Microstructural Characterization of X70 Heat Treated Welded Pipeline Steel

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***Abstract*— This research, presents effect of isothermal heat treatments on microstructure of micro alloyed welded pipeline steel. In this study a shielded metal arc welding (SMAW) process has been realized. Scanning electron microscope (SEM) and X-ray diffraction have been used as characterization techniques to observe the different weld metal microstructures, in addition hardness are also measured. The results showed that the isothermal heat treatment motived restoration and recristallization reactions in the weld zone, and the hardness of weld joints decreased, were the main transformations after increasing of heat treatment temperature.**

Keywords— heat treatment, low carbon steel, microstructure, welding

Introduction

In many branches of industry, Welding occupies an important place as technological processes; with is used in industrial engineering, pipeline fabrication among others [1]. Low carbon steels are widely used in the manufacturing sectors due to their good formability and easy weld ability than other carbon steels. Usually, the welding processes like shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and electro slag welding are used for welding thick low carbon steel plates[2]It is known also that the shielded metal arc welding (SMAW) process is the oldest and most widely used methods of welding [3]The microstructures changes of base metal during welded thermal cycle as a function of distance from the fusion boundary[4,5]. 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) **[6].** The HAZ has a composition which is essentially the same as the base metal and is identifiable region because of the structural changes induced by the weld thermal cycle, for example the reheat of this region has effect of refining the microstructure **[7,8]** . The HAZ has a potential to evolve structures which adversely affect the properties of the welded joint **[7].** The HAZ microstructure is determined by the welding condition, mechanical and previous thermal history and more importantly the chemical composition of the material [**7, 9**] Jan. Bog. Jua et al **[10]** confirmed that HAZ region affects three or four thermal cycles during multi-pass welding process, the first and second cycles may industriously change the microstructure of the zone, whereas the third and fourth cycle's effects on the microstructure are very restricted due to their low peak temperature. The HAZ microstructures exposed to the first thermal cycle are usually classified into four sub-regions based on the peak temperature (TP1): subcritical HAZ (SCHAZ: AC1 > TP1 > 450 °C). Inter-critical HAZ (ICHAZ: AC3 > TP1 > AC1) fine-grained HAZ (FGHAZ: 1100°C > TP1 > AC3), and Coarse-grained HAZ (CGHAZ: (TP1 >1100°C). Consequently, an annealing heat treatment subsequent to the welding operation can reduce these negatives effects [11]. The microstructure and mechanical properties of multi-pass welds has been discussed in previous papers [12- 17].

In this study, the effect of isothermal treatments at 200, 400 and 600°C for 1h on the microstructures and hardness evolution in different zones, BM, HAZ and FZ after arc welding of X70 pipeline steel is investigated. This work is based on some scientific works in welding of low and micro alloyed carbon steel [1, 17-20].

I. EXPIREMENTAL

A. 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 1and 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. Isothermal annealing was applied on welded specimens at

200,400 and 600°C during 1 hour in order to study their effects. for scanning electron microscopy observations, we have do the metallographic preparation of specimens by polishing and etching with 4% Nital solution . The hardness across the welded joint was measured by Vickers microhardness tester (LECO M-400-A hardness tester) using 200gf. X-ray diffraction applying a Rietveld analysis was used to identify crystalline phases and their intensities. The X-ray diffraction pattern was obtained at room temperature with a diffractometer. Data were collected using Cu_{Ka} radiation in the range$10° \leq 2\Theta \leq 120°$ with a step interval of 0.02°.

