LIBRARY SEARCH ON PENETRATORS IN ERW PIPES

Number of references: 17

1) **The effect of heat input on the defect phases in high frequency electric resistance welding.** Choong-Myeong Kim, Jung Kyu Kim. Metals and Materials International Vol. 15, No. 1, February 2009, pp. 141-148.

The effect of the chemical compositions of base material and ERW conditions on defect formation is studied by an analysis of defect formation mechanism and defect phases in variation to heat input and apex angle. In the high heat input range, a comet shape narrow gap is formed due to higher current density and higher Lorentz force at the welding point than at the apex point. The comet shape narrow gap, which has a wider width at the welding point, causes a penetrator rate increase by leading the retardation of sweeping speed of molten metal bridge that discharges the oxides from the narrow gap. The increase of apex angle is very effective in minimize the penetrator defect rate with the optimization of heat input. The oxides in cold weld at low heat input range have an FeO phase, and the oxides in penetrator at high heat input range have an Fe_3O_4 phase. The reason for the Fe_3O_4 phase in the penetrators is that the molten metal can be oxidized first on the strip edges, and then the oxidation increase after being discharged from the narrow gap and are refilled into the narrow gap due to the retardation of sweeping speed. Therefore, penetrators have Fe_3O_4-MnO_2 rather than FeO-MnO-SiO_2 phases as proposed in previous articles. Mn amount contained in the base material gives a more effective role to the penetrator defect rate than to the Mn/Si ratio.

2) **The effect of electromagnetic forces on the penetrator formation during high-frequency electric resistance welding.** Choong-Myeong Kim, Jung Kyu Kim. Journal of Materials Processing Technology Volume 209, Issue 2, 19 January 2009, pp. 838-846

During high-frequency electric resistance welding (HF-ERW), the electromagnetic force induced by the high-frequency electric current was studied to improve the understanding of penetrator formation mechanism. ERW melting zone behavior is investigated by the cinematography and the three-dimensional numerical analysis of electromagnetic field around molten metal bridge. Based on the results, the penetrator formation is mainly influenced by the narrow gap shape, the variation of electromagnetic forces along the narrow gap, the molten metal bridge traveling speed, and the second bridge formation frequency. Electromagnetic force acting on the molten metal bridge is rapidly decreasing as the bridge is traveling away from the apex point. The 'comet' shape narrow gap produced by the variation of

Lorentz forces makes the bridge pushing pressure decrease. Due to the decrease of electromagnetic force and pushing pressure, the sweeping speed of molten metal bridge slows down until the bridge reaches the welding point. Previous molten metal bridge traveling is arrested when the next bridge is formed before the previous bridge arrives at the welding point. Thus, the molten metal and oxide are refilled into the narrow gap due to the capillary force and then remained as a penetrator. According to the analysis of penetrator formation mechanism, the new penetrator formation model is proposed.

3) **Correlation of Metallurgical Factors with the Susceptibility to HIC in ERW Pipes Using Slitted Hot Coils.** Hyun Uk Hong, Jong Bong Lee, Ho Jin Choi. Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference, Vancouver, BC, Canada, July 6-11, 2008.

A study has been made to correlate metallurgical factors with the susceptibility to hydrogen induced cracking (HIC) at bondline in small diameter API X60 ERW pipes from slit coils. The elongated (Si, Mn, Al) rich oxide inclusions at bondline provided a preferential site for HIC, and no evidence on center-segregation effect was found. It can be suggested that the fraction of the penetrators be lower than 0.03 % to have satisfactory HIC resistance. The optimum ERW condition determined by DOE successfully led to an excellent HIC resistance, although the center-segregation index (Mnmax / Mnavg) was high as much as 1.3.

4) **Common HF Welding Defects.** R. K. Nichols. Thermatool pamphlet

High Frequency Welding is undoubtedly the fastest and most efficient method of making pipe and tube. However, it can also present the operator with a bewildering variety of weld defects. It is the object of this paper to present 9 of the most common defects, their causes and how they can be prevented.

5) **Destructive testing of welded steel tubular.** R.K. Nichols, Thermatool Pamphlet.

