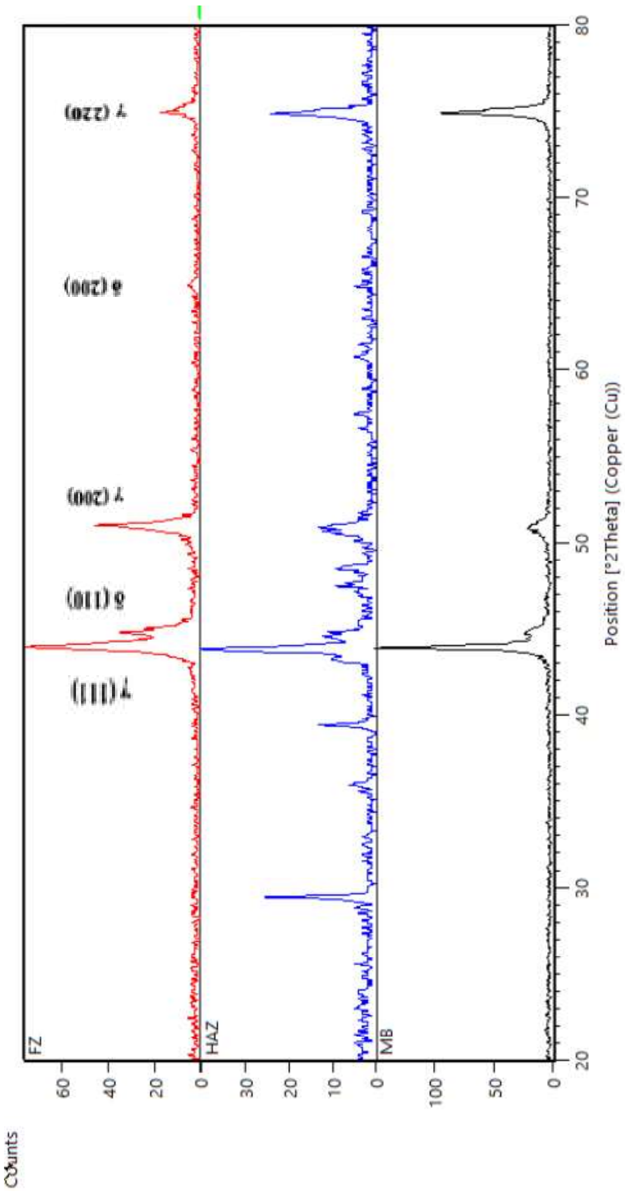

Figure 4. XRD spectrum at different zones : B M , HAZ and FZ of welded austenitic stainless steel AISI 304L .

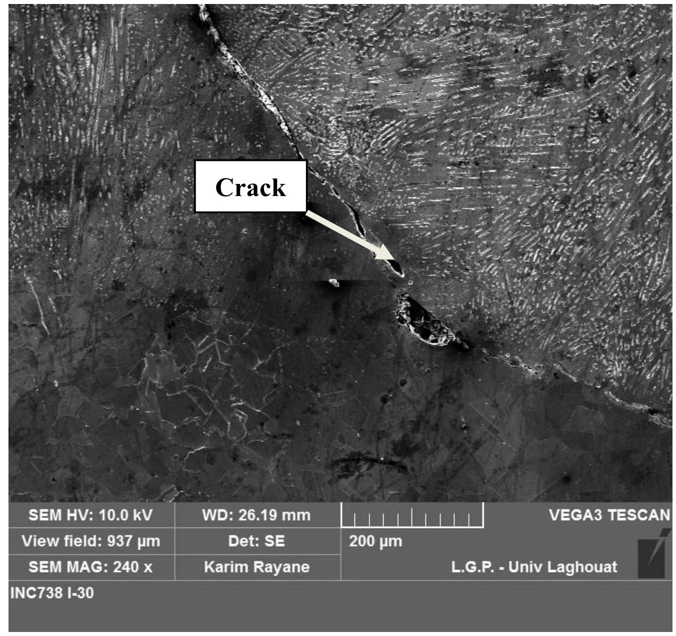

Figure 5. SEM observation of the welded joint in fusion zone of welded austenitic stainless steel AISI 304L .

Microstructures Evolution of Heat Treated Welded Steel

Figure 6 presents the microstructures of the welded joint after isothermal heat treatments at 300 °C during 60 minutes. Concerning the heat treating of welded joints at 300°C for 60 minutes is considered as tempering heat treatment after a severe heat treatment caused by the welding process. This treatment does not change the microstructures of welded joint, but it reveals clearly the morphology of each zones. First of all, there is not microstructural evolution in base metal (Fig. 6a). The heat affected zone is characterized by a slight grain growth (Fig. 6b). However, the fuzion zone (Fig. 6c) shows a dendritic structure with two distinct regions which indicated by A and B. Region A corresponds to the dendrite phase while region B belongs to the interdendritic phase. The same microstructure has been observed by Mirshekari et al [1].

