LOCAL POST WELD HEAT TREATMENT OF WELDED STEEL PIPES

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Abstract: *In this paper, local post weld heat treatment (LPWHT) effects on the metallurgical and mechanical properties of high frequency electric resistance welded (HFERW) steel pipes were investigated. Local post weld heat treatment (LPWHT) of the welded joint was carried out by an induction heating device which selectively heat only the weld area from the outside surface of the welded steel pipes. Optical microscopy, tensile testing, Charpy-V-notch testing, hardness testing and flattening testing were used to evaluate local post weld heat treatment (LPWHT) effects on the metallurgical and mechanical properties of high frequency electric resistance welded (HFERW) steel pipes.*

KEYWORDS: HEAT TREATMENT, MECHANICAL PROPERTIES, TECHNOLOGICAL PROPERTIES.

1. *Introduction*

Welding is a complex process and the quality of a weld is a function of interaction of significant number of variables together with the microstructural changes attendant upon welding. High-frequency electric resistance welding (HFERW) process is one of the most extensively methods for production of high quality longitudinal seam welded carbon steel pipes suitable for line pipe, casing, tubing and for other constructive uses . In this process, hot rolled strip is gradually formed into round shape through roll-forming stands, and its edges are joined by a combination of localized high-frequency electric resistance heating and forge pressure, as schematically illustrated in figure 1 [1, 2]. Forge pressure imposes significant plastic deformation to the welded joint and this represents a peculiarity of such welding process. Most of the high frequency electric resistance welded steel pipes are produced according to API Standard [3] plus client supplementary requirements.

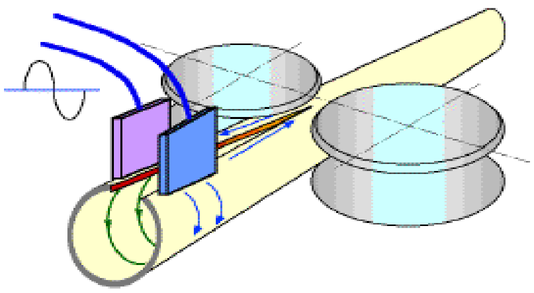


Fig.1 *Schematic illustration of HFERW*

The high-frequency current applied to the strip edges through sliding contacts, concentrated on the surface layer of the strip edges due to the "skin" and "proximity" effects, generate joule heat and the hot " Vee" converge edges are forged together in the weld squeeze rolls and a forge type weld is achieved [4]. The HF weld is a true forge weld in that no filler metal is added and, if done properly, no molten or oxidized metal is left on the bond line. Figure 2 shows that all of the molten thin layer and metal oxides and other inclusions are squeezed out of the weld toward the outside and inside surfaces as the edges pass between the weld rolls.

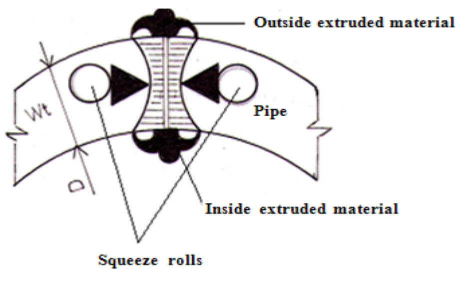


Fig.2 *High frequency forge type weld*

The material extruded on the inside and outside weld surfaces, usually removed mechanically while still hot and forms a typical HFERW weld with narrow bond line (BL) or fusion line (FL) and associated heat affected zone (HAZ) is formed. The normal HFERW weld area is shown in figure 3 [4]. Note that the heat affected zone is shaped like an hourglass.

