The Influence of the Plastic Deformation on the Metal Flow During High Frequency Electric Resistance Welding of Longitudinally Welded Pipes

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Abstract: High frequency electric resistance welding is one of the most extensively used methods for production of longitudinally welded carbon steel pipes suitable for line pipe, casing and tubing. Line pipe production process involved cold forming previously hot rolled strips into round shape and joining the strip edges by a combination of localized high frequency electric resistance heating and mechanical pressure. The heated edges up to the welding temperature squeezed together at the "Vee" apex by the forge pressure rolls, plastically deformed and a forge type weld is formed. The material extruded on the inside and outside weld surfaces, usually removed by scarfing while still hot. The plastic deformation which is realized under the action of the squeezing rolls caused orientation of the constituents of the metal in the different directions and plays principal role on the quality of welded zone. Understanding and control of the metal flow or fibres of strip edges is the key to a successful welding operation to obtaining the desired shape and properties. Metal flow determines both the mechanical properties related to local deformation and the formation of defects such as cracks, cold welds and slanting or twist fusion line. The obtained results using light microscopy (LM) and flattening testing are presented in this work and this is an attempt to estimate the influence of plastic deformation on the metal flow during high frequency electric resistance welding of longitudinally welded carbon steel pipes suitable for line pipe, casing and tubing.

Introduction

High-frequency electric resistance welding (HF-ERW) process is one of the most extensively used methods for production high quality longitudinally 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 mechanical pressure, as schematically illustrated in fig.1 [1,2].

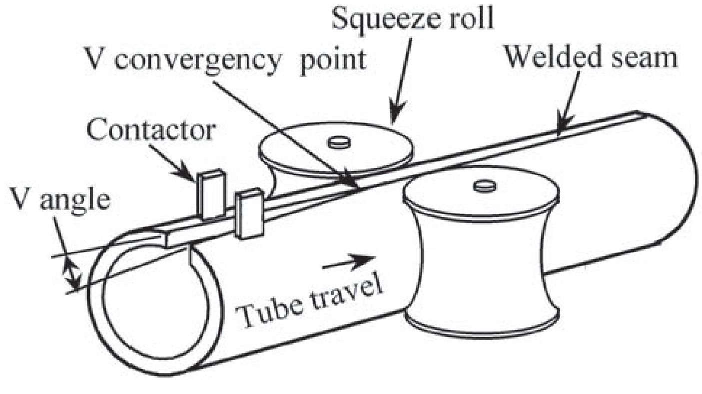


Fig.1. Schematic illustration of high-frequency electric resistance welding of steel pipes

The high-frequency current is 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 [3]. 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 plane. Fig. 2 shows that all of the liquidus and metal oxides are squeezed out of the weld as the edges pass between the weld rolls [4].

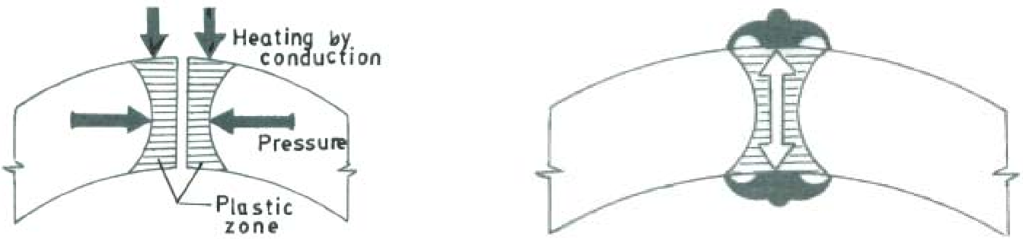


Fig.2. Schematic sequence of high-frequency electric resistance welding process

The two side squeezing rolls put pressure on the strip edges and extrudes foreign particles, such as oxides and others debris from the weld zone. Metal extrusion can occur on the inside (ID) and outside (OD) surfaces.

The material extruded on the inside and outside weld surfaces, usually removed by scarfing while still hot and forms a typical HF-ERW weld with narrow bond line (fusion zone) 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 for quality improvement.

