MICROSTRUCTURAL CHANGES IN THE FORGE WELD AREA DURING HIGH-FREQUENCY ELECTRIC RESISTANCE WELDING

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Abstract: *High-frequency electric resistance welding is one of the most common process for production of longitudinal seam welded carbon steel pipes suitable for line pipe, casing and tubing. In this pipe production process, the hot rolled strip goes into the forming mill where it is gradually cold formed into a tubular shape in several stages of forming rolls and its edges are continuously joined by a combination of localized electrical resistance heating and forge pressure. High frequency electric resistance welding generally involves high temperature, forge pressure and subsequent cooling, and as the result of this thermal cycle occurs significant microstructural changes. These microstructural changes provides a wealth of information on weld seam quality and edge preparation of hot rolled strips.*

In this paper, microstructural changes in the forge weld area during high frequency electric resistance welding (HFERW) of longitudinal seam welded pipes Ø114.3x5.21mm were investigated.

Keywords: MICROSTRUCTURAL CHANGES, WELD AREA, HEAT AFFECTED ZONE, STEEL PIPES

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 high quality longitudinal seam welded carbon steel pipes suitable for line pipe, casing and tubing. 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]. Most of these pipes are produced according to API Standard [3] plus client supplementary requirements. Under this heat input condition and forge pressure it is possible to improve the weld joint quality and productivity of longitudinal seam welded carbon steel pipes.

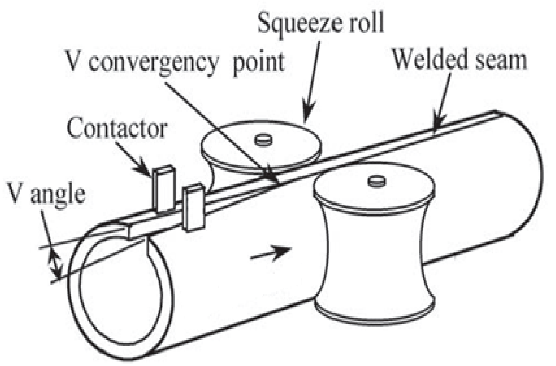


Fig.1 *Schematic illustration of HFERW*

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.

The high frequency current follows a “Vee” shaped path down one edge of the “Vee” and up the other, from one sliding contact (A) to the other (B), completing electrical cicuit, Figure 3.

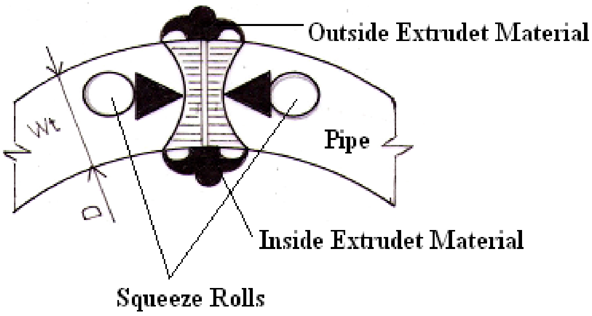


Fig.2 *High frequency electric resistance forge weld*

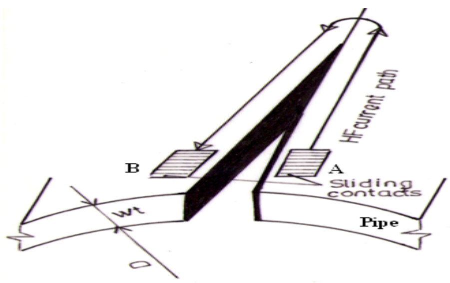


Fig.3 *Sliding contacts of high frequency current*

During high frequency heating, high frequency current enters the strip edge from the top and the side of the edge. The parent metal melting occurs in butting (roughness) surfaces and this molten layer formed is squeezed out from the edges together with the oxide films. Heat penetration produced by high frequency current into the edges of the parent metal is greater at the top and bottom corners and less at the middle wall thickness, Figure 4.

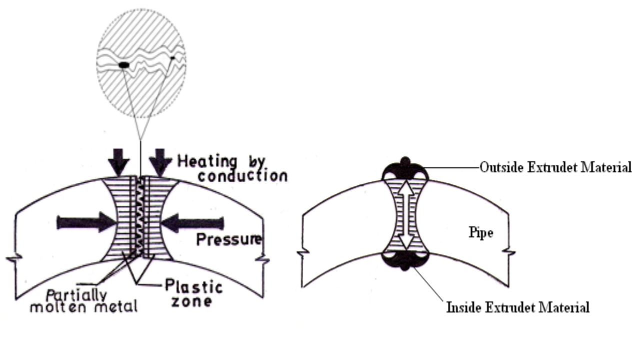


Fig.4 *Schematic sequence of HFERW*

From the metallurgical point of view, high frequency electric resistance welding (HFERW) is characterized by extremely rapid heating and cooling over a very short period combined with forging pressure.This specific thermal cycles combined with forging pressure are important metallurgical factors. As a result of these metallurgical factors some complex microstructure changes can occur.