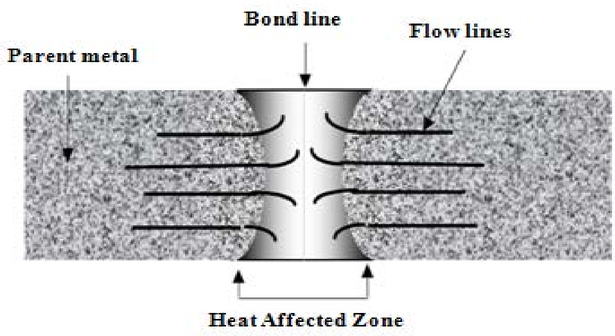


Fig.3 *High frequency electric resistance weld area*

The plastic deformation which is realized under the action pressure of the squeezing rolls caused metal flows of the hot rolled coils towards the outside and inside surfaces of the bond line. This flow pattern consists of streaks and striations. The orientation of this pattern, with respect to the new surface, indicates the direction of metal flow lines (fibres), respectively flow angles during plastic deformation [5].

The high frequency electric resistance welded joint is subjected to a local post weld heat treatment (LPWHT) in-line by the inductive heating, followed by air cooling. The aims of this heat treatment is to produce certain microstructure and desired mechanical properties (hardness, yield strength, ultimate tensile strength, toughness, ductility etc.). During local post weld heat treatment (LPWHT) of the welded joint, depending on the temperature range and the cooling rate, metallurgical changes takes place and these changes covers the properties of the welded joint and the performance of welded pipes in service [6, 7, 8, 9, 10].

Therefore the objective of this paper was to investigate local post weld heat treatment (LPWHT) effects on the mechanical and metallurgical properties of high frequency electric resistance welded steel pipes.

2. *Experimental procedure*

High-frequency electric resistance welding (HFERW) was conducted using an L-16 inch, pipe mill Newco IMK-Ferizaj, Kosova. Newco IMK-Ferizaj-Kosova produces high frequency electric resistance longitudinal seam welded steel pipes with Ø114.3-406.4mm diameter and 3.2-12.7mm wall thickness. In this paper Ø 406.4 x 6.35mm welded pipes were investigated. Pipes Ø 406.4 x 6.35 mm were fabricated from high strength steel coils X52 according to API [3, 11] standard, using the pipe mill equipped with a contact type high frequency electric resistance welding machine-Thermatool. The frequency of current was 400kHz.

Chemical composition and mechanical properties of the used steel are given in Table 1 and 2.

Table 1: *Chemical composition of steel API Grade X52*

Steel coils	Chemical composition [wt-%]						
	C	Mn	Si	P	S	Al	V
API grade X52	0.140	1.25	0.23	0.018	0.015	0.020	0.041

Table 2: *Mechanical properties of used steel coils X52*

Steel coils	Re	Rm	Re/Rm	A_2"	KV
					ISO-V-0°C
	MPa			%	J
API grade X52	399	497	0.802	32.5	121

The induction local post weld heat treatment (LPWHT) of the welded joint (bond line-BL and heat affected zone-HAZ) of the produced pipes were performed in line by inductive heating device, figure 4 which is located in the continuation of the production line L-16 inch and makes only selective heating of the welded joint, figure 4, in three zones:

-in the first zone, heating at the temperature 740-760°C,
-in the second zone, heating at the temperature 840-860°C,
-in the third zone, heating at the temperature 900-920°C.

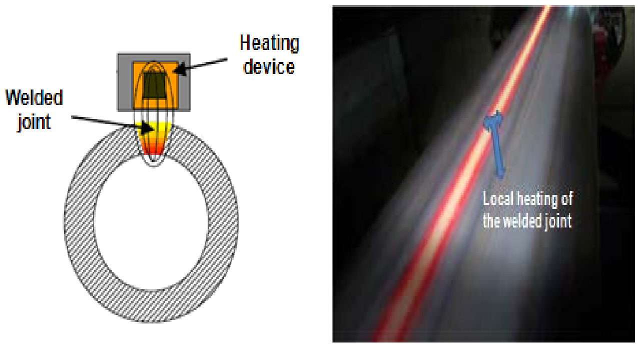
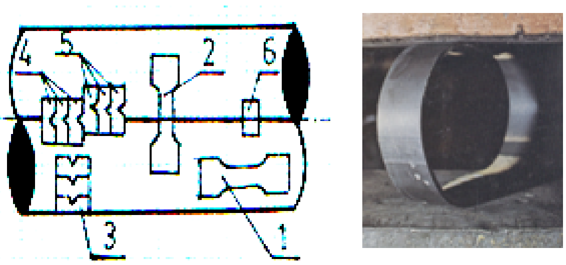


Fig.4 *In line local post weld heat treatment of HFERW of welded pipes*

Whether or not appropriate local post weld heat treatment (LPWHT) were performed, in this presentation confirmed by:

-tensile testing,
-impact toughness testing,
-hardness testing,
-flattening testing
-metallographic analysis.