Hot rolled coils used for HF-ERW 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 [6]. 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. In hot rolled coils or skelp obtained from continuous casting process, pressure of the squeezing rolls also caused flows of the centreline segregation towards the outside or inside surface of the bond line [7]. Orientation of the homogeneous and nonhomogeneous constituents of the metal in the different directions, fig. 3, determines the quality of the weld joints.

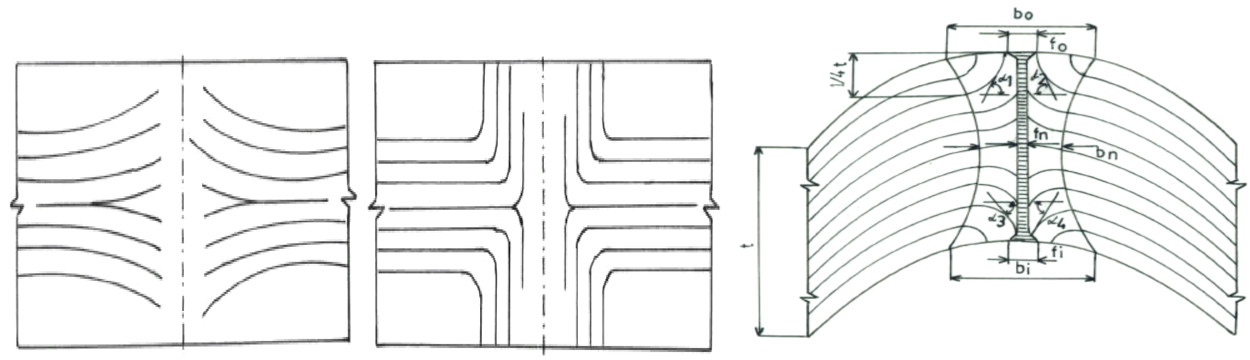


Fig.3. Flow lines (fibres) and flow angles around bond line during plastic deformation

Experimental Procedure

High frequency electric resistance welding of longitudinal casing pipes Ø 114.3x5.21mm were fabricated from high strength steel coils J55 according to API (American Petroleum Institute) 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 tab. 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		
API grade J55	Re, MPa	Rm, MPa	A_2, %
	453	557	32.5

Whether or not appropriate welding has been performed was confirmed by conducting flattening tests and metallographic examination.

Two rings (10-15cm long) were extracted from several pipes for use as the specimens for flattening tests. Specimens for metallographic examination were cut out from the weld jonit of casing pipes Ø 114.3x5.21mm, perpendicular to the welding direction.

In order to determine metal flow in the weld area, the metallographic specimens were prepared by standard metallographic techniques and subsequently lightly etched by Nital and Oberhoffer to reveal the degree of upset of the flow lines that has been achieved as well as the width and uniformity of the bond region.

Results and Discussion

Flattening Testing. The test specimens were flattened in a press 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, fig.4, and the obtained results are shown in tab.3. These tests reveal both imperfections in the weld and a lack of ductility in the parent metal adjecent to the weld.

