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# X-Ray Analysis of Residual Stress in Weld Region of X70 Pipeline Steel

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**Abstract:** X-ray diffraction method has been used to analyze the residual stress distribution in weld region of an X70 pipeline steel before and after heat treatment. The welding process has been realized by industrial arc welding with circular weld seams. The effect of heat treatments on the level and the distribution of residual stresses were investigated. Stress distribution was characterized by relative high compressive stresses in weld seam just after welding. However, residual stress relaxation phenomenon was observed in weld region after heat treatments due to microstructure restoration and recrystalization. Optical microscope observation and Vickers hardness measurements were also realized as complementary microstructure characterization techniques.

## Introduction

Welding is a process of joining materials into one piece. Welding is one of the most important technological process used in many branches of industry such as industrial engineering, shipbuilding, pipeline fabrication among others. Generally, welding is the prefered joining method and most common steels are weldable.

However, welding is a complicated process accompanied by shrinkage effects, phase transformations, intensification of corrosion and arising of residual stresses. Residual stresses arising after welding exert a considerable influence on the service characteristics of welded equipment and their control allows to avoid failure of welded joint [1].

In arc welding operations residual stresses are introduced within the welded metal owing to the non-uniform tmerature distribution and severe temperature gradients. These residual stresses may be responsible for brittle fracture, decreasing fatigue life as well as stress corrosion cracking [2]. Consequently, it is very important to understand and quantify the residual stresses.

A wide variety of residual stress measurement techniques exist [ 3-9]. but one of the important is the X-ray diffraction technique. The aim of the present work is to analyze by X-ray diffraction the residual stress development in the heataffected zone (HAZ) of an X70 pipeline steel. This investigation is a contribution as many scientific works which have been done on welding of low carbon steel [10-13]

## Experimental procedure

X70 pipeline steel with single-V preparation joint were welded by arc welding (Fig.1).

Fig. 1 X70 pipeline steel after industrial arc welding.

Figure 2 presents the analysis by EDAX of this steel which indicates the high quantity of Mn.

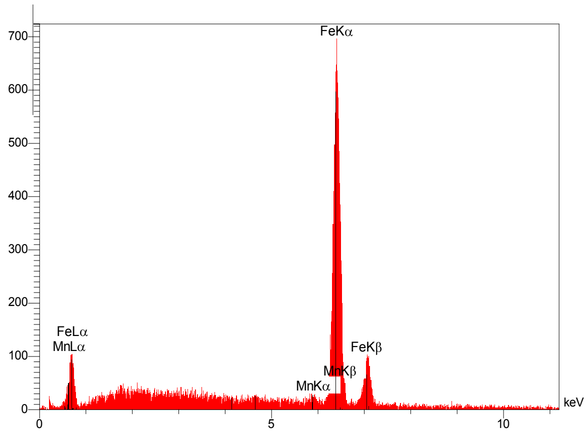


Fig. 2 Spectrum of EDAX analysis of X70 pipeline steel.

The chemical composition of this pipeline steel is given in table 1:

TABLE 1 CHEMICAL COMPOSITION OF PIPELINE STEEL(WT %).

| C | Si | Mn | P | S | Cr | Ni | Cu | Al | N | Mo |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.064 | 0.2047 | 1.573 | 0.0154 | 0.0015 | 0.0553 | 0.1922 | 0.0291 | 0.0319 | 0.007 | 0.1353 |

The microstructure of this base metal is presented in figure 3. This material is composed of ferrite (85%) with bands of pearlite (15%). The average hardness is 200 $HV_{10}$. These bands of perlite-rich area (banding) were observed. This macrosegregation phenomenon which called banding is due to the presence of high percentage of Mn in these zones. However, in more alloyed weld metals elements such as chromuim and molybdenum can be found to be segregated in these areas [14].

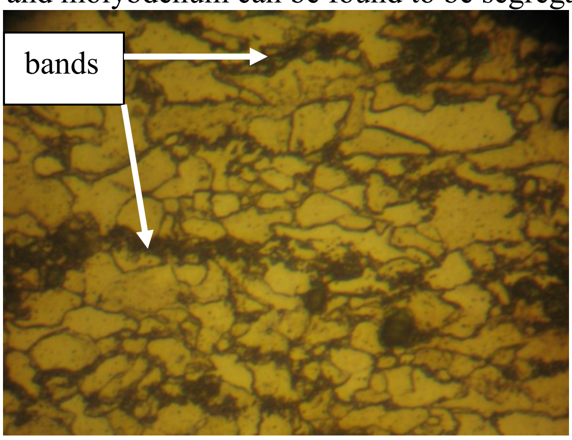


Fig. 3 Microstructure of X70 pipeline steel.

