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WELDABILITY STUDIES OF 18 mm THICK AISI 409 FERRITIC STEEL PLATE USING ELECTRON BEAM WELDING PROCESS

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Abstract: Ferritic stainless steel is admired for its corrosion resistance property in chloride atmosphere, and low cost. It is designed as an alternative to carbon steel, and in some applications it has also replaced austenitic stainless steel. Despite its appreciating mechanical properties, it suffers from drawback of low weldability which constraint its utilization. High grain growth is observed at heat affected zone and fusion zone during welding. This degrades its mechanical and microstructural properties. Further, welding of plate above 8mm thickness, with conventional welding process, exhibits high deterioration of properties which restrict the thickness of plate to be welded. In the present research, attempts have been made to weld 18mm thick AISI 409 ferritic steel plate in a single pass weld. Electron beam welding process was used to prepare the joint. The joint was investigated for macro-structural, micro-structural, micro-hardness, impact toughness and tensile strength. The coarse ferrite grains of base metal were converted into fine equiaxed columnar grains in the weld zone. The results revealed higher tensile strength, yield strength and micro-hardness values of weld joint than the base metal. The weld joint properties improved after subjecting to post weld heat treatment at 550°C for 75 minutes.

Keywords: AISI 409 ferritic stainless steel, microstructure, post weld heat treatment, mechanical properties