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Original Scientific Paper

QUALITY EVALUATION OF HIGH FREQUENCY ELECTRIC RESISTANCE WELDED JOINT

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Abstract

Aim: This article aims to evaluate the quality of welded joint by solid state high-frequency electric resistance welding (HF-ERW), which is one of the most common process for production of longitudinal welded carbon steel pipes, mainly used as line pipes, casing, tubing as well as in machine structures in a wide range of applications including different industrial field. Production process involved pipe forming by gradually cold plastic deformation of hot rolled strips and joining the strip edges by a combination of localized high frequency electric resistance conductive heating and mechanical pressure by forge rolls. Heat input in combination with mechanical pressure are key process parameters for high frequency electric resistance welding.
Method: These process parameters which have determining influence on the welding process must be continuously monitored and in order to evaluate the quality of the chosen steel welded joint, in this research, destructive testing were performed. In this respect, to determine the welded joint integrity, mechanical testing and metallographic analysis of the welded joint cross section were performed, as the most direct and effective methods to evaluate quality of the welded joint. Specimens for mechanical testing and metallographic analysis were taken from the welded joint, transversally to the welding direction.
Results: The obtained results from the mechanical testing and metallographic analysis in this work give indirectly important information related to the welding process parameters and directly, bring the necessary information for the quality evaluation of the welded joint.
Conclusion: Based on these results, it is concluded that mechanical properties and metallographic analysis are very important characteristics for quality evaluation of the welded joint.

Keywords: steel pipes, welded joint, quality evaluation, mechanical testing, metallographic analysis.

1. Introduction

High frequency electric resistance conductive welding (HF-ERW) process is one of the most extensively methods for the production of high quality longitudinally welded carbon steel pipes suitable for line pipe, casing, tubing as well as in machine structures in a wide range of applications including different industrial field. In this process, hot rolled strip is gradually formed into a round shape through roll-forming stands, and its edges are joined by a combination of localized high-frequency electric resistance conductive heating and mechanical pressure (Choi, Chang, Kim, & Oh, 2004) (Kim, et al., March, 2007). 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 in the weld squeeze rolls and forge type weld is achieved, Figure 1 (Nicols, 1999) (Simon, Dia, Istrate, & Monteanu, 2014). The angle and length of the "Vee" are the other important parameters in the process of HF-ERW (Sabzi, Mesagh, Kianpour, Ghobeiti, & Mesagh, 2018). The material extruded on the inside and outside weld surfaces, usually removed by cutting while still hot and forms a typical metallurgical forge clean weld with a narrow bond line and associated local heat affected zone (HAZ) is formed (Maksuti, Mehmeti, & Oettel, 2007) (Maksuti, 2016).

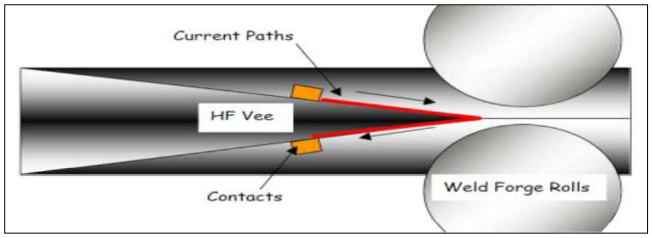


Figure 1. High frequency electric resistance conductive welding (HF-ERW)

During pipe production, there is a need continuously monitoring welding processes parameters such as heat input and magnitude of pressure rolls. Monitoring of these welding process parameters is of great importance in HF-ERW for the purpose of making pipes with consistent and defined quality of the welded joint. It is therefore imperative to control and monitor welding process parameters in real time, to prevent welding defects and effectively manage the process of production (Simon, Dia, Istrate, & Monteanu, 2014). Modern Japanese steel pipes producers, developed the weld monitoring technology by employing the real-time image processing and frequency measurement and applied this technology to the current production processes and confirmed that the quality of the welded joint can be controlled at a high level (Hasegawa, et al., 2015). But unable in real time to monitoring these welding process parameters, evaluation of the welded joint quality by destructive and non-destructive testing is often used to verify indirectly welding process parameters and on the other hand, these testing results used in order to evaluate quality of the welded joint as integral parts of the welded pipes. Mechanical testing and metallographic analysis of the welded joint are valuable analytical procedures widely used in the welded pipe industry, including: set up of the production process, monitoring of the production process and finally for the quality evaluation of the welded joint. In steel pipe production, mechanical testing and metallographic analysis covers the wide range of pre-HF-ERW, during-HF-ERW and post-HF-ERW activities. Metallographic analysis combined with mechanical testing can extract the most detailed information that can lead to quality evaluation of the welded joint.