TABLE I. HE chemical composition of the base metal (wt %)

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

TABLE II. The chemical composition of the filler metal (wt%)

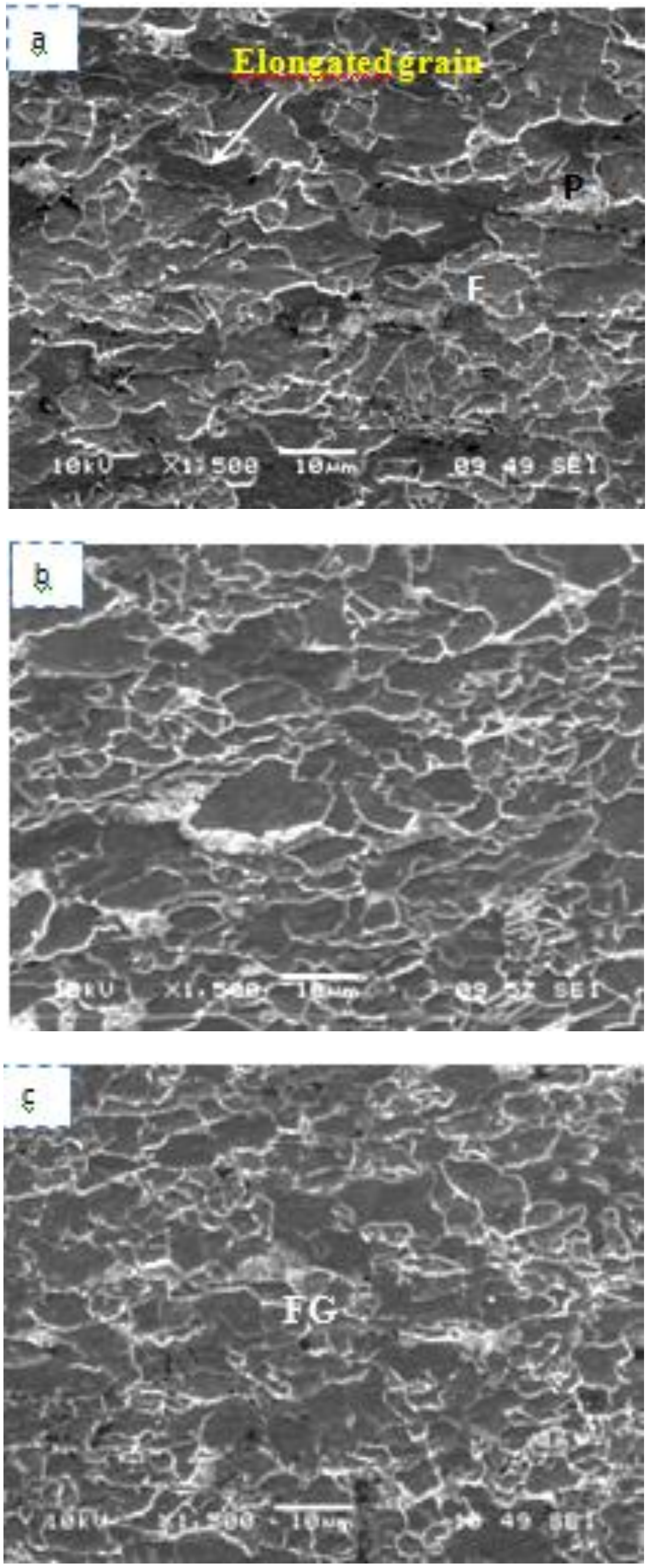
C	Si	Mn	P	S	Cr
0.05	0.32	0.87	0.013	0.006	0.03
Ni	**Cu**	**V**	**Mo**		
0.71	0.039	0.01	0.01		

II. RESULTS AND DISCUSSION

A. Scanning electron microscope analysis

A.1. Microstructure of the base metal

The microstructures of the base metal consist of ferrite phase (dark) with rare pearlite colonies(white) observed at some grain boundaries , Some elongated ferrite entities that are were found all over the observed region (Figure 1.a). The base matrix consists of ferritic grains because our steel contains a low amount of carbon. Similar result is obtained by Chung et al [21] with a low carbon steel (X65) and they confirmed that the microstructure of the base metal consisted of predominantly polygonal ferrite (black) and pearlite (white).after isothermal heat treatment at (200°C and 600°C) for 1 h we found slight microstructural evolution, but grain refinement after 1 h of heat treatment at 400°C.



