# INFLUENCE OF HEAT TREATMENTS ON THE MICROSTRUCTURE OF WELDED API X70 PIPELINE STEEL

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**Abstract**
Welding is one of the most important technological processes used in many branches of industry such us industrial engineering, shipbuilding, pipeline fabrication among others. Generally, welding is the preferred joining method and most common steel are weldable. This investigation is a contribution to some scientific works which have been done on welding of low carbon steel. This work, presents some heat treatments were used to alter the microstructure of base metal (BM), heat affected zone (HAZ) and weld metal (WM) in the welded pipe steel of grade API X70. It presents the microstructures obtained after three heat treatments at 200°C, 400°C and 600°C for 30 min. Scanning electron microscopy and X-ray diffraction have been used as characterization techniques to observe the WM microstructures, in addition the Vickers hardness test are also achieved. The results revealed that the isothermal heat treatment caused grain growth and coarsening reactions in the weld zone and the hardness of weld joints decreased were the main transformations after increasing the temperature of the heat treatment.

**Keywords:** heat treatment; low carbon steel; microstructure; welding

## 1 Introduction

In modern pipeline technology, an appropriate selection of microstructure is the main parameter to modify the strength and toughness behaviors of the oil and gas pipeline steels [1]. Heat generated during welding induces an important temperature gradient in and around the welded area. The region outside the welded joint that is thermally affected by the welding treatment is known as the heat-affected zone (HAZ) [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 as a function of the distance from the fusion boundary [3, 4]. Consequently, an annealing heat treatment subsequent to the welding operation can reduce these negatives effects. Generally, the metallurgy of the welded joints 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 [5] .The weld interface which is referred to as mushy zone, is a narrow zone consisting of partially melted base material which has not got an opportunity for mixing. This zone separates the fusion zone and the heat affected zone.

In our previous investigation focused on study of the distributions of residual stresses on the X70 pipeline steel jointed by industrial arc welding. We have found that the stress distribution is

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characterized by high compressive stresses in weld seam. However, the heat treatments at 200°C and 600°C cause relaxation phenomenon in weld region which is due to the recrystalization reaction caused by the heat treatment [6] The main goal of the present work is to study deeply the effect of heat treatments at 200, 400 and 600°C on microstructural and hardness evolution in different zones after arc welding of X70 pipeline steel. This investigation is contribution as some scientific works which have been done on welding of low carbon steel [6-10].

## 2 Experimental Material and Techniques

The material under investigation was X70 pipeline steel with single-V preparation joints were welded by arc welding. The chemical composition, wt%, is given in **Tables 1** and **2**, and for the real welding, steel electrodes were used to deposit the welds using the shielded metal arc welding process (SMAW) with a speed of 0.028mmmin−1, where the inputs were 42V and (60–95) A. The dimensions of the real welded specimens are 9mm thick 10×20 mm2.The weld performed by SMAW was cut in three passes. Heat treatments were applied on welded specimens by isothermal annealing at 200,400 and 600°C during 30 min in order to study their effects. Specimens used for scanning electron microscopy observations were polished and etched with 4% Nital solution. The hardness across the welded joint was measured by Vickers microhardness tester (LECO M-400-A hardness tester) using 200gf. In order to identify the microstructures in each heat treatment, X-ray diffraction applying a Rietveld analysis was used. The X-ray diffraction pattern was obtained at room temperature with a diffractometer. Data were collected using CuKa radiation in the range10°≤ 2ϴ≤ 120° with a step interval of 0.02°.