Therefore, this is the main aim of this paper, thus through the destructive testing (mechanical testing and metallographic analysis), indirectly to monitoring the welding process parameters in the production process and on the other hand, directly to evaluate the quality of the welded joint.

2. Material and experimental procedure

High frequency electric resistance welding of longitudinal casing pipes Ø 114.3x5.21mm was fabricated from high strength steel coils J55 according to API (American Petroleum Institute) standard, using pipe production equipment (model: THERMATOOL) (Institute, 2004). Chemical composition and mechanical properties of the used steel are given in Table 1.

Table 1. Chemical composition and mechanical properties of used steel coils API grade J55

Steel coils	Chemical Composition								Mechanical Properties		
	C	Mn	Si	P	S	Al	Nb	N	Re	Rm	A_2"
	wt-%								MPa		%
J55	0.141	1.113	0.229	0.014	0.008	0.047	0.017	0.0072	453	557	32.5

Pipe rings were cut out from the several produced pipes Ø 114.3x5.21mm on the production lines (L-16) and from these rings were extracted specimens by oxy-acetylene flame cutting with subsequent machining to avoid thermal effect, for mechanical testing and metallographic analysis, Figure 2. Anisotropy of mechanical properties or orientation dependence of mechanical properties as one particular phenomenon in steel pipe production will be investigated in further investigation.

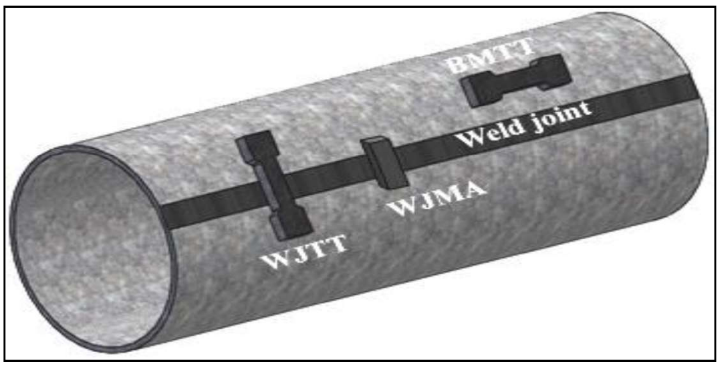


Figure 2. Sketch illustrating the locations of the specimens for tensile testing and metallographic analysis

2.1. Mechanical testing: Mechanical properties of the welded joint (WJ) and the base metal (BM) were evaluated by tensile test. Tensile tests were conducted on specimens taken perpendicular to the welded joint (WJTT), to measure the ultimate tensile strength of the welded joint (Rm_{WJ}) and longitudinal to the welded joint axis from the base metal (BMTT), to measure yield strength (Re_{BM}), ultimate tensile strength (Rm_{BM}) and elongation (A_{BM}), Figure 2. All tensile tests specimens were conducted according to the ASTM A370, in the universal testing machine (model: MOHR-FEDERHAFF-LOSENHAUSEN).

2.2. Metallographic analysis: In order to determine macro and microstructure, the metallographic specimens were taken from the welded joint (WJMA), Figure 2 and prepared according to the standard metallographic techniques that includes grinding, polishing and etching with suitable etchant (Nital, Picral, Oberhoffer) to reveal the macro and microstructure. Flow angles and micro structural constituents can be determined using standard metallurgical preparation techniques. 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 (model: NEOPHOT 21). Micro metallographic analysis is performed on the etched cross section of the welded joint with the same optical microscope.

3. Results and discussion

All the tensile test results are shown in Figure 3. Average value from the five tested specimens of the ultimate tensile strength (UTS) of the welded joint (Rm_{WJ}=580 MPa) was about 17 MPa higher than the ultimate tensile strength of base metal (Rm_{BM}=563 MPa), or 3.0 %. In this study, all 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 4.