The material extruded on the inside and outside weld surfaces, usually removed by scarfing while still hot and forms a typical HFERW weld with narrow bond line (BL) or fusion line (FL) and associated local heat affected zone (HAZ) is formed [4]. The high frequency electric resistance welded seam is subjected to post weld heat treatment in-line such as induction heating and gradually air cooling, the purpose of which is to eliminate zones of excessive hardness from the initial welding process as such zones could be susceptible to various forms of environmental cracking.

Microstructural changes that takes place during the welding covers the properties of welded pipes, defects associated with welding and the performance of welded pipes in service.

The normal HFERW weld area is shown in Figure 5 [4]. Note that the heat affected zone (HAZ) is shaped like an hourglass. Weld fusion line (FL) or weld bond line (BL) is in the centre of the heat affected zone, vertical to the pipe wall thickness. The flow lines are symmetrical around the bond line.

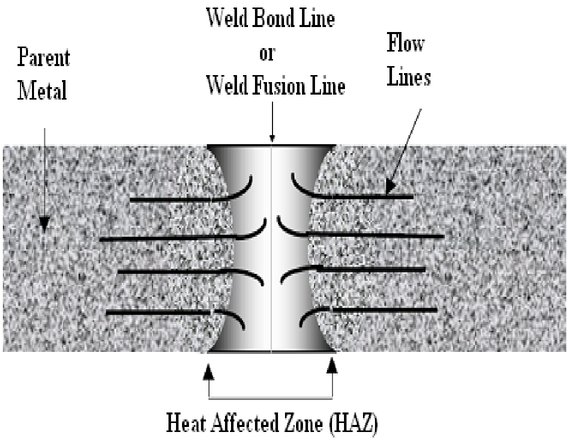


Fig.5 High frequency electric resistance weld area

Hot rolled coils used for HFERW pipes has fine grained microstructure showing a prominent banding as a results of the rolling operations at the steel mill. These bands are usually straight, running along the rolling direction [5]. Hot rolled coils or skelp used for HFERW steel pipes often contain alternating thin layers or bands of ferrite and pearlite.

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 [6]. The flow lines, respectively flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$), Figure 6, are a natural consequence of applied mechanical pressure of the squeezing rolls. The orientation of the flow lines indicates the direction of the metal flow during plastic deformation. By the measurement of the flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) it is possible to determine directly whether the squeezing pressure and relevant welding temperature are correct or not.

The high frequency electric resistance welded joint is subjected to a local post weld heat treatment (PWHT) in-line by the inductive heating, followed by air cooling, Figure 7. 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 (PWHT) of the welded joint, depending on the temperature range and the cooling rate, microstructural changes takes place and these changes covers the properties of the welded joint and the performance of welded pipes in service

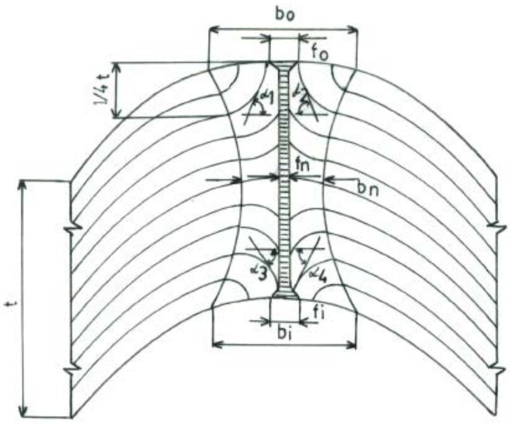


Fig.6 *Flow lines (fibres) and flow angles around bond line during plastic deformation*

