Development of Advanced Electric Resistance Welding (ERW) Linepipe "Mighty Seam™" with High Quality Weld Seam Suitable for Extra-Low Temperature Services†

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Abstract:

JFE Steel has developed an advanced electric resistance welding (ERW) linepipe "Mighty Seam™." This new process controls the morphology and distribution of oxides generated during welding, and checks for flaws along an entire length of wolds on a real-time basis. "Mighty Seam™" offers cost savings to extra low temperature services for which mainly seamless pipes or UOE pipes have been used until now.

1. Introduction

JFE Steel developed an electric resistance welding (ERW) linepipe, "Mighty Seam™," with a high performance weld seam. This new product is used in oil and gas linepipe in severe applications such as arctic regions, etc. where seamless pipes or UOE pipes have mainly been used until now.

2. Quality Issues for ERW Linepipe

2.1 Manufacture/Inspection and Advantages of ERW Linepipe

Electric resistance welding (ERW) pipes are manufactured by continuously roll-forming hot coil material into a pipe shape, and butt-welding the weld seam after heating/melting the coil edges using the Joule heat generated by passing a high frequency current through the edges. At the seam of the ERW butt weld (hereinafter, seam), the welding beads on the pipe inside and outside surfaces are removed by online, full-length grinding, followed by seam heat treatment to improve the weld microstructure (**Fig. 1**).

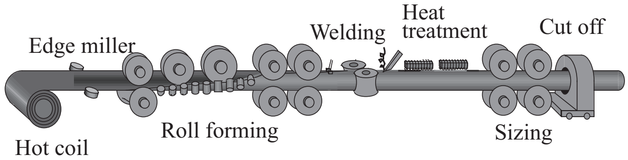

Fig. 1 Manufacturing method of ERW tube

After ERW linepipes are cut to the specified length, product pass through the quality assurance process, which includes hydrostatic testing, ultrasonic testing of the seam and pipe body, inspections of external appearance and dimensions, etc.

In general, ERW pipes have the following advantages.

(1) Because hot coils are used as the starting material, thin wall thickness pipe can be manufactured, and its thickness accuracy is good and the pipe has a smooth surface which is free of roughness, pits, etc.

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(2) The pipemaking process is characterized by high productivity and high dimensional accuracy. As a result, lower costs can be expected in the pipe-laying process due to reduction of the work load in girth welding to join pipes, etc.

2.2 Quality Issues and Restrictions on Applications of ERW Linepipe

JFE Steel devoted great effort to improving the weld seam of ERW pipes from an early date. The company produces ERW pipes for high grade linepipe by optimizing the chemical composition and rolling conditions of the steel coils used as starting material, and optimizing the welding conditions and the seam heat treatment conditions during electric resistance welding. Nevertheless, it had been difficult to apply ERW pipes under extra-low temperature conditions in regions such as Alaska, etc.

3. Development of "Mighty Seam™" Manufacturing Technology

In order to assure stable quality over the full length of the seam, JFE Steel developed an ERW technology which controls the shape and density of the oxide inclusions generated during welding. In combination with this, JFE Steel also developed a flaw detection technology using phased array ultrasonic inspection, which enables continuous, real-time inspection of the full length of the seam. Inspection of the shape and density of oxide inclusions is possible using this new flaw detection technology. The ERW linepipe "Mighty Seam™" with high seam reliability was developed by combining these technologies.

3.1 Development of Technology for Improvement of ERW Seam Quality

To secure the quality of the weld seam in ERW linepipe, including low temperature toughness and other properties, it is necessary to reduce oxide inclusions in the seam and optimize the chemical composition and microstructure. In reducing oxide inclusions in the seam, stabilization of the weld butt shape, proper control of the welding input corresponding to the thickness and speed of the steel band, etc. are important[1–3]. In order to obtain a fine microstructure with excellent toughness, a combination of a low carbon equivalent composition system[4] and online heat treatment[5] of the seam is applied.