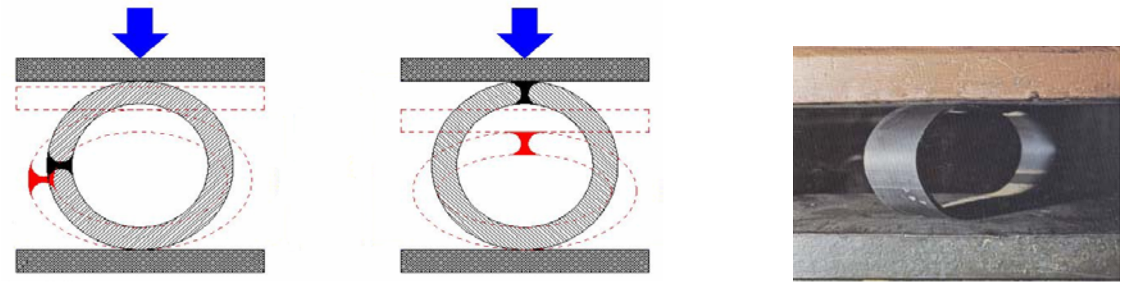


Fig.4. Schematic illustration of flattening tests

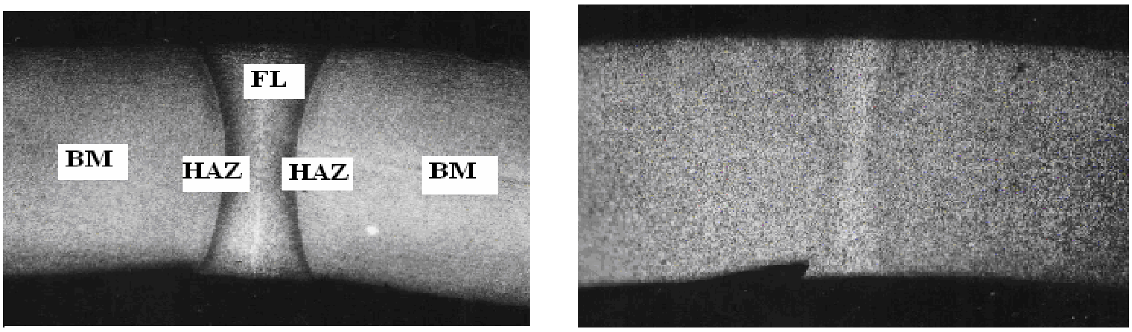
Crashing the ring in the position (90^o) puts the outside surface of the weld in tension and the inside surface in the compresion; the position (0^o) does the opposite.

During flattening testing, in all rings, there is no occurence of cracks or breaks in the weld in the position (0^o) until the height specified (38.1mm) according to API. Weld of specimens 1 and 2 in the position (90^o) failed before the minimum height is reached (76.2mm) according to API.

Table 3. Flattenig tests results

Specimens	Flattening tests	
	Position [0^o]	Position [90^o]
	h_{min}=1/3D=38.1 [mm]	h_{min}=2/3D=76.2 [mm]
1	+	-
2	+	-
3	+	+
4	+	+
5	+	+

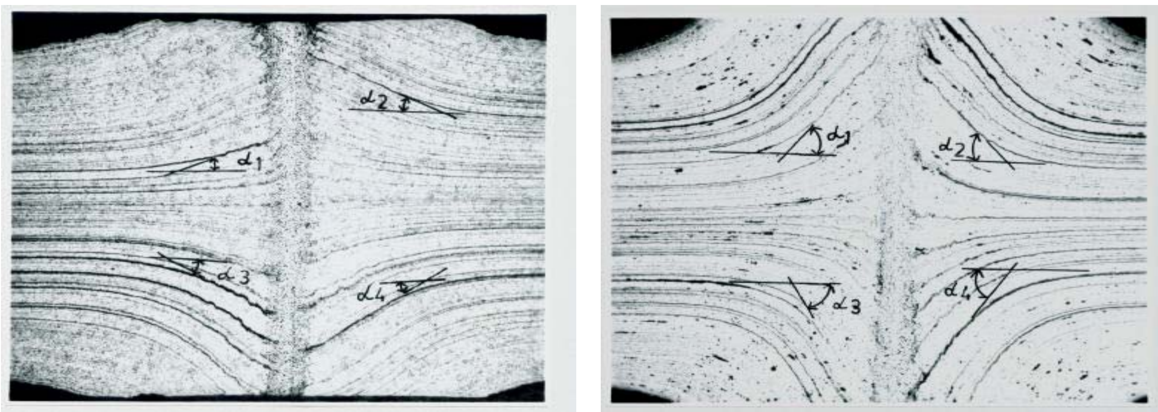
Metallographic Examination. In order to determine metal flow in the weld area, the metallographic specimens were prepared by standard metallographic techniques and subsequently etched by Nital and Oberhoffer to reveal the width and uniformity of the bond region as well as the degree of upset of the flow lines (fibres) and flow angles that has been achieved, fig. 5 and 6.



Nital 10X Nital 10X

a) b)

Fig.5. Macroscopic weld geometry



Oberhoffer Oberhoffer

a) b)

Fig.6. Macroscopic view of flow lines (fibres) and flow angles around bond line

Macrostructure in Fig. 5a shows a cross section of a typical high frequency electric resistance weld in 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 heat affected zone (HAZ) is shaped like an hourglass as a result of the heat generated by the high frequency current. Macrostructure in Fig.5b indicates that after heat treatment, the forge weld areas are undiscernable from the rest of the base metal (BM).