**Table 1** The chemical composition of the base metal (wt %)

| C | Si | Mn | P | S | Cr | Ni | Cu | Al | N | Mo |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.064 | 0.2047 | 1.5173 | 0.0154 | 0.0015 | 0.0553 | 0.1922 | 0.0291 | 0.0319 | 0.0057 | 0.1353 |

**Table 2** The chemical composition of the fil metal(wt%)

| C | Si | Mn | P | S | Cr | Ni | Cu | V | Mo |
|---|---|---|---|---|---|---|---|---|---|
| 0.05 | 0.32 | 0.87 | 0.013 | 0.006 | 0.03 | 0.71 | 0.039 | 0.01 | 0.01 |

## 3 Results and Discussion

### 3.1 Scanning electron microscope (SEM) analysis

*A. Microstructure of the base metal using scanning electron microscope (SEM)*

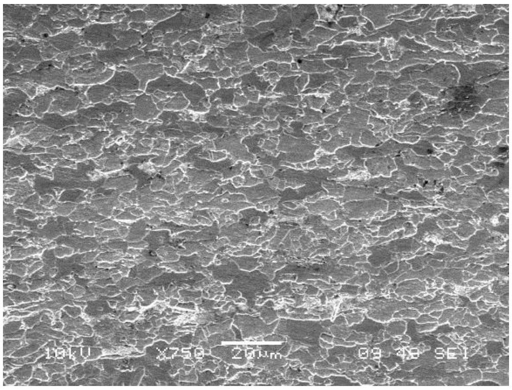


**Fig. 1** SEM micrographs of the base metal

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SEM images of the longitudinal welded joints on API 5L X-70 steel pipe are shown in **Fig. 1**. It mainly formed by a ferritic matrix (dark areas),and small amount of pearlitic colonies (white areas).

*B. Micro-structural evolution of the heat affected zone*

First of all, the microstructure of the heat affected zone (HAZ) shows fine ferrite grains with some elongated entities (**Fig. 2a**) However, a progressive recrystallization reaction of ferrite grains was observed after increasing the temperature of the isothermal heat treatments (**Fig. 2b,c** and **d**).