In "Mighty Seam™," the heating/melting/welding behavior was also clarified and optimized. First, an analytical model of the ERW seam was constructed by finite element analysis (FEA), and its electric resistance welding behavior was clarified. **Figure 2** shows an outline of the analytical model. A large number of 2-dimensional models corresponding to the pipe cross-sectional direction were prepared for the section from the contact

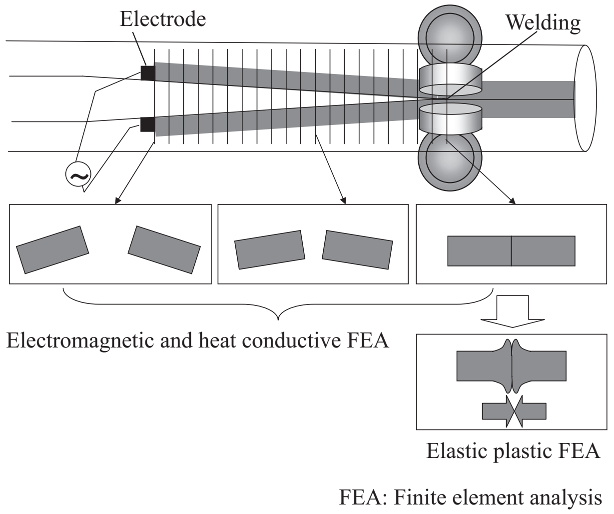

Fig. 2 Overview of the finite element analysis system of the electric resistance welding (ERW)

points of electrode to the weld. Electromagnetic field analysis and heat transfer analysis were performed for the analytical model of the contact points, and the temperature distribution of the contact points was obtained. As the initial value of this temperature distribution, the same electromagnetic field analysis and heat transfer analysis were performed for positions shifted by small distances. The temperature distribution of the seam was clarified by repeatedly calculating this procedure from the weld point. Elastic-plastic structural analysis was performed after completing this analysis immediately before the weld point. The stress-strain distribution and deformation shape of the weld were obtained by moving the steel band in the horizontal direction while maintaining the temperature distribution of the weld point. In this manner, it was possible to analyze the heating-melting-welding behavior of the ERW seam by combining elastic and plastic analysis with electromagnetic field analysis and heat transfer analysis[6,7].

Figure 3 shows an example of the temperature analysis obtained in this manner. The analysis was performed under conditions of outer diameter = 610 mm, wall thickness = 16 mm, welding speed = 0.2 m/s, and welding pressure = 5 mm. From Fig. 3, remarkable heating occurred at the inside and outside corners beginning 200 mm from the weld point. At 60 mm from the welding point, the corners were heated to above the melting point, while the center of the strip thickness was still below the melting point. The current is thought to concentrate at the corners, where it causes remarkable heating, because the skin effect, which is a distinctive feature of high frequency currents, appears strongly in pipes with a thick strip thickness like that under these analysis conditions. The phenomenon in which the part heated by welding bulged from the inside and outside surfaces due to the 5 mm upsetting pressure at the weld