The welds were deposited using steel electrodes by the shielded metal arc welding process. The chemical composition of the weld metal is presented in table 2.

TABLE 2 : CHEMICAL COMPOSITION OF ELECTRODE (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 |

X-ray stress measurements were carried out by SET-X equipment. A general view of this apparatus is shown on figure 4. Cr-Ka radiation and (211) reflections were used to study residual stress distribution in weld region.

Fig. 4 General view of the X-ray apparatus.

For optical microscopy, chemical etchning was used to reveal microstructures ofdifferent zones. The hardness across the weld was measured by microhardness tester using a 2 kg load. Stress measurements were made in the longitudinal and transversal directions (parallel and perpendicular to the weld joint, respectively). In order to remove residual stresses introduced by machining, an electropoloishing technique has been applied. Optical observation after chemical etchning by Nital of the weld material has revealed the microsstructures of different zones, i.e, weld seam, heat affected zone (HAZ) and base metal. Heat treatments were applied on welded specimens by isothermal annealing at 200 and 600 °C during 1 hour in order to study their effects on residual stresses distribution in X70 pipeline steel.

## Results and discussion

In order to have a general idea about the effect of heat treatments on microstructural evolution in weld region of X70 pipeline steel, figure 5 reveals microstructural transformation from non-heated to heated specimen at 600°C in weld seam which represents the core of welding region. This zone submits recrystallization reaction after heat treatments.

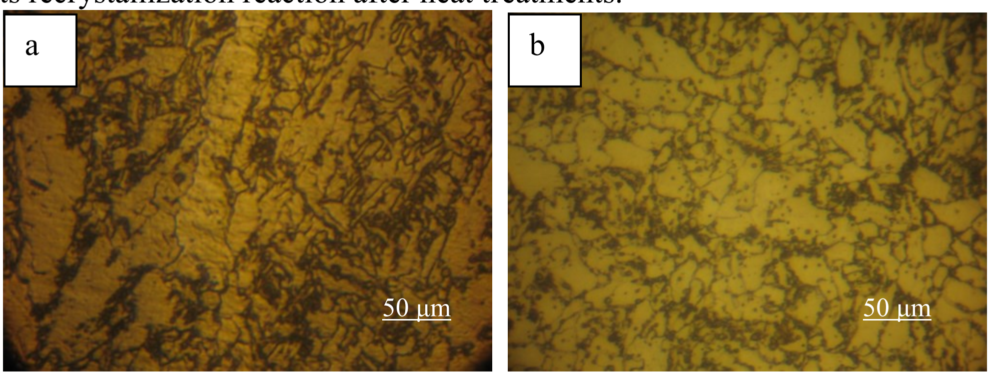


Fig. 5 Microstructures of X70 pipeline steel in weld region:
(a) non-heat treated and (b) heat treated 1h at 600°C.

It was reported that a hardness testing is the usual approach in dilinealing the properties of these various zones, but the information obtained is very limited [15]. For other researchers, a simple rapid way to obtain important information is by hardness testing [ 16]. Concerning our material, the hardness distribution in different zones is shown in figure 6. The hardness values of 192-214 HV in figure 6 are observed at location within 1 mm from the fusion zone, through the HAZ to the other base metal. Our hardness results are in good agreement with literature. Because, Gul et al [17], 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 contribuate to this hardening like grain size, phase composition, metallic inclusions.

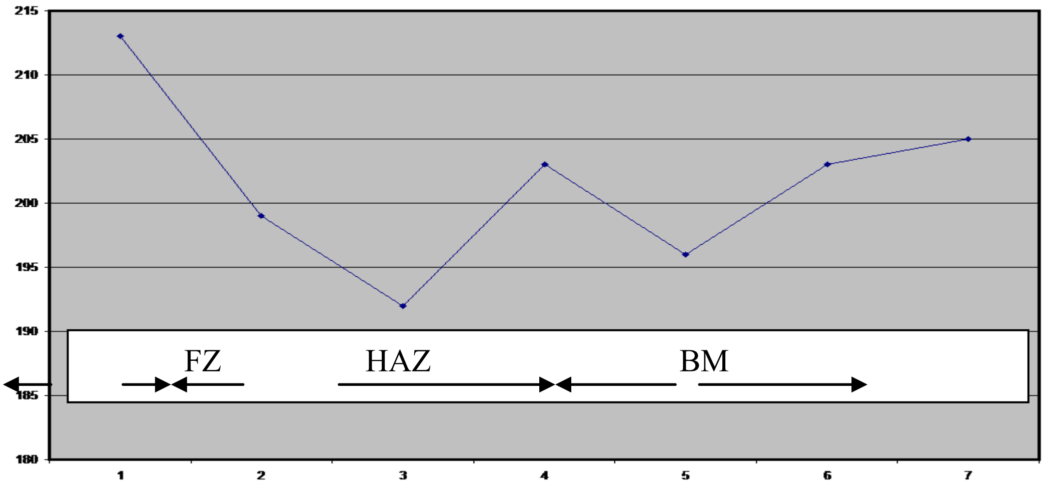


Fig. 6 Microhardness from the fusion zone ( FZ ) across the weld metal after welding of X70 pipeline steel.