Steady evolution of Non-Destructive Testing equipment has dramatically reduced the number of weld defects being sent to customers. However, even the best NDT equipment does nothing to prevent those defects from occurring. Total reliance on NDT technology can lead to serious losses in productivity when inspection is used to replace prevention. Early detection of defects is essential to rectifying the problem in order to minimize the defective footage produced. Because the interpretation of NDT results can be made in error, destructive methods are often used as verification. The destructive methods can also supply a "quick and dirty" evaluation for immediate use by production personnel. While destructive methods cannot evaluate an entire run of pipe as can NDT, they can give a fair evaluation of the mill setup, steel quality, and welding and normalizing practice. The following is a brief review of destructive testing commonly used in the production of High Frequency Induction and Contact welded pipe and tube.

6) **Estimation of weld quality in High Frequency Electric Resistance Welding with image processing.** D. Kim, T. Kim, Y. W. Park, K. Sung, M. Kang, C. Kim, C. Lee, S. Rhee. Welding Journal 71-s-79-s.

In high-frequency electric resistance welding (HF-ERW), the weld quality is determined by the welding phenomenon in the welding spot proximity. Methods to eliminate or minimize defects, therefore, include real-time monitoring of the weld quality and problem solving as problems arise. It is possible to estimate weld quality qualitatively by using the weld image data during HF-ERW. A method to predict the weld quality using image processing in the heating process of the HFERW point is proposed. An algorithm, which predicts the weld quality by using a vision sensor to obtain the image of the welding spot proximity thus best expressing the welding phenomenon, is developed. The heated area, which shows the image data with the highest correlation to the weld quality and the smallest amount of noise, is consequently calculated.

7) **Fatigue Behavior of Electric Resistance Welded Seams in API-X70 Steel.** H. U. Hong, C. M. Kim, J. B. Lee. Proceedings of the 15^{th} International Off-Shore and Polar Engineering Conference, Seoul, South Korea, June 19-24, 2005 Only p. 185.

The susceptibility to pressure reversals of electric resistance welded seams in X70 grade line pipe steel has been investigated by varying power input in the range of 230~270kW and seam annealing temperatures of 850~970. Repeated loading was applied to notched three point bend specimens in this study. Radiographic inspection has shown that the defects length ratio (sum of defects length per meter of bond line) ranged from 0 to 1.2%. The defects were mainly identified as Ca, Al-rich oxides inclusions in the elongated shape. There was no occurrence of pressure reversals in all of the conditions investigated. Furthermore, the bond line ductility was found to be satisfactory. These results can be explained by the fact that a bond line free from defects is successfully obtained from a wide range of electric resistance welding conditions, and also that the fusion zone is tough enough to inhibit initiation of microcracks.

8) **Penetrator Formation Mechanisms during High-Frequency Electric Resistance Welding.** J.-H. Choi, Y. S. Chang, C.-M. Kim, J.-S. Oh, Y.-S. Kim. Welding Journal, 2004, vol. 83, n°1, pp. 27S-31S

In this study, welding phenomena involved in penetrator formation during high-frequency electric resistance welding were investigated. High-speed cinematography of the phenomena revealed that molten metal bridges, which formed between neighboring strip edges near the apex point, travel along a narrow gap toward the welding point at a speed much faster than that of the strip. Frequency of formation, travel distance, and speed of the bridge were affected mainly by the heat input power into the strip. Among the variables of the bridge traveling behavior, standard deviation of the travel distance appeared to have a strong relationship with defect density in weldments. Based on observation, a new mechanism of the penetrator formation during HF ERW process was proposed.

9) **Qualification of ERW/HFI Manufactured Pipe For Wet, Sour Crude and Gas Services.** G. D. Stark. Greg Stark Consultancy.