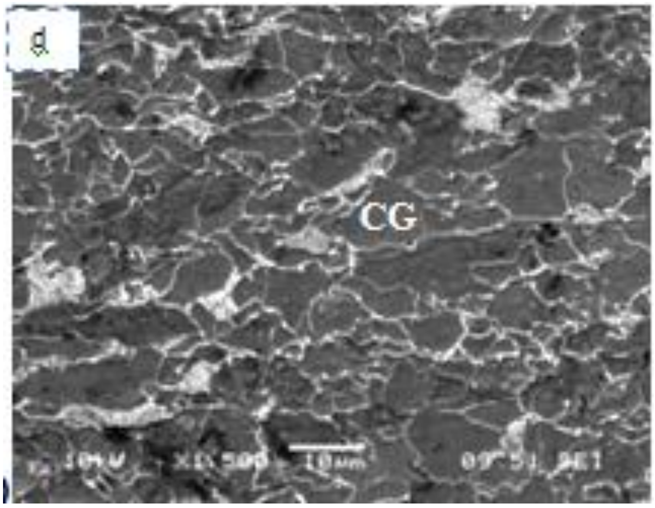
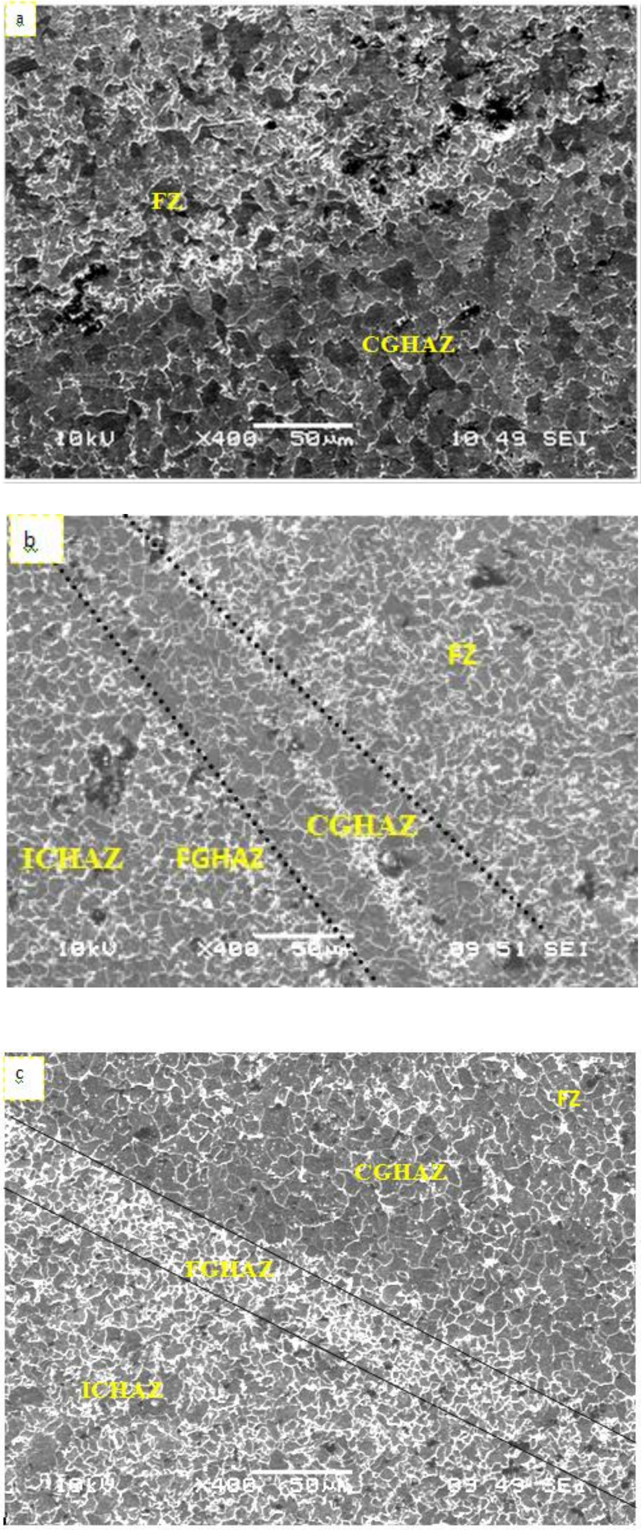


Fig. 1 SEM micrographs base metal before (a), and after heat treatment for 1h; at 200°C (b) At, 400°C (c) and At 600°C (d) .