However, figures 7, 8 and 9 present both residual stresses distribution in the weld region of X70 pipeline steel at different states and the peak width evolution in weld region respectively. Concerning the stress distributions, it is clear that all curves have the same shape but not the same magnitude because the the effect of heat treatments is obvious. The magnitude of residual stresses decrease significantly with increasing a temperature.

For example, figure 7 presents the stress distributions in the weld region of X70 pipeline steel. Compressive residual stresses in two directions were observed in weld seam, heat affected zone (HAZ) and base metal. The results indicate that in weld seam the value of stress is -195 in longitudinal direction and – 265 MPa in transversal direction. The maximum of compressive residual stresses are at 2 mm from weld seam (– 265 Mpa and 300 MPa ). From 10 mm to weld seam the level of stress becames low compressive in both directions ( - 100 MPa ). For example, Ranjbarnodeh et al [18 ] habe been found that when dissimilar metals are joined by fusion process such as TIG welding technique, mixing of the base metals and the filler metal results in the weld region to have different mechanical properties and this phenomenon affects the distribution of residual stress after welding operation.Generally, the predominant cause of welded residual stresses is quenching, because according to Macherauch et al [19] the principal sources of residual stresses after welding are: shrinkage, quenching or phase transformation. Shrinkage causes the appearance of tensile stresses, whereas quenching and phase transformation cause compressive stresses at the weld seam. On the other hand, Prabhat et al [20] considered that the distribution of residual stresses in a girth welded pipe is complex. Weld shrinkage in the circumferential direction induces both shearing and bending that result in stress components in the circumferential direction (hoop stress) and in the axial direction (meridian stress).

However, heat treatments induce a phenomenon of relaxation in the material , because the width peak diminishs with increasing temperature. For example, the heat treated specimen at 200°C, the width peak of diffraction varies from 1,34° to 1,97° which corresponds to high relaxation in all zones ( Fig; 8b). The same evolution has been observed in heat treated sample at 600°C ( Fig.9). In addition, the level of stresses became nul after the heat treatment at 600°C. There is reasonable agreement between the the stress distributions and width peak of diffraction in weld region.

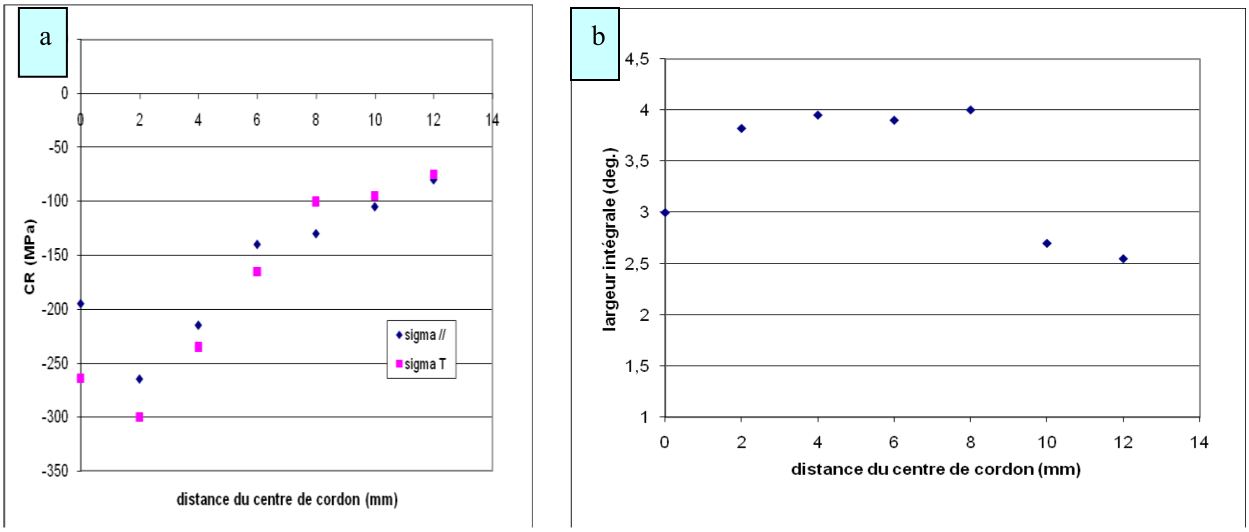


Fig.7 : (a) The stress distributions and (b) width peak evolution in the weld region of X70 pipeline steel