The influence of plastic deformation can be observed by examining the flow lines, respectively flow angles around fusion (bond) line.

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. Fig.6a and 6b shows flow lines, respectively flow angles from two characteristic metallographic specimens (specimen 1 and 5).

The flow lines with the slight banding around fusion line, fig.6a (specimen 1 and 2) with low angle values (25^o-37^o) indicates the low squeezing pressure.

The flow lines with the slight banding around fusion line, fig.6b (specimen 3, 4, 5) with medium angle values (52^o-62^o) indicates the optimal squeezing pressure.

The flow lines pass parallel to and away from the fusion line, i.e., approaching vertical with high angle values (>80^o) indicating the high squeezing pressure.

Flow angles were measured and the obtained results are shown in tab. 4.

The measured angles are nearly symmetrical and within the range of 25-62^o.

Table 4. Flow angles

Specimens	**Flow angles [^{o}]**			
	α_1	α_2	α_3	α_4
1	25	27	30	32
2	35	37	32	35
3	53	52	55	57
4	54	60	60	60
5	55	57	62	60

Conclusion

From this work, it is possible to draw the following conclusions when evaluating the effect of plastic deformation on the metal flow during HF-ERW of longitudinaly welded pipes:

Plastic deformation applied by the squeeze weld rolls, which forces the heated edges into contact forming a hot diffusional bond. This pressure forces molten metal and any impurities out of the weldment, so the resulting structure is that of a forging , rather than the casting formed by most other welding processes, and it results in one of the strongest welded structures possible.

Metal flow lines (fibres), respectively flow angles are in direct proportional relation with the squeezing amount.

Flow lines (fibres), respectively flow angles around fusion line are the most direct and effective methods to control the weld joints quality of the casing pipes.

From the obtainet results it was confirmed that an appropriate weld was attained when the metal flow angles are within a range 52-62^o.

Orientation of the nonhomogeneous and homogeneous constituents of the metal in the different directions determines both the mechanical properties related to local plastic deformation and the formation of defects such as cracks, cold welds and slanting or twist fusion line.

Metallographic examination of weld cross section in combination with flattening tests are a very suitable tools to monitor not only the accuracy of the weld mill set up but also to monitor quality during productions runs.

References

[1] J.H.Choi, Y.S. Chang, C.M.Kim, J.S.Oh, and Y.S.Kim, Penetrator Formation Mchanisms during High-Frequency Electric Resistance Welding, Welding Journal, January 2004, 27s-31s.

[2] D.Kim, T.Kim, Y.W.Park, K.Sung, M.Kang, C.Kim, C.Lee, and S.Rhee, Estimation of Weld Quality in High-Frequency Electric Resistance Welding with Image Processing, Welding Journal, March 2007, 71s-79s

[3] J. H. Choi, Y.S. Chang, C.M.Kim, Penetrator Formation Mechanisms during High-Frequency Electric Resistance Welding, Welding Journal, January 2004, 27s-31s.

[4] R. K. Nicols, Thermatool Corp. Publication # 116, Rev. A11-98, East Haven,CT, USA.

[5] F.A.Khalid, M.Farooque, A.ul Haq and A.Q.Khan, Role of ferrit/pearlite bande structure and segregation on mechanical properties of microalloyed hot rolled stele, Materials Science and Technology, October 1999, Vol.15, 1209-1215.

[6] L. Warren, Examining electric resistance weld nuggets in tube and pipe usinë the microscope to study weld characteristics, Practical Welding Today, April 24, 2001.

[7] Rr. Maksuti, N. Çerkini, S. Qorrolli, Utjecaj Centralne segregacije toplovaljane trake na kvalitet zavarenog spoja cjevi sa uzdužnim šavom, Splošno Združenje Crne Metalurgije Jugoslavije, Slovenske Železarne, Zbornik del za IX Posvetovanje valjarev, Štore, 16-18 (1990), 463-472.