API 5L pipe manufactured with the Electric Resistance Weld (ERW) or High Frequency Induction (HFIW) welding processes offers considerable cost saving to the end user in place of similar seamless or Submerged Arc Welded (SAW) pipe. Historically, such pipe has never been fully trusted for full application by the oil and gas industry due to catastrophic failures in the field. No universally recognized industry standard exists for qualification of manufacturers of ERW/HFI pipe, and there is no robust standard for promoting a high level of quality and reliability of such a product. Saudi Aramco learned first hand the impact of such lack of product reliability with 10 field failures during hydrostatic testing of a newly constructed pipeline. The experience resulted in significant project delay and cost over run. As a result of this experience, Saudi Aramco eventually developed an extremely comprehensive qualification and manufacturing specification for such pipe. The specification incorporates a statistically proven qualification procedure and a rigorous manufacturing process control regimen to maintain extremely high quality and mechanical properties of the ERW/HFI weld seam. At the same time, Saudi Aramco developed a proprietary computer program for the collection, manipulation, and reporting of qualification and production test data. Currently four such pipe manufacturers in the world are approved to manufacture pipe in accordance with the new specifications. Because of the greatly increased reliability of pipe produced to the new specification, Saudi Aramco has been able to consider the use of ERW/HFI manufactured pipe in applications which were considered more critical. As projects begin to utilize this new approach Saudi Aramco will be able to realize as much as $100/ton savings in the future.

10) **Effects on penetrator defect of welding conditions and Mn/Si ratio of ERW high manganese linepipe.** E. Yokoyama, M. Yamagata, N. Kano, Sh. Watanabe. Kawasaki Steel Ghio (In Japanese, but figures and tables in English).

Such effects as shown in the totle have been investigated using ERW steel pipe of 1.5%Mn and from 0.17 to 0.41%Si. Penetrator defects increase with an increase of heat input and with a decrease of welding speed, and moreover with a decrease of Mn/Si ratio. The non-metallic inclusions, which are the main cause of the penetrator, are mainly FeO-MnO-SiO2 oxides, and with an increase of Mn/Si ratio, SiO2 content decreases and FeO and MnO content increases. Manganese and silicon content at the welded zone noticeably decreases with heat coefficient, although carbon content shows no particular change. In the thermodynamic considerations, reactions of penetrator formation ($FeO+Mn=Fe+MnO$ and $2FeO+Si=2Fe+SiO_2$) in high manganese ERW pipe reach very rapidly to quasi-equilibrium state.

11) **Definition and identification of defects and other features occurring in resistance but welds.** Technical Commission on Resistance Welding, Japan Welding Society, July 1986.

Although resistance butt welding has a high productivity compared with arc welding, the application is limited. One of the reasons is recognized that sinnificance or validity of mechanical tests has not been made clear for the welded joint in butt welds. In addition, the terms are not always common among resistance welds.
In August 1984, therefore, a working group was organized in the Technical Commission on Resistance Welding of Japan Welding Society for the following purposes.

To classify and unify the defects and other features found in butt welds such as flash welding, upset welding and high-frequency electric resistance welding, HF-ERW.
To clarify the significance of mechanical tests such as tensile test and bend test, etc., for the welded joints made by resistance butt welding.

The working group is composed of researchers engineers who dealt with resistance butt welding for years. As the first step, the terms are listed, which are popularly used in the three resistance butt welding such as flash welding, upset welding, and high-frequency electric resistance welding, respectively.
The report proposes the classification, definition, identification procedure and the new technical terms of defects and other features in the butt weld of carbon steels.

12) **An automatic power input control system in high-frequency electric resistance welding.** Watanabe, N., Funaki, M., Sanmiya, S., Kosuge, N., Haga, H., Mizuhashi, N. Transactions of ISIJ 1986 26:453–460.

It was found that monitoring the variation in oscillation frequency of welding current enables to detect the optimum welding state that produces the fewest weld defects. Applying this finding, new automatic power input control system was developed. This new system establishes and maintains the optimum welding state rapidly by the feed-forward system and precisely by the feed-back system. Besides the power input, other welding conditions were also optimized. Synthesizing these techniques, it has been possible to produce E RW pipes without weld defect.

13) **Manufacture of alloy steel tube by high-frequency electric resistance welding.** Ichihara, H., Sumimoto, D., Kimura, T., Kimiya, Y., Yoshizawa, M. Transactions of ISIJ, 1986, 26:468–475.