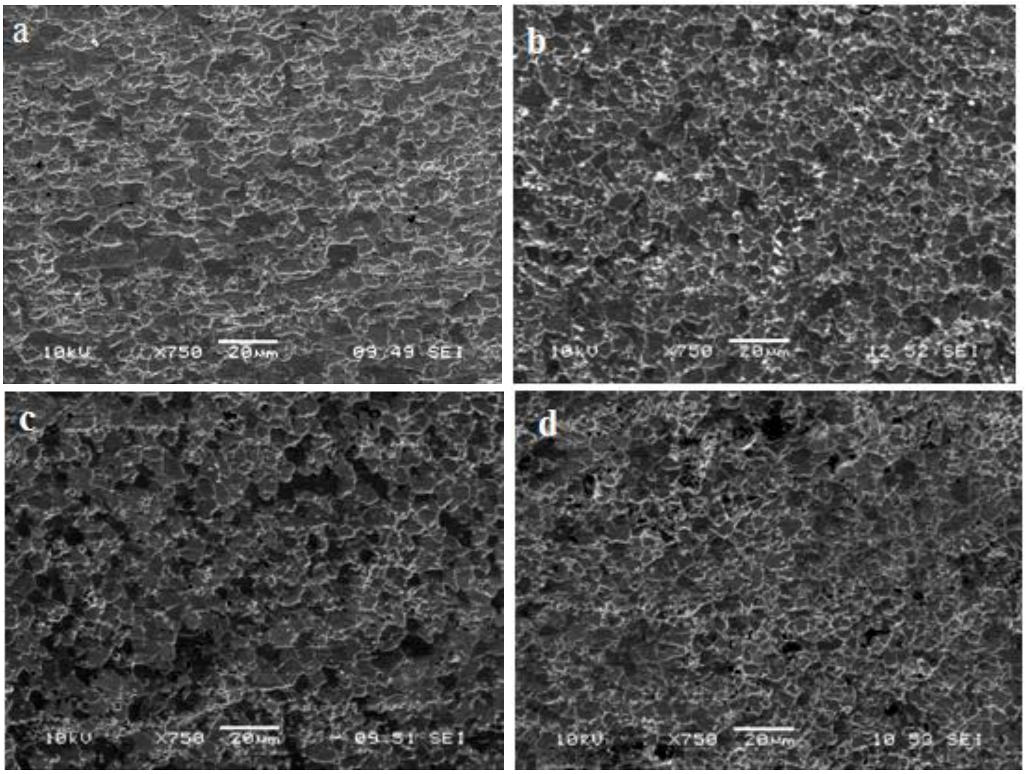


**Fig. 2** SEM micrographs of experimentalsteel of the heataffected zone, (a) untreatedsample; (b) heattreatedsampleat 200°C for 30min; c)heattreatedsampleat 400°C for 30min and (d)heat treated sampleat 600°C for 30 min.

*C. Micro-structural analysis of the fusion zone*

Concerning this critical zone, we have observed two subzones in the fusion zone; the region of the first pass and the region of the third pass. The SEM observations reveal different microstructures (**Fig. 3**). The region of the first pass contains ferrite grains with some colonies of pearlite (**Fig. 3a**), however region of the third pass is totally different which contains acicular ferrite and ferrite side plates (**Fig. 3b**).We have found that the heat treating of welded joints at 200°C for 30 min minutes is considered as temper after the severe heat treatment caused by the welding process. The region of the first pass undergoes progressive grain growth reaction of

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ferrite grains efter increasing the temperature of the isothermal heat treatment(**Fig. 2c** and **e**),but the heat treatments at 400 and 600°C induce a considerable coarsening reaction of acicular ferrite and ferrite side plates in the region of the third pass(**Fig. 3d** and **3f**).