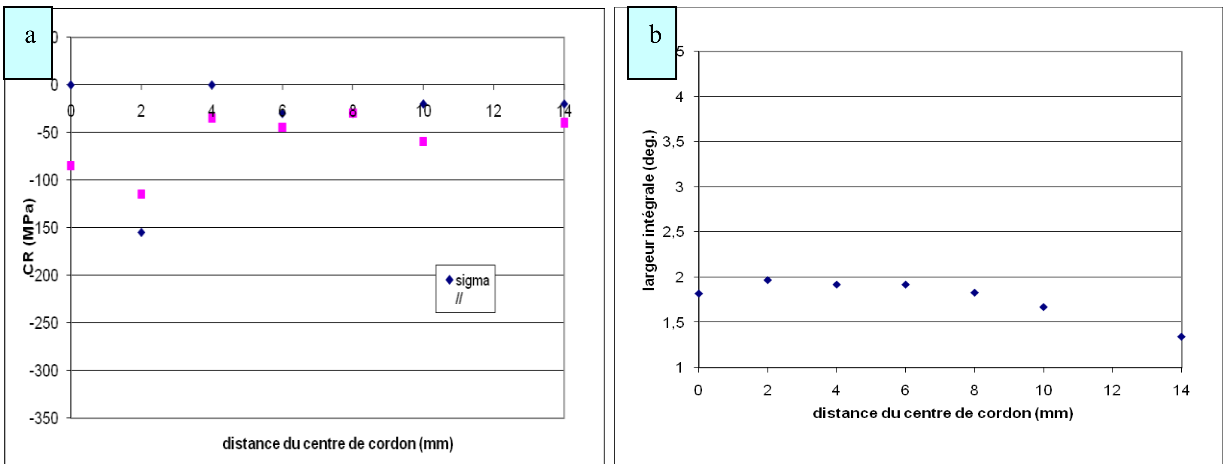


Fig. 8 : (a) The stress distributions and (b) width peak diffraction evolution in the weld region of X70 pipeline steel heat treated 1 h at 200°C.

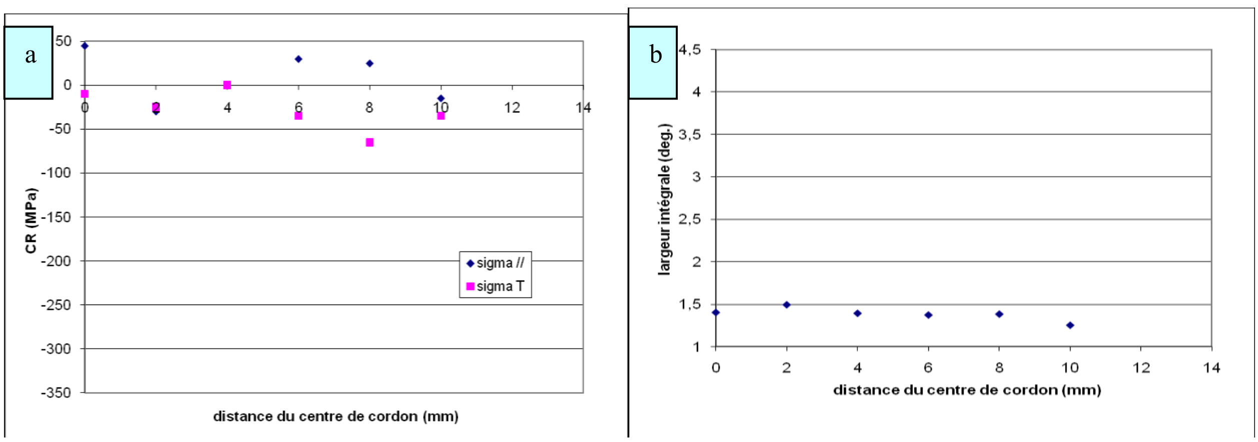


Fig. 9 : The stress distributions and (b) width peak diffraction evolution in the weld region of X70 pipeline steel heat treat 1 h at 600°C.

## Conclusion

Our investigation represents a contribution to the study of the distributions of residual stresses on the X70 pipeline steel jointed by industrial arc welding. Stress distribution is characterised by high compressive stresses in weld seam. However, the heat treatments cause relaxation phenomenon in weld region which is due to the recrystalization reaction caused by the heat treatments.

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