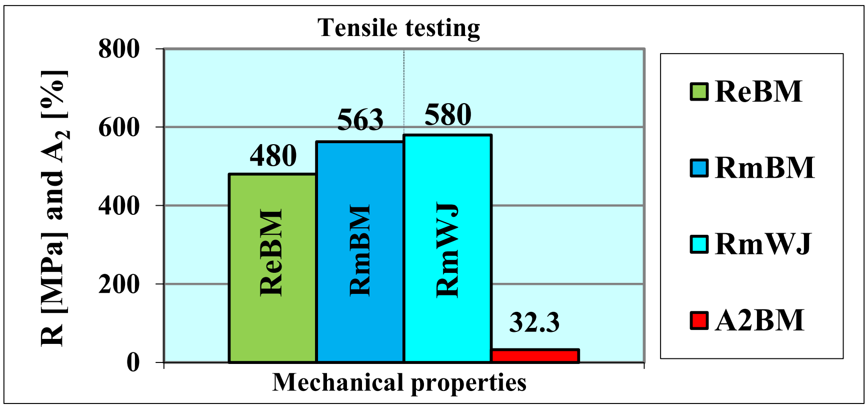
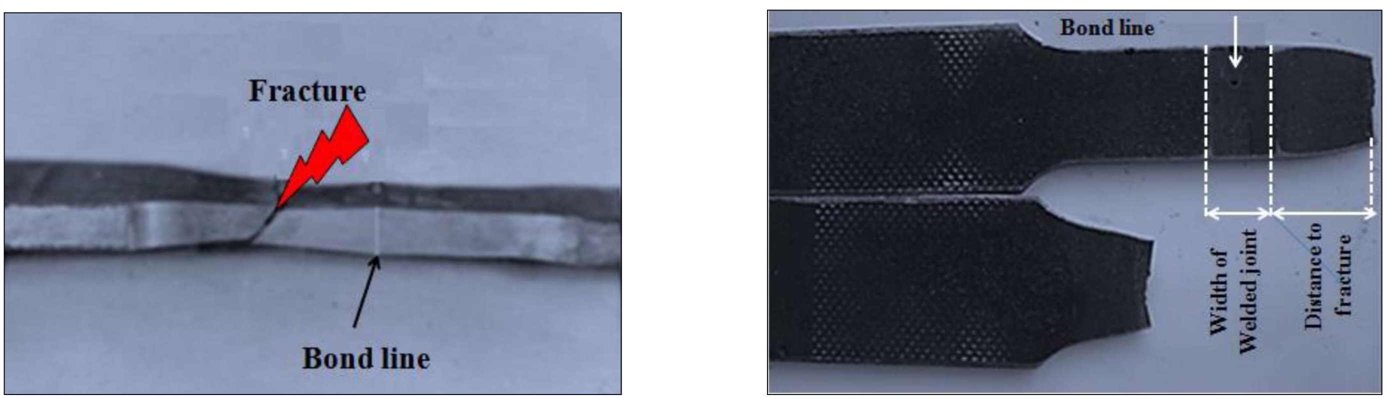


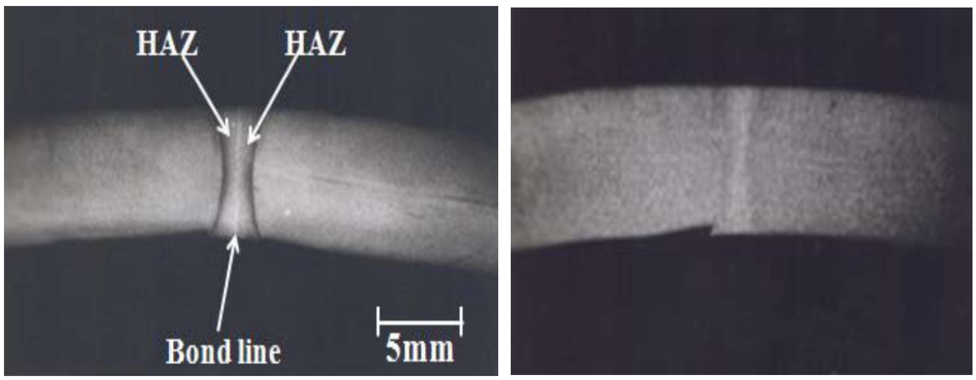
Figure 3. Tensile properties of the welded joint of HF-ERW



(a) **(b)**

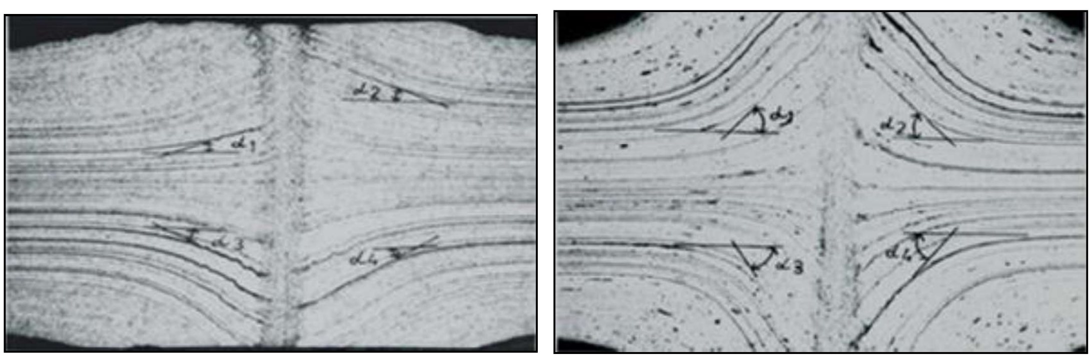
Figure 4. Typical fractured surfaces of tensile tested specimens