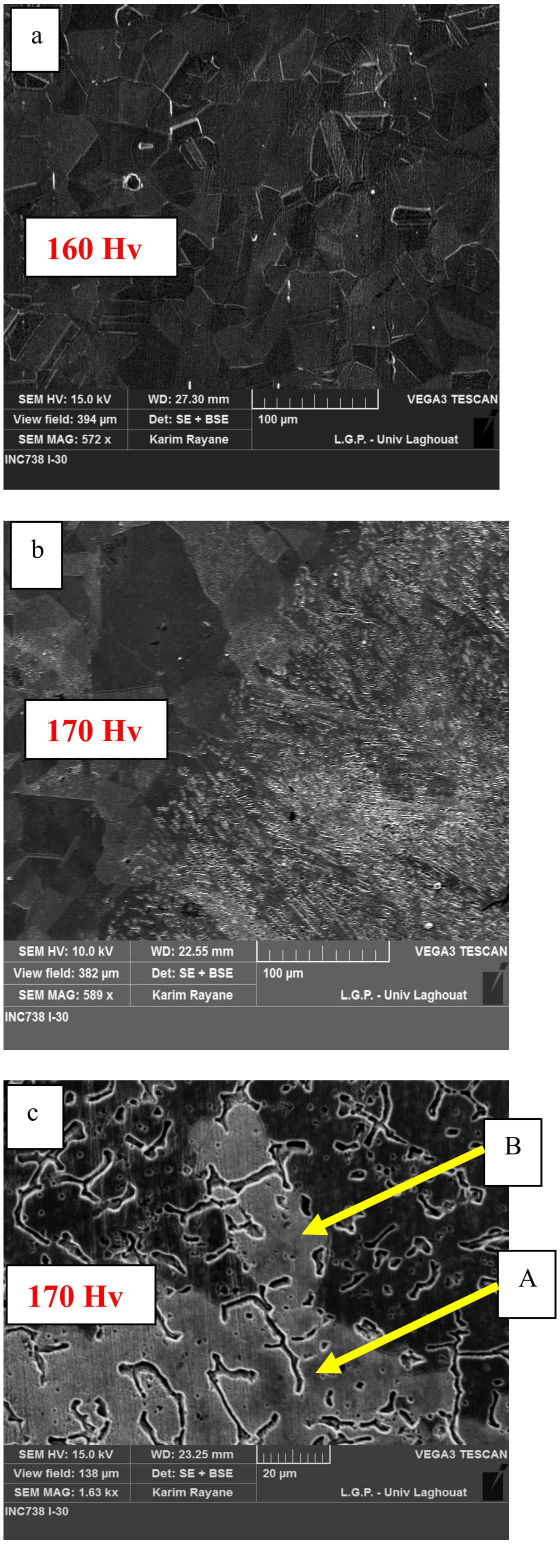

Figure 6. SEM observations of the base metal (BM), (b) the heat affected zone (HAZ) , and (c) the fusion zone (FZ) after annealing at 300°C for 60 min.

However, after isothermal heat treatments, the three zones (BM, HAZ and FZ) were affected. In general, these isothermal heat treatments induce a homogenisation of hardness values between FZ, HAZ and base metal, with an average hardness value around 165 Hv. In addition, hardness was found to be a reliable method of estimating the yield and tensile strength of the different zones of the weldment before post weld heat treatment and after post weld heat treatment [19]. For our case, this heat treatment at 300 °C induced a relaxation of the internal stresses

However, XRD analysis of these zones after the isothermal heat treatment at 300 °C (Fig.7) shows just the austenite peaks which indicates that the ferrite delta is dissolved in the matrix. It has been reported [1] that XRD technique is not capable of detecting phase under 5% wt. Thus, very small amount of δ-ferrite may be present in the structure that cannot be detected.

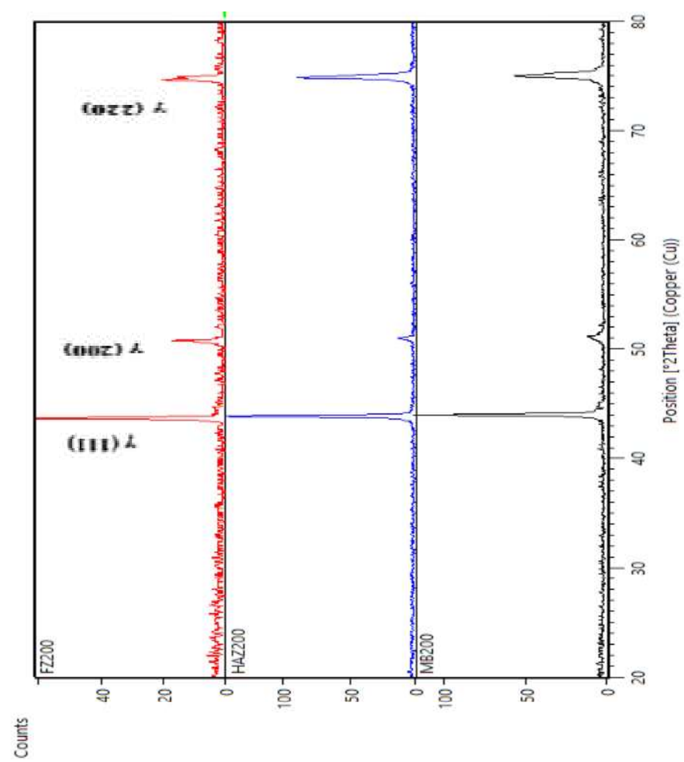

Figure 7. XRD spectrum at different zones: B M , HAZ and FZ Aafter annealing at 300°C for 60 min.

CONCLUSION

The effect of isothermal heat treatments at 300 °C on microstructure evolution after welding by Tungsten Inert Gas (TIG) welding technique of 304L pipeline steel has been studied. Three distinct zones were observed in welded joint of AISI 304L stainless steel which are base metal, heat affected zone and fusion zone with different hardness. Heat affected zone and fusion zone contain ferrite delta, formed after welding process. However, this ferrite delta disappears after isothermal heat treatment at 300 °C. Hardness values of different zones decrease after this heat treatments. Unfortunately, a small crack has been observed and a future careful analysis of crack characteristics will be necessary in order to determine the cause and to take the appropriate correction. Using of narrow welds can be the best mean of avoiding cracking in the welding.

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