B. Microstructural evolution in junction zone

The microstructure of the junction zone between the fusion zone (FZ) and the heat affected zone (HAZ) is showed in the figure 2. The HAZ can be divided into number of sub-regions. Each sub-region has its own distinct microstructure, a unique thermal cycle associated with it, and therefore possesses its own mechanical properties [7,22]. Before heat treatment (figure 2a), it presents a large coarse grained heat affected zone (CGHAZ), which is near of the fusion zone. It consists of equiaxed ferrite grains and the pearlite is distributed unevenly in small quantities among the ferrite grains. However the fusion zone shows a microstructure rich by the pearlite phase than the CGHAZ, it contains predominantly fine-grained ferrite (FG)with some elongated ferrite entities. The microstructures after heat treatments at 200°C, 400°C and 600°C for 1 h are illustrated in the figures 2b, 2c And 2d respectively. Figure 2b presents a microstructure of fine ferrite grains and pearlite in the fusion zone and a microstructure of the equi-axed ferrite grains with few amount of pearlite in all sub-zones of the heat affected zone. We observed al We observed also that microstructures of the HAZ became more homogenous with convergent grains size. The figure 2c shows a microstructure of equi-axed ferrite grains and little amount of pearlite in the CGHAZ, However the FGHAZ and ICHAZ are composed by fine ferrite grains and some coarse grains with convergent grains size. This heat treatment does not affect really the initial microstructures but we can observe a slight growth in of the grain size . In figure 2d we observed that CGHAZ and FZ are composed by fine equi-axed grains with high amount of pearlite in the FZ; we found that microstructures of FZ and CGHAZ are very homogenous . FGHAZ and ICHAZ consist of smaller ferrite grains. In general this heat treatment caused a decrease in grains size of the HAZ.



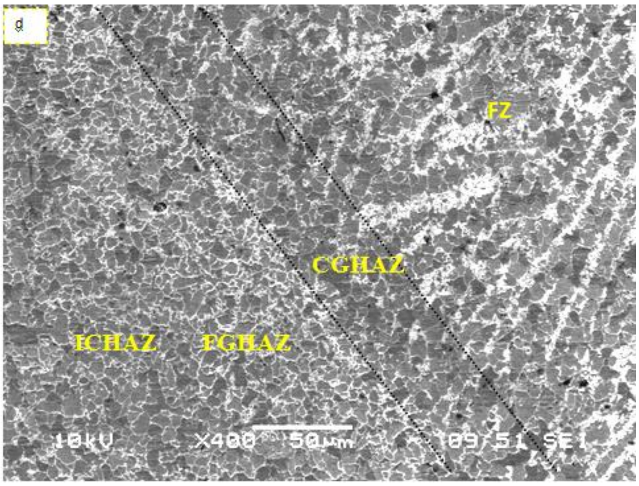
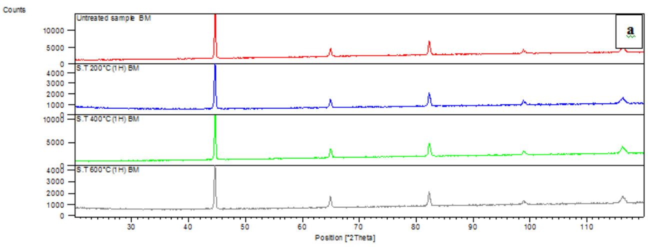
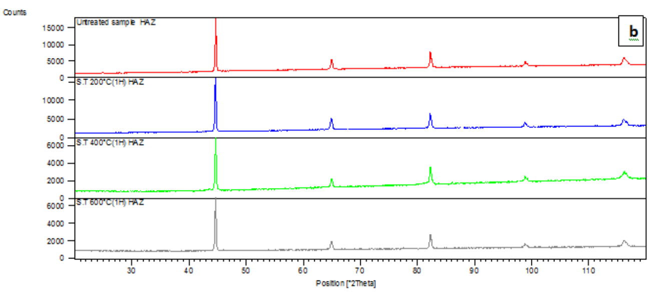