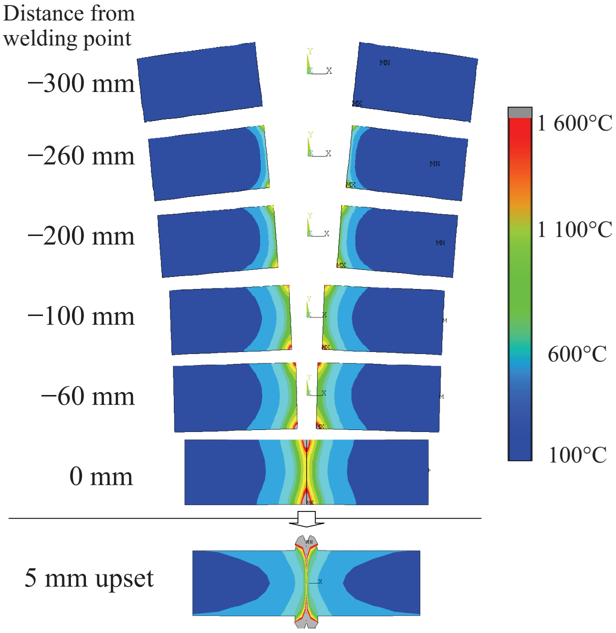

Fig. 3 Contour maps of the temperature distribution

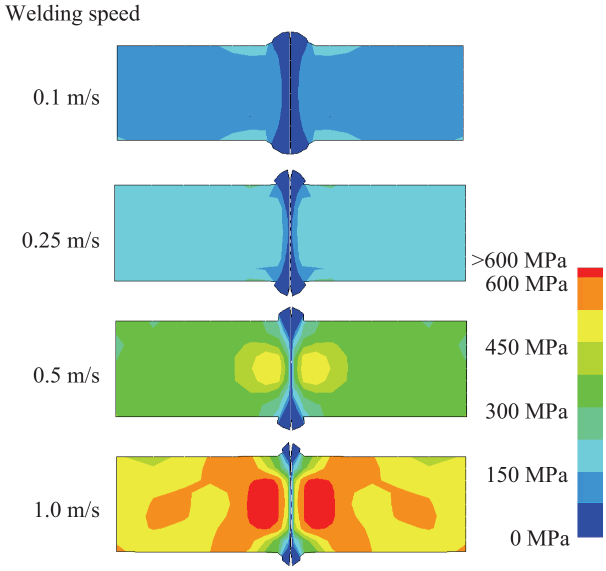

Fig. 5 Effect of the welding speed on stress distribution

could also be analyzed.

The effects of forming conditions and welding conditions on ERW phenomena were investigated using this analytical model. As one example, **Fig. 4**, shows the effect of welding speed on the heating width immediately before the weld is closed. The heating width decreased as the welding speed increased. Since the heating time becomes shorter as the welding speed increases, it is considered that circumferential heat transfer from the edge decreases, and as a result, the heating width also decreases. **Figure 5** shows the effect of the welding speed on the stress distribution of the seam. As the welding speed increases, the stress around the edges increases remarkably. As a result, the bulging shape on the inside and outside of the seam changes from a moderate shape with a wide width to a sharp shape with a narrow width as speed increases. As illustrated by these examples, the effects of forming conditions and welding conditions on the heating and welding behavior of the ERW seam were quantified using the FEA model.

In the "Mighty Seam™" linepipe, optimization of the ERW welding conditions and control of the shape and density conditions of inclusions generated during ERW were possible based on this knowledge.

Figure 6 shows the results of an investigation of the heating condition in the sheet thickness direction during welding[8,9]. In the case of conventional ERW pipes, the outside and inside corner edges of the steel band heat and melt preferentially, resulting in non-uniform heating in the sheet thickness direction. In contrast, with "Mighty Seam™," the material is heated and melted homogeneously in the wall-thickness direction. Improved seam mechanical properties were achieved by the development of this homogeneous heating technology, as inclusions generated during welding are easily expelled to the outside.

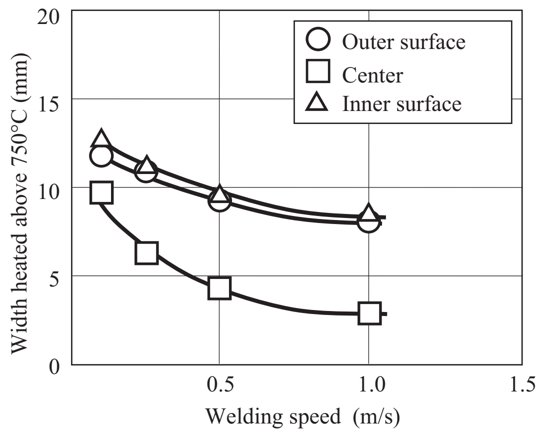

Fig. 4 Effect of the V-convergence angle on width heated above 750°C

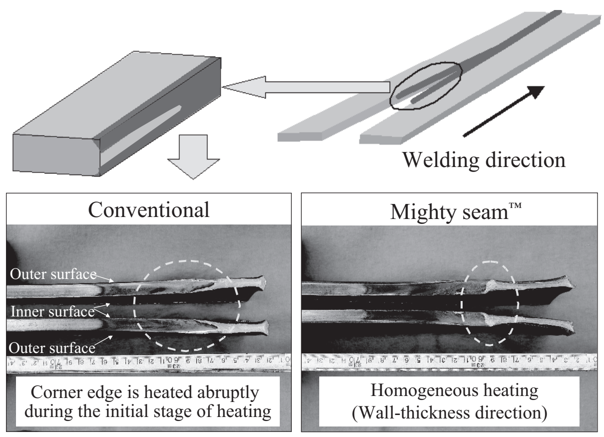

Fig. 6 Heating and melting of the edge of welding portion

3.2 Development of Ultrasonic Testing System That Can Evaluate Quality of Weld Seam of ERW

With ERW pipes which are to be used in applications with severe requirements, not only the above-mentioned oxide inclusion control technology, but also higher level seam inspection technologies are indispensible.