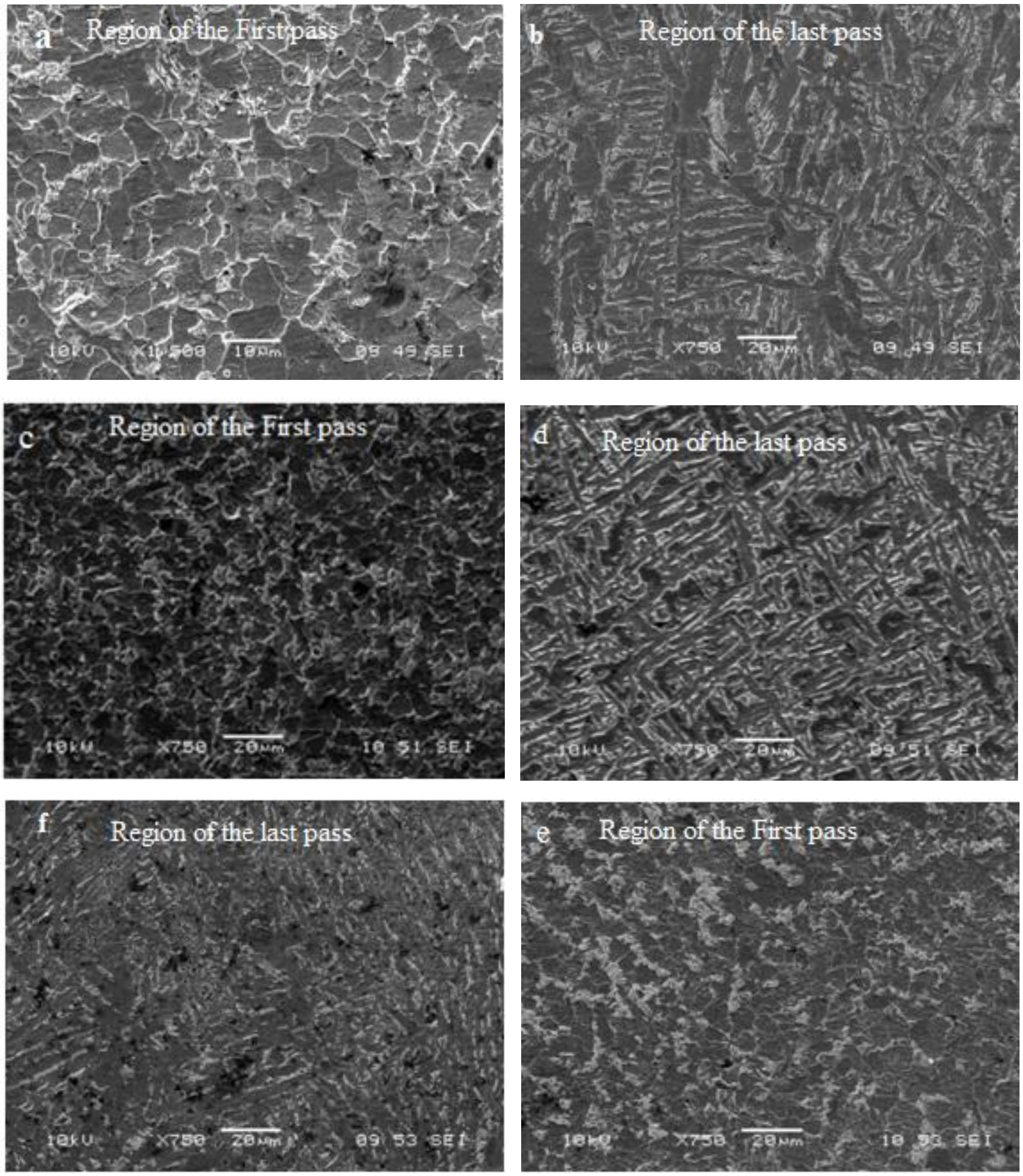


**Fig. 3** SEM micrographs the fusion zone(first pass and the second pass respectively ,(a,b))untreated sample;(c,d) heattreatedsample 400°C for 30; (e,f) heat treated sample at 600°C for 30 min.

## 3.2 PHASES ANALYSIS

**Fig. 4** represents the XRD profiles of the samples before and after heat treatment. All profiles show the intense peaks for the ferrite (α).This figure clearly reveals also the changes in the intensity of patterns due to the recrystallization reaction after all heat treatments.