Fig. 2 SEM micrographs of junction zone before (a) and after heat treatment for 1h; at 200°C (b) At, 400°C (c) and At 600°C (d) .

C. Phases Analysis

One of the major techniques which maybe successfully used for characterization of structure is X-ray diffraction (XRD) [23]. We can obtain an important information about particles shape, Data on the crystallite size by X-ray diffraction (XRD) technique. It can give also the crystallite size wich is related to the diffraction peak broadening. It is important that XRD method allows not only to measure the crystallite size, but also to identify crystalline phases [24, 25]. XRD patterns of different zones of studied welded joint before and after isothermal annealing (Figures 3a, b and c) exhibit high-intensity peaks corresponding to the α-Fe phase. As can be seen, the diffraction from three first crystalline planes is more intense than the others; (1 1 0), (2 0 0) and (211) respectively.





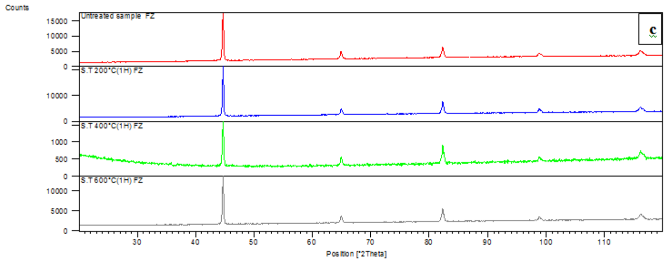


Fig. 3 X-ray diffraction profiles, (a) Base metal (BM) , (b) Heat affected zone (HAZ) and (c) Fusion zone (FZ) before and after heat treatments for 1h at 200°C, 400°C and 600°

D. Hardness examination

A hardness testing is the usual approach to determine the properties of various zones of material, but the information obtained is very limited [26]. For other researchers, a simple rapid way to obtain important information is by hardness testing [27].

The hardness graph of untreated sample and heat treated at 200°C, 400°C and 600°C for 1 h are given in the figure 3. From this figure, it can be seen an increase in the hardness in weld zone; may be induced by residual stress on microstructure refinement, due to the rapid solidification of the weld pool [19]. Is investigated it was observed the highest hardness was obtained in the fusion zone (FZ) of the main specimen (untreated sample), and the hardness values decreased towards the heat affected zone (HAZ). The weld metal has the highest hardness before and after heat treatments. This increase can be attributed to the presence of some ferrite morphologies like acicular ferrite [19]. And of lower transformation products such as Widmanstätten ferrite (WF)[28]. This increase due also In addition to microstructural transformation, plastic deformation due to residual stress increased the WM hardness. As result of plastic deformation the dislocation density increased throughout WM. The hardness of WM decreased during heat treatment due to reduction of lattice defects generated during welding, removing the residual stress, , grain growth and formation of considerable ferrite in the microstructure [29,30].

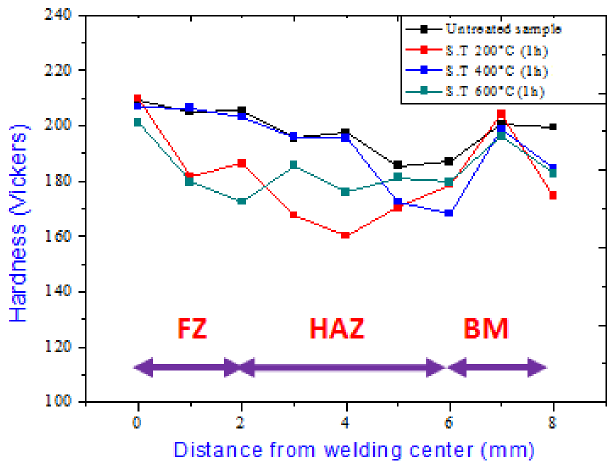


Fig. 4 Hardness graphs in welded joint before and after heat treatments at 200°C, 400°C and 600°C for 1h.

III. Conclusion

This study is a contribution to the understanding of isothermal annealing effect 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.

3 . . Grain growth refining and coarsening reactions were the main transformations after increasing the temperature of the heat treatment in base metal, heat affected zone, and fusion zone.

4 . X-rays diffraction profiles reveal also the changes in the intensity of patterns after all heat treatments due to the restoration and recrystallization reaction.

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

IV. References

[1] . Z. Boumerzoug, K. Digheche, and V. Ji,'' X-Ray Analysis of Residual Stress in Weld Region of X70 Pipeline Steel'': Advanced Materials Research, Vol.936, pp2011-2016. (2014)

[2] . N.Sankar, S.Malarvizhi, and V.Balasubramanian, ''Effect of Rotating Arc on Mechanical Properties and Microstructural Characteristics of Gas Metal Arc Welded Carbon Steel Joints''. Metallogr. Microstruct. Anal. (2021).

[3] . G. S. Sidhu , S. S. Chatha ''Role of shielded metal arc welding consumables on pipe weld joint'', International Journal of Emerging Technology and Advanced Engineering , Volume 2, Issue 12,(2012). ISSN 2250-2459.

[4] . H.K.D.H.Bhadeshia and S.R.Honeycombe, ''Steels : Microstructure and Properties'',Third edition, Published by Elsevier Ltd, 2006.

[5] . G.Spanos, R.W Fonda, R.A. Vandermeer, A. Matuszeski, ''Microstructural changes in HSLA-100 steel thermally cycled to simulate the heat affected zone during welding'': Metall. Mater. Trans, Vo.26,No.12, p.3277-3293, (1995).

[6] . Z.Boumerzoug, E.Raouache, F.Delaunois, ''Thermal cycle simulation of welding process in low carbon steel'', Materials Science and Engineering sectionA, Vol.530, pp.191–195, (2011)

[7] . X.Lin, ''Heat affected zone,structure and properties of welded copper bearing HSLA steel'', Ph.D thesis in philosophy, Departement of materials and engeneering, university of Wollongong, Australia,(1991).

[8] . T.Cool, ''Design of weld steel deposit'' Ph.D thesis in philosophy,university of cambridge,(1996).

[9] . E.Gharibshahiyan, A.H.Raouf, N.Parvin, M.Rahimian, ''The effect of microstructure on hardness and toughness of low carbon welded steel using inert gas welding'', Materials and Design, Vo.l32, pp.2042–2048, (2011).

[10] . J.B.Ju , W.S.Kim J.i. Jang ''Variations in DBTT and CTOD within weld heat-affected zone of API X65 pipeline steel''material science and ingeneering,section A, Vol.546, pp.258-262 (2012).

[11] . K. Digheche, Z.Boumerzoug, Malika Diafi, and K.Saadi, ''Influence of heat treatments on the microstructure of welded API X70 pipeline steel, Acta Metallurgica Slovaca, Vol. 23, 2017, No. 1, p. 72-78.

[12] . G.M. Evans The effect of chromium on the microstructure and properties of C–Mn all-weld metal deposits''. Weld Met Fabr, volume 57, no7, pp 346–58, (1989).

[13] . J.C.F . Jorge, J.M. A. Rebello, G.M. Evans Microstructure and toughness relationship in C– Mn – Cr all weld metal deposits. P454-461 IIW DOC. II-A-880-93.doi WJ-1990-12-s445

[14] . J.C.F. Jorgea, L.F.G. Souzaa, J.M.A. Rebello The effect of chromium on the microstructure/toughness relationship of C–Mn weld metal deposits. Materials Characterization vol 47, Pages 195– 205, (2001).

[15] . Z. Boumerzoug, C. Derfouf, T. Baudin: Journal of Engineering, Vol. 2, No. 7, p. 502-506, (2010).

[16] . F Khamouli, M Zidani K Digheche, A Saoudi, L Atoui , ''Effect of E6010- and E8018-G Fluxes Utilization on SMAW Multi-Pass Welded Steel'' Diffusion Foundations,Vol 18,pp55-64 (2018).

[17] . F.Khamouli, M. Zidani, K. Digheche, A.Saoudi, L. Atoui, Influence of Cellulosic Fluxes on the Chemical Composition Microstructure, Inclusions and Micro-Hardness of SMAW Multi-Pass Welds of X42 Steel Solid State Phenomena, Vol297,pp62-70,(2019).

[18] . A.Güral, B.Bostan, and A.T. Özdemir, ''Heat treatment in two phase region and its effect on microstructure and mechanical strength after welding of a low carbon steel'' : Materials and Design, Vo.28, ,2007, No 3,p.897-903, Doi:10.1016/j.matdes.2005.10.005.

[19] . P. Sathiya, M.K.Mishra, and B.Shanmugarajan, ''Effect of shielding gases on microstructure and mechanical properties of super austenitic stainless steel by hybrid welding: Journal of Materials and Design, Vol.33, 2012, p. 203–212. Doi:10.1016/j.matdes.2011.06.065

[20] . S. Bordbar, M .Alizadeh and S.H.Hashemi ''Effects of microstructure alteration on corrosion behavior of welded joint in API X70 pipeline steel : journal of Materials and Design, Vol.45, , pp597–604, (2013)

[21] . .C.Chung, Y.Ham, S. Kim, J. Lim, C. Lee, ''Effects of post-weld heat treatment cycles on microstructure and mechanical properties of electric resistance welded pipe welds'', Materials and Design, Vol.34, pp.685–690 (2012).

[22] . P.C.Reed, ''The characterization an modeling of multipass steel weld heat affected zone'' Ph.D thesis in phylosophy, university of Cambridge, (1990).

[23] . Y. Zhong F.Xiao , J.Zhang , Y.Shan , W.Wang, and K.Yang,'' In situ TEM study of the effect of M/A films at grain boundaries on crack propagation in an ultra-fine

acicular ferrite pipeline steel'', Acta Materialia, Vol.54 pp.435–443, (2006).
[24] . V. Uvarov, I. Popov,'' Metrological characterization of X-ray diffraction methods for determination of crystallite size in nano-scale materials'', Materials Characterization, Vol.58, pp.883–891,(2007).
[25] . M. Abdellatief, M. Abele, M. Leoni and P. Scardi,'' Solid State Nuclear Magnetic Resonance and X-ray Diffraction Line Profile Analysis of heavily deformed fluorite'', journal of thin solid films, Vol.530, p44-48. (2013).
[26] . G.R.Stewart, A.M. Elwazri, and R Varano, N. Pokutylowicz, S. Yue and J.J. Jonas, ''Testing of Welded Pipeline Steel'', Materials Science and Engineering, section A,Vol.420, pp.115-121,(2006.).
[27] . A.Güral, B.Bostan, and A.T. Özdemir, ''Heat treatment in two phase region and its effect on microstructure and mechanical strength after welding of a low carbon steel,Materials and Design Vol.28, pp.897-903, (2007).
[28] . G.Aggen et al, ''ASM Handbook, Properties and Selection: Irons, Steels, and High Performance Alloys'', Vol. 1,
[29] . S.Bordbar, M.Alizadeh and S.H.Hashemi ''Effects of microstructure alteration on corrosion behavior of welded joint in API X70 pipeline steel''journal of Materials and Design, Vol.45, pp.597–604, (2013).
[30] . K.digheche, Z.Boumerzoug F.Khamouli A.Saoudi K. Saadi ''Applying of Heat Treatments to Improve the Properties of Welded Pipeline Steel'', Solid State Phenomena,Vol 297,pp 143-150,(2019).