The quality of chromium, chromium-molybdenum and austenitic stainless steel tubes manufactured by an electric resistance welding (ER W) is highly dependent on the sophisticated technologies of non-oxidizing welding, precise control of welding energy and smooth cutting of inside flush. In this report a newly developed manufacturing technology for ERW alloy steel tubes is described on the following items; oxygen content in the welding atmosphere for a non-oxidizing welding and its control equipment, appropriate welding energy and its control system and a high performance impeder. Furthermore, the quality of the mass-produced ERW alloy steel tubes by the new technology is investigated focusing on their corrosion resistance, high temperature creep rupture strength and fatigue strength.

14) **A new automatic heat input control for production of electric resistance welded pipe.** Mihara, Y., Suzuki, K., Ohkawa, T., Harada, N., Komine, I., Ishiro, S. Transactions ISIJ 1986 26: 476–483.

Basic characteristics of electric resistance welding (ERW) were studied by using a Bead Shape meter and a temperature distribution measuring system with a silicon photodiode array in order to establish the controlling technique of ER W. Based on the information from these studies, the integrated heat control system, which is composed of on-line bead shape monitoring system and the automatic temperature distribution control system, has been developed. These systems were installed in small, medium
and large diameter pipe mills. These systems are proved to be very effective to produce high quality tubes and pipes.

15) **A new ERW-SAW process for spiral pipe manufacture.** N. Andou, H. Chino, Ch. Hamamoto, H. Majima, R. Nomura, H. Haga, N. Mizuhashi, Sh. Fujimori, Y. Kitamura. Transactions ISIJ, Vol. 26, 1986, pp. 445-452.

A new welding process which combines ERW and SA1N has been developed to improve the productivity and product quality of spiral pipe manufacturing lines. The features of this process are as follows.
(I) Construction of a compact and highly efficient spiral pipe mill is made possible by the combination of ERW and SAW in one welding line.
(2) Lap type ERW is applied in which the pipe-side edge and the strip-side edge approach each other in the vertical direction.
(3) High-speed cosmetic SAW is applied with the use of multiple twin wire system to cover the weld from both inside and outside after ERW.
The features of the cosmetic SAW are low heat input, high-efficiency deposit and high oblate ratio of heat source shape to prevent formation of undercuts.
(4) The welding speed of the new ER W-SAW process is 5-6m/min, compared with the 3 m/min maximum of the conventional process, and the joint performance is equal to or higher than that by the conventional SAW process.

16) **Automatic welding control system of electric resistance weld tube mill.** Kyogoku, T., Takamadate, C., Hotta, K., Tatsuwaki, M., Nemoto, S. Transactions ISIJ, Vol. 24, 1984, pp. 846-856.

Recently, high quality Electric Resistance Welded Tubes (ERW Tubes) have been requested by the customers. To meet this demand, the Sumitomo Metals has successfully developed an Automatic Welding Control System, using Pattern Thermometer, Upset Gauge, etc., which were newly developed for this system. The results obtained by applying this system to a small size ER W tube mill are as follows:

Welding temperature was stabilized by computer according to the conditions of the tube size, material and welding speed.

This system has been found to be useful for welding low alloy steel and high carbon steel which have more severe welding conditions.

17) **The Mechanisms of Formation of Weld Defects in High-Frequency Electric Resistance Welding.** H. Haca, K. Aoki, T. Sato. Welding Research Supplement, June 1981, 104S-109S.

In order to clarify the mechanisms by which weld defects are formed, welding phenomena were observed using high speed cameras, and weld defects produced in relation to corresponding phenomena were examined. It is found that the possible occurrence of certain kinds of weld defects is determined by the types of phenomena encountered during welding: A possible weld defect accompanied by the 1st type phenomenon is a cold weld; a penetrator is accompanied by 2nd and 3rd types of phenomena. The cold weld is composed of a colony of oxides which are formed on the edge surfaces and remain because they are not squeezed out from between them. The penetrator by nature is a slag inclusion produced when molten slag is drawn into a gapped zone by the action of surface tension and capillary effects in a returning process of the molten bead.