At present, nondestructive inspection by angled-beam ultrasonic testing, tests of mechanical properties such as Charpy impact testing, etc., practical tests such as the flattening test, and others are applied to seam inspections of ERW pipes. The main object of angled-beam ultrasonic testing is to detect welding imperfections and cracks originating from inclusions in the base material. Inspection of weld quality, such as low temperature toughness, etc., are performed by mechanical testing.

In "Mighty SeamTM," in addition to the technology for suppressing oxide inclusions described in Section 3.1, JFE Steel also developed and introduced a continuous inspection technology[10,11] for microscopic oxide inclusions, which influence seam quality, enabling full-length inspection of the quality of the weld seam. In this technology, seam inspection using focused beam was realized by applying phased array ultrasonic technique, thereby achieving high sensitivity more than 10 times superior to that of the conventional ultrasonic angled beam inspection.

Phased array ultrasonic technology is a method that uses an array probe comprising an arrangement of a large number of micro vibrators. As features of this technology, flaw inspections can be performed while arbitrarily changing the beam direction and focal position by applying very small differential time to the timing of signal transmission and reception in each vibrator.

Figure 7 shows the principle of the developed high sensitivity ultrasonic inspection technology for the ERW weld seam. The tandem configuration is employed using a phased array probe with a different transmission unit and reception unit. The use of the array probe allows the focus point of the ultrasonic beam to be scanned from the inner surface side to the outer surface side in the thickness direction of the weld part by switching the group of transducer elements between the transmission unit and the reception unit, and the refraction angle between wave transmission and wave reception sequentially. This technique has made it possible to detect flaws from the inner surface side to the outer surface side without forming a dead zone.

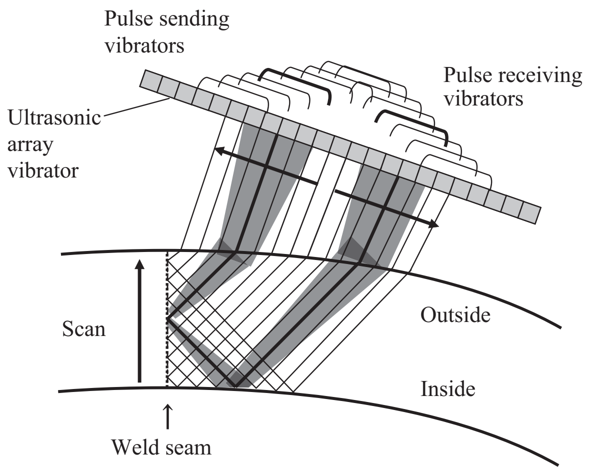

Fig. 7 High sensitivity ultrasonic inspection technology for electric resistance welding (ERW) weld seam[12]

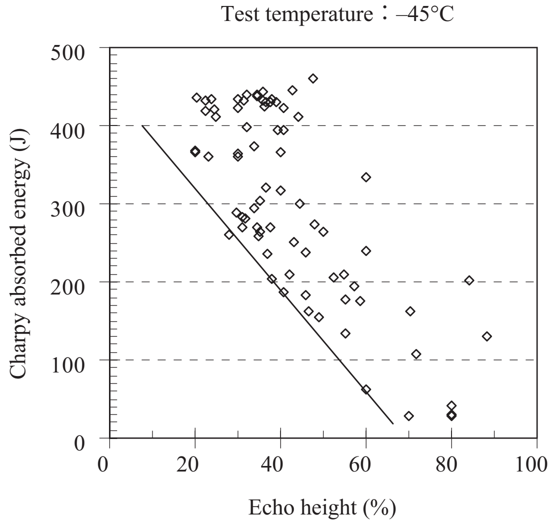

Fig. 8 Example of high sensitivity ultrasonic inspection for low temperature charpy toughness at electric resistance welding (ERW) seam[12]

This enables high sensitivity detection of weak echoes from microscopic oxide inclusions which had been under the detection limit of conventional angled-beam ultrasonic inspection, and mapping of distribution of the oxide inclusions in the L cross section of the seam over 100% of the seam length.