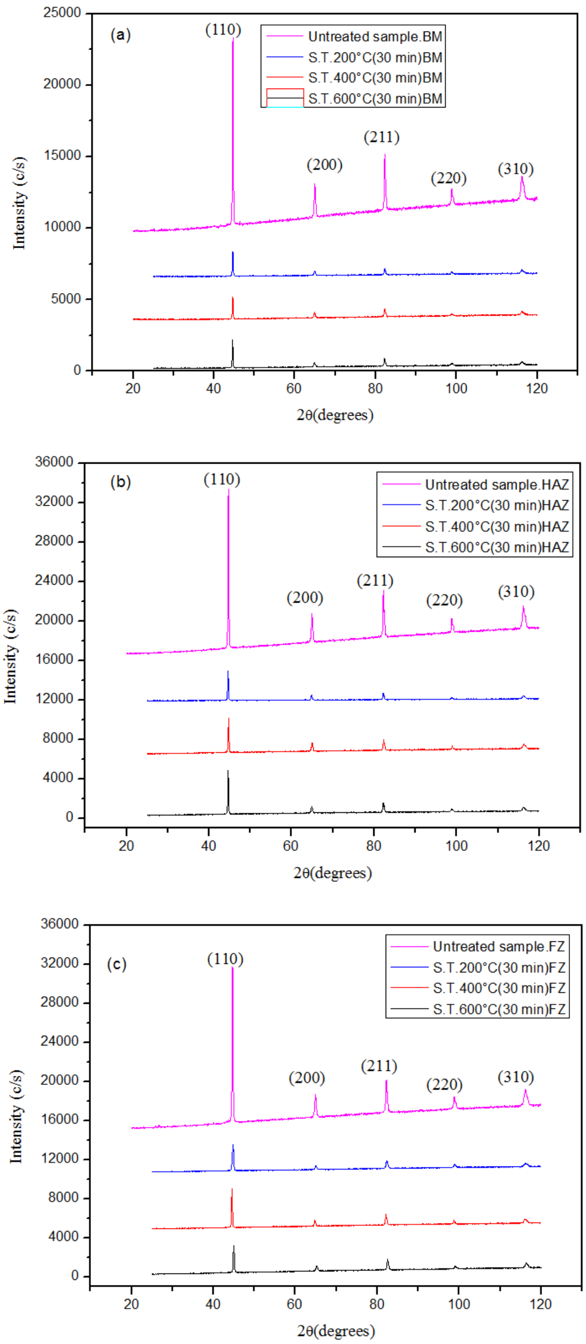


**Fig. 4** X-ray diffraction profiles of the sample before and after heat treatment at 200,400 and 600°C for 30 min in the tree zones, (a) BM, (b) HAZ and(c) the FZ.

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### 3.3 The hardness examination

Concerning our material, the hardness distribution in different zones before and after heat treatments is shown in **Fig. 5**.for the untreated sample, the hardness values of 170-215 HV in figure 5 are observed at location within 1 mm from the fusion zone, through the HAZ to the other base metal. Is investigated it was observed the highest hardness was obtained in the fusion zone (FZ), and the hardness values decreased towards the heat affected zone (HAZ), Our hardness results are in good agreement with literature, because Gural et al [11] and Boumerzoug et al. [6], have found the highest hardness values are measured in the weld metal area (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, metallic inclusions, and it can be attributed also to the presence of lower transformation products such as widmanstätten ferrite (WF) and some ferrite morphologies like acicular ferrite [6,12. 13]. The hardness of Weld joints decreased with the increasing of isothermal heat treatments due to the removing the residual stress, reduction of lattice defects generated during welding, grain growth and formation of considerable ferrite in the microstructure [14].

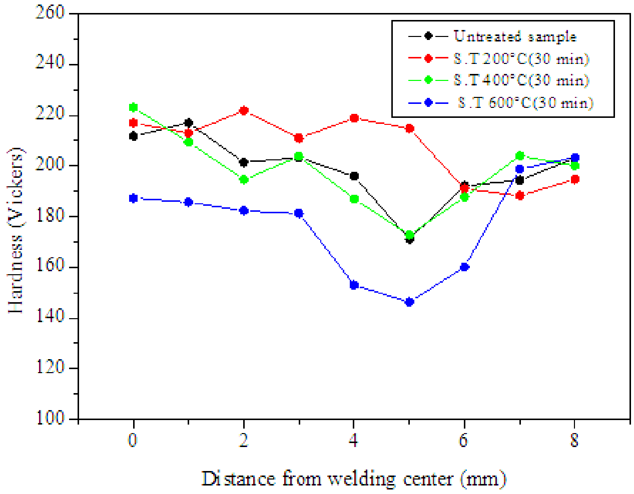


**Fig. 5** Hardness distribution across weldment

## 4 Conclusion

The present work is a contribution to the understanding the effect of isothermal annealing on microstructures and Hardness evolution of welded joint of low carbon steel by using SEM, X-ray diffraction techniques and hardness tests. Microstructure of the heat affected zone and fusion zone are identified after welding.

- We have found that the fusion zone was affected by different passes of welding, where two subzones were observed with different microstructures. Grain growth and coarsening reactions were the main transformations after increasing the temperature of the heat treatment.
- Phase analysis clearly reveals also the changes in the intensity of patterns due to the recrystallization reaction after all heat treatments.

- The hardness of weld joints decreased with the increasing of isothermal heat treatments due to the removing the residual stress, reduction of lattice defects generated during welding, grain growth and formation of considerable ferrite in the microstructure.

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