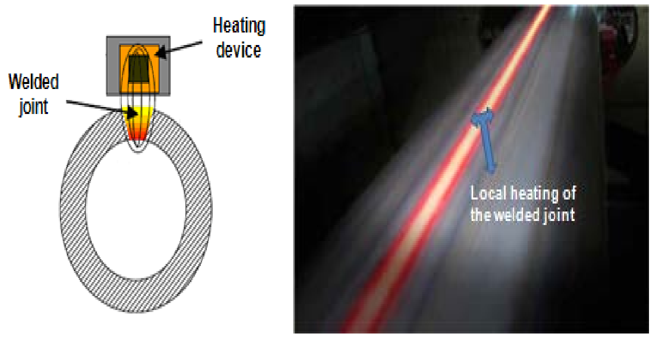


Fig.7 *Local postweld normalizing heat treatment of HFERW*

Forge weld area of HFERW may be divided into four zones, Figure 8, [4]: 1-bond line (BL) or fusion line (FL); 2-heat affected zone (HAZ); 3-Edge of the heat affected zone and 4-base metal (BM). These different zones are normally defined by the peak temperature experienced at certain distance from the fusion line during welding. Each zone in the weld area is characterized by a unique microstructure and hence different mechanical properties. The zones of the weld area are quite narrow and it is difficult to investigate the behavior of specific location without interference from the adjacent zones with different properties.

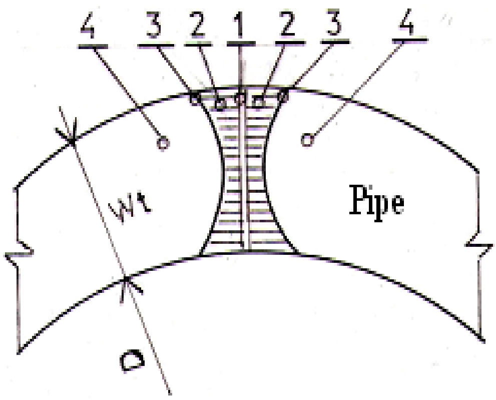


Fig.8 *Schematic illustration of constitutive parts of weld area*

2. Experimental procedure

High-frequency electric resistance welding was conducted using an L-16 in, 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. Casing pipes Ø114.3x5.21mm are typical case in the mill production schedule, hence in this paper these pipes were investigated. Pipes Ø114.3x5.21mm were fabricated from high strength steel coils J55 according to API [3] 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 used steel coils J55*

Steel coils	Chemical composition [wt-%]							
	C	Mn	Si	P	S	Al	Nb	N
API grade J55	0.141	1.113	0.229	0.014	0.008	0.047	0.017	0.0072

Table 2: *Mechanical properties of used steel coils J55*

Steel coils	Mechanical properties		
	Re	Rm	$A_{2"}$
	[MPa]		[%]
API grade J55	453	557	32.5

Whether or not appropriate welding has been performed was confirmed by conducting flattening test and metallographic examination [7].

Two rings (10-15cm long) were extracted from several pipes for use as the specimens for flattening test, Figure 9.

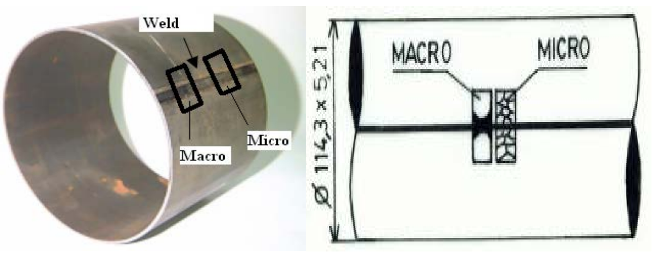


Fig.9 *Sketch illustrating the orientations of the metallographic specimens used*

Specimens for metallographic examination were cut out from the weld joint of casing pipes Ø 114.3x5.21mm, perpendicular to the welding direction.

In order to determine metallographic macro and micro analysis, the metallographic specimens were prepared by standard metallographic techniques that includes grinding, polishing and etching with suitable etchant (nital and Oberhoffer) to reveal the macro and microstructure.

Mechanical grinding is performed in successive steps using SiC abrasive papers of different grit sizes, usually 180, 220, 320, 600, 800 and 1000 with continuous cooling to avoid structural changes. Mechanical polishing is performed using diamond paste on a short nap cloth disc. After polishing, the specimens were etched with suitable etchant (nital and Oberhoffer), followed by thorough washing and finally rinsed in alcohol and dried in a stream of warm air.

Macro metallographic analysis is performed on a etched cross section of the welded joint by standard visual examination with the naked eye and with optical microscope, NEOPHOT 21, at low magnification.

Micro metallographic analysis is performed on a etched cross section of the welded joint by optical microscope NEOPHOT 21, at high magnification.

3. Results and discussion

The test specimens were flattened in a hydraulic press, DIHNAFORIN PS 2043, at room temperature between to parallel plates with the weld line located 90^o and 0^o to the applied force. The specimens (rings) were flattened to a specified height according to API, Figure 9.