Specimens were obtained before (as welded) and after (as reheated) local post weld heat treatment (LPWHT), according to the illustration in figure 5a and 5b.



(a) (b)

Fig.5 *Sketch illustrating the specimens used for mechanical testing (a) and pipe ring for flattening testing (b)*

Tensile testing were carried out on the base metal (BM), specimen-1 and on the welded joint (WJ), specimen-2, figure 5a.

Impact toughness testing were carried out at the temperature (0°C), by Charpy V-notch (CVN) specimens on the base metal (BM), specimen-3, on the bond line (BL), specimen-4 and on the heat affected zone (HAZ), specimens-3, figure 5a.

Hardness testing across the welded joint, figure 6 were carried out using Vickers (HV30/15) method, specimen-6, figure 5a.

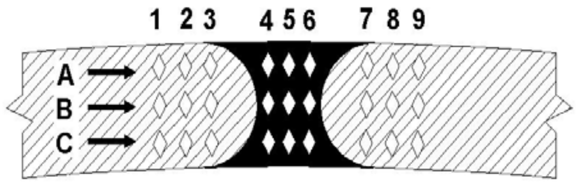


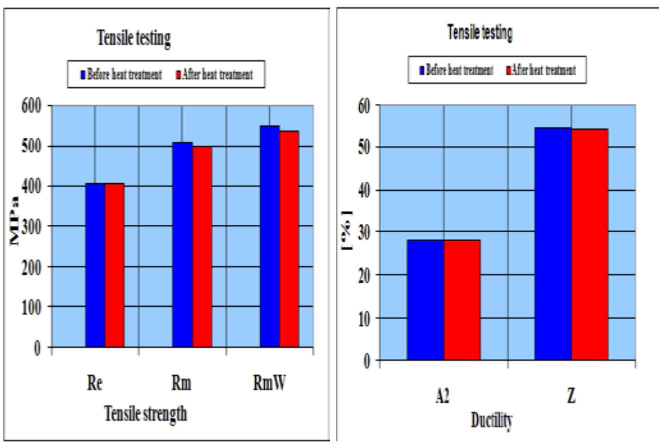
Fig.6 *Hardness (HV30/15) measurement positions*

Pipe rings (15-20 cm long) were extracted from several pipes for use as the specimens for flattening test, figure 5b.

In order to determine metallographic macro and micro analysis by optical light microscope (NEOPHOT), the specimens from hardness testing or from flattening testing were prepared by standard metallographic techniques that includes grinding, polishing and etching with suitable etchant (2% nital).

3. Results and discussion

Tensile specimens before and after local post weld heat treatment (PWHT) are subjected to the tensile testing on the universal machine MOHR-FEDERHAFF-LOSENHAUSEN, and obtained results are shown in figure 7.



(a) (b)

Fig.7 *Tensile testing characteristics*

From the tensile testing characteristics in this case, only ultimate tensile strength of the welded joint (Rm_W), specimen 2, slightly decreased after local heat treatment, but obtained values are above the minimum required values by the API standard. It should be noted that in all cases fracture occurs in the base metal, far from the welded joint, figure 8.

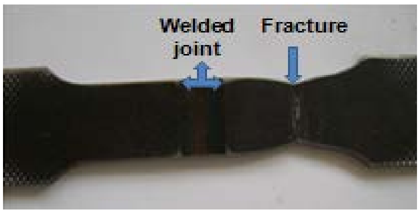


Fig.8 *Tensile testing specimen after tensile testing*

Results from the impact toughness testing in the Charp-y pendulum, MOHR- FEDERHAFF-LOSSENHAUSEN, are shown in figure 9.