Figure 5(a) shows the macrograph of the welded joint of high frequency electric resistance conductive welding (HF-ERW) 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 white line in the center is the weld line (bond line), typical of high frequency conductive electric resistance welding (HF-ERW). The weld (bond line) is uniform in width and without voids or interruptions. The hourglass shaped heat affected zone (HAZ) is symmetrical around the bond line (Asperheim, 2000) (Scott, 2005). This hourglass shape is the result of the high frequency current applied to the strip edges through sliding contacts (Warren, 2001)(Warren, 2001). Figure 5(b) shows macrograph of the welded joint of high frequency electric resistance conductive welding (HF-ERW) in the final condition, after heat treatment. Macrographs also reveal the degree of upset that has been achieved as well as the width and uniformity of the welded joint. The degree of the upset can be observed by examining of flow lines visible from the slight banding that occurs during squeezing, Figure 6(a) and 6(b). The flow lines, respectively flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) 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 (Maksuti, Mehmeti, Rama, & Beqiri, 2012). 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. Flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) were measured and the obtained results are presented in Table 2.



(a) (b)

Figure 5. Macrographs of the welded joint



(a) (b)

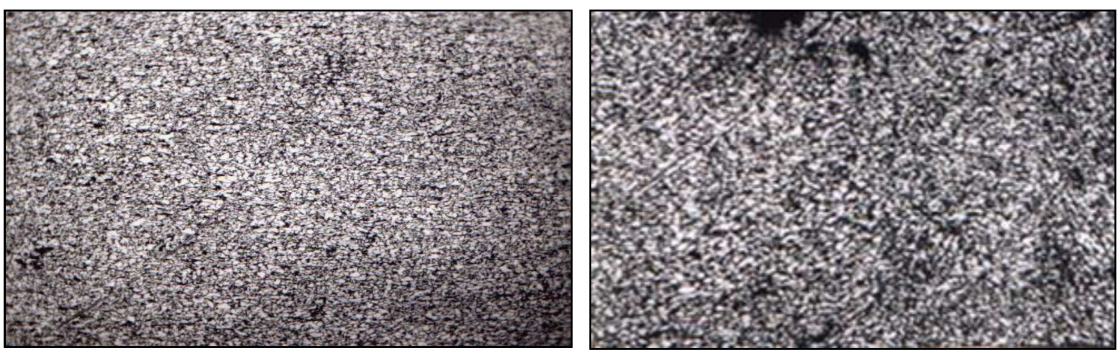
Figure 6. Flow lines (fibres) and flow angles around bond line of the welded joint

Heat affected zone (HAZ) and bond line width observed in Figure 2, directly reflect the magnitude of heat input and the relevant squeezing amount and can determine whether the welding parameters are adjusted properly or not.

Table 2. Flow angles around bond line of the welded joint

Specimens	Flow angles (°)			
	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

Flow angles are nearly symmetrical and within the range of 25-62° (Maksuti, Mehmeti, Rama, & Beqiri, 2012). From the obtained results it was confirmed that an appropriate weld joint was attained when the metal flow angles are within a range 52-62°. The micro metallographic analysis is performed for a number of purposes, the most obvious of which is to assess the microstructure of the welded joint, prior to heat treatment and post heat treatment. Figure 7(a) and 7(b) shows micrographs of post heat treatment of the welded joint. Heat treatment improve the microstructure of the heat affected zone (HAZ) and the microstructure of the weld (bond) line. The microstructure of the heat affected zone (HAZ) consists of fine equiaxed ferrite-pearlite grains to the entire wall thickness.



HNO_3 (a) 100X HNO_3 (b) 100X

Figure 7. Microscopic view of the HAZ

4. Conclusions

The main conclusions that can be drawn from this paper are:

Mechanical properties of the welded joint in this study were determined through ultimate tensile strength (Rm_{WJ}) and compared to the ultimate tensile strength of the base metal (Rm_{BM}) is slightly higher (3.0%). This is attributed to the optimal selection of welding process parameters. On the other hand, ultimate tensile strength of the welded joint meet the standard requirements and overmatching effect is achieved in this case, which is also an important indicator for the quality evaluation of the welded joint in terms of the mechanical properties.

Metallographic analysis of welded joint is a valuable analytical procedure widely used in the welde pipe industry and extremely important indispensable tool. It is used for a variety of reasons, including: evaluation of the production set up process, monitoring of the production process and finally, quality evaluation of the welded joint. The obtained metallographic results are clearly and fully documented by permanent record. In combination with fractured surfaces from the tensile testing, metallographic analysis can extract the most detailed information about the quality evaluation of high frequency electric resistance welded joint.

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