The ultrasonic echo level obtained using the tandem probe technique was compared with the absorbed energy in the Charpy impact test. The results showed that there is a correlation between the ultrasonic echo and absorbed energy, as shown **Fig. 8**. The straight line in the figure is a criterion for weld seam quality. It was possible to confirm the quality of weld seams by evaluation based on that criterion. Therefore, it realized to evaluate quality of the weld seam along entire length of weld.

4. Production Results

The "Mighty SeamTM" manufacturing technology was introduced at the 24-inches (609.6 mm) large diameter ERW pipe mill at JFE Steel's East Japan Works (Keihin Area), and ERW linepipes for North America were produced. **Table 1** shows the specification of

Table 1 Mighty Seam™ production for North America[12)]

Grade	CSA Z245.1, Gr.414, Cat.II, M45C (Equivalent to API5L, X60M)
Size	OD406.4 mm × WT14.3 mm

CSA: The Canadian Standards Association
API: The American Petroleum Institute

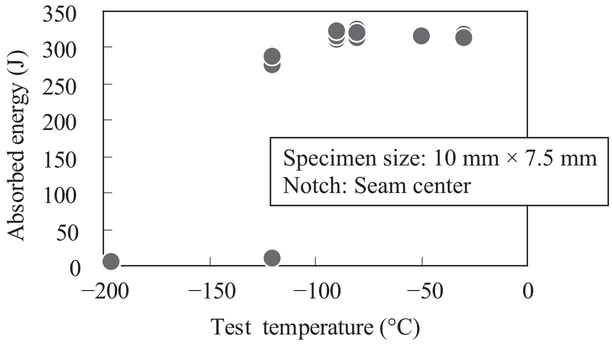

Fig. 9 Example of ERW weld charpy transition curve at Mighty Seam™ production for North America

"Mighty Seam™" production for North America. **Figure 9** shows the Charpy transition curve results for the ERW seam. In comparison with the specification guarantee of −45°C, the transition temperature displayed a value of −100°C or lower, and it was possible to ship products with excellent low temperature toughness as expected.

5. "Mighty Seam™" Product Information

An online phased array ultrasonic inspection system was introduced in the 24-inches large diameter ERW pipe mill at JFE Steel's East Japan Works (Keihin Area), and a system enabling real-time flaw detection of the full length of the weld seam was constructed. In addition to the inspections performed with ordinary ERW linepipe (hydrostatic testing, ultrasonic testing of the full length of the weld seam by angled beam inspection, and inspections of external appearance and dimensions), various other tests are also performed with "Mighty Seam™," including full-body ultrasonic inspection for lamination in pipe body, and when required, ultrasonic inspection of the full length of the seam by tandem flaw detection, among others. These are quality assurance devices that meet the requirements of DNV Offshore Standard OS-F101 2010 (DNV: Det Norske Veritas), which is the most recent standard for submarine linepipes.

Table 2 shows the available size range of "Mighty Seam™." At present, the available size range covers outer diameters from 219.1 mm to 610 mm and wall thicknesses from 4.8 mm to 16.3 mm. Expansion of this range to an outer diameter of 660 mm and thickness of 20.6 mm is planned. By commercializing "Mighty Seam™," JFE Steel has expanded its product line of pipes for linepipe use and can respond to even more diverse customer needs.

Table 2 Mighty Seam™ Available size (As of March, 2011)[12)]

Manufacturing plant	24 inches (609.6 mm) Electric Resistance Welding (ERW) Pipe Mill, East Japan Works (Keihin), JFE Steel
Outside diameter	219.1 mm–610 mm
Wall thickness	4.8 mm–16.3 mm
Grade (API 5L)	Max. X80M (L555M) PSL2 Offshore, Sour (Max. X65)

API: The American Petroleum Institute

6. Conclusion

"Mighty Seam™" manufactured at JFE Steel's East Japan Works (Keihin Area) has already been shipped to users in North America and Southeast Asia. By developing "Mighty Seam™," JFE Steel further expanded the applications of ERW pipes and can now respond to a wider range of customer needs for ERW pipes than in the past. Because ERW pipes have the advantages of high productivity and excellent dimensional accuracy, cost reductions can be expected in the linepipe construction, for example, by reduction of the work load in girth welding of pipes, etc.

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