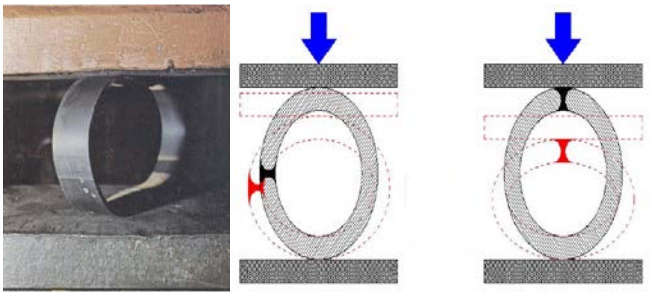
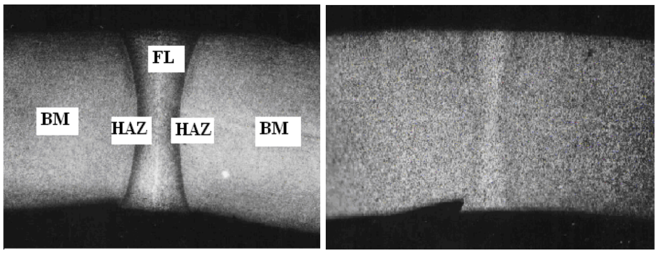


Fig.10 *Schematic illustration of flattening test*

During flattening testing, in all rings, there is no occurrence of cracks or breaks in the weld area in the position (90^o and 0^o) until the height specified according to API.

The shape, width and uniformity of the weld area as well as the degree of upset of the flow lines (fibres) and flow angles are presented in Figure 11, 12 and 13.



Nital a 10X Nital b 10X

Fig.11 *Macrostructure of a cross-section weld* area

Macrostructure in Figure 10a shows a cross section of a typical high frequency electric resistance weld of the longitudinal steel pipes in the as welded condition prior to heat treatment. The width of the weld is uniform from top to bottom, indicating that the heat energy input was uniform. The fusion line (FL) or bond line (BL) is vertical to the wall thickness and is usually light colored because it is very low in carbon. Due to high temperature, the carbon amount at the fusion line oxidizes, leaving the iron without carbon to darken it. This part of the weld area called decarbonisation layer or light area [8].

Adjacent to the fusion line (FL) is the heat affected zone (HAZ) where the materials is affected by the heat of the welding process. The heat affected zone (HAZ) is shaped like an hourglass as a result of the heat generated by the high frequency current.

Macrostructure in Figure 10b indicates that after normalizing heat treatment, the forge weld areas is indiscernible from the rest of the base metal (BM).

Microstructure of the base metal (BM) and heat affected zone (HAZ) are shown by the photomicrographs in Figure 12. The photomicrograph on the left shows the microstructure of the base metal (BM), whereas the photomicrograph on the right shows the microstructure of the heat affected zone (HAZ) after normalizing heat treatment. The base metal (BM) has fine grained ferrite-pearlite microstructure with some bands in the entire the wall thickness. The heat affected zone (HAZ) has also fine grained ferrite-pearlite microstructure as a result of the proper normalizing heat treatment.

Nital BM 100X Nital HAZ 100X

Fig.12 *Microstructure of a cross-section weld* area

Flow lines and flow angles, Figure 13 illustrates the influence of the forge pressure in the weld area.

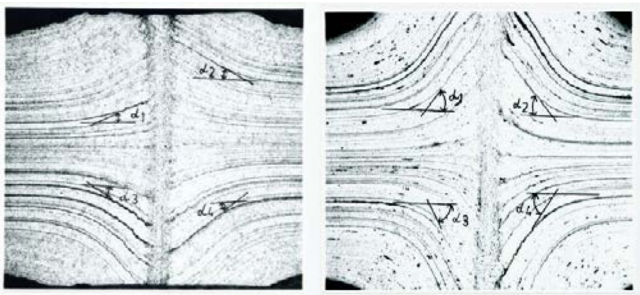


Fig.13 *Flow lines and flow angles in the weld area*

The flow lines are visible in all metallographic specimens and the degree of upset is different, depending from the intensity of plastic deformation of squeeze weld rolls. Figure 13 shows flow lines, respectively flow angles from some characteristic metallographic specimens of HFERW pipes Ø 114.3x5.21mm.

4. Conclusion

Following conclusions can be drawn from the present study:

Forge weld area during high frequency electric resistance welding (HFERW), undergoes considerable microstructural changes. Microstructural changes that occur in the forge weld area during high frequency electric resistance welding (HFERW) of carbon steel API Grade J55 are a result of the complex simultaneous interactions between thermal and mechanical factors. These microstructural changes affect the mechanical properties of the weld area and the performance of the welded joint.

Microstructural changes in the forge weld area can provide a wealth of information on the mill setup operations, weld quality, edge preparation and normalizing heat treatment in line as an important part of the production process.

5. References

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