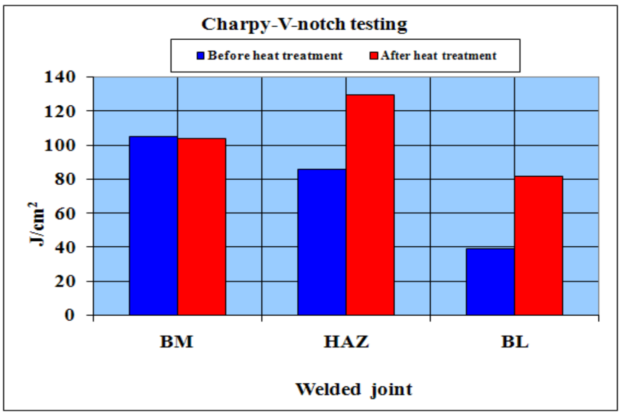


Fig.8. *Impact toughness characteristics*

Average value of three test results of bond line (BL-specimen-4) and heat affected zone (HAZ-specimen-5) increased as a result of the local post weld heat treatment (PWHT) of the welded joint, figure 8.

Hardness measurements across the welded joint were carried out using (HV30/15) method according to the schematic illustration in figure 6 and the obtained results are shown in figure 9. From the hardness test results, it can be deducted that hardness of the welded joint, particularly the hardness of the heat affected zone (HAZ) and hardness of the bond line (BL), after local post weld heat treatment (PWHT) decreases significantly, figure 9. After local post weld heat treatment (LPWHT) hardness distribution across the welded joint is uniform, figure 9.

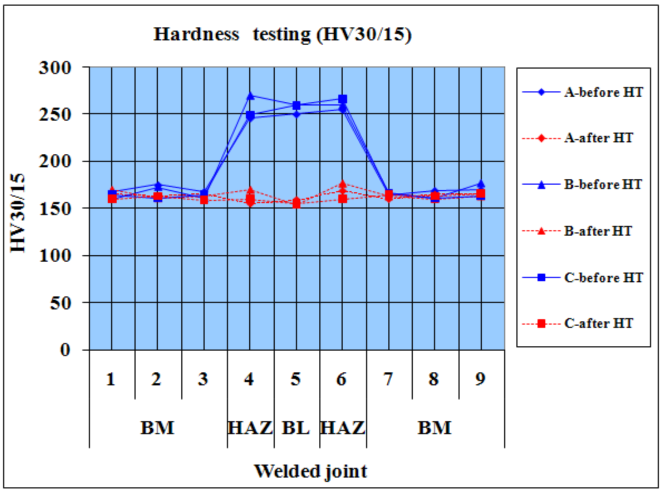


Fig.9 *Hardness (HV30/15) testing results*

Fracture surfaces from the Charpy-V-notch testing are shown in figure 10, separately from base metal (BM), heat affected zone (HAZ) and bond line (BL), before and after local heat treatment.

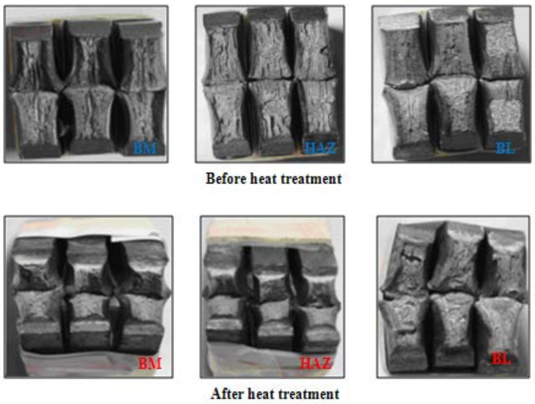


Fig.10 *Fracture surfaces from Charpy-V-notch (CVN) testing*

The test specimens (rings for flattening testing) were flattened in a hydraulic press, DIHNAFORIN PS 2043, at room temperature between two parallel plates with the weld line located 90^o and 0^o to the applied force, figure 11.

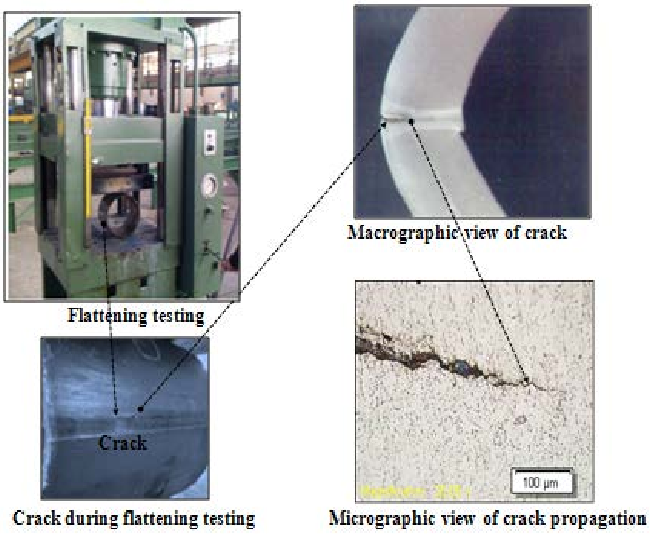


Fig.11 *Flattening testing and view of crack*

In all Specimens before local post weld heat treatment (LPWHT) were occurred cracks or breaks within or in the vicinity of welded joint, which path of propagation is different within welded joint and these results indicates low ductility of welded joint. Some fracture surfaces from the flattenig testing are shown in figure 12.

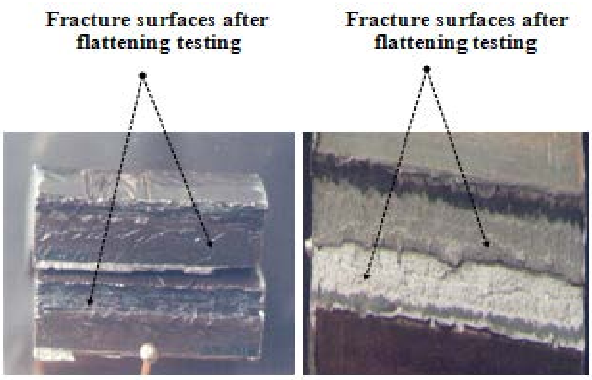


Fig.9 *Fracture surfaces from flattening testing*

During flattening testing, after local post weld heat treatment (LPWHT) is no occurrence of any cracks or breaks in the weld area in the position (90^o and 0^o) until the height specified according to API.

4. Conclusion

The following conclusions can be drawn from the present study:

Welded joint of high frequency electric resistance welding (HFERW) steel pipes, undergoes considerable metallurgical changes during local post weld heat treatment (PWHT). Metallurgical changes that occur in the forge weld area during local post weld heat treatment (LPWHT) are a result of the temperature range and cooling rate. These metallurgical changes refine and unify the final microstructure across the welded joint and improve mechanical properties of the welded joint, especially ductility and impact toughness.

Local post weld heat treatment (LPWHT) of welded pipes is an important constitutive part of the steel pipes production line and through metallurgical changes covers the properties of the welded joint and the performance of welded pipes in service.

Local post weld heat treatment (LPWHT) is recommended after high frequency electric resistance welding (HFERW) to refine and unify grain size structure and improve mechanical properties of the steel pipes welded joint. The mechanical properties that develop as a function of local post weld heat treatment (LPWHT) have been correlated to the microstructural evolution.

The best parameters for evaluation of the effects of local post weld heat treatment (LPWHT) are: toughness values, hardness values and occurrence of cracks and breaks in the welded joint, so Charpy-V-notch testing, hardness testing and flattening testing, accompanied with standard metallographic analysis are valuable and necessary testing in the production of welded steel pipes by high frequency electric resistance welding (HFERW).

The results of this investigation have demonstrated that the X52 steel grade meets all the accepted requirements according to API standard after local post weld heat treatment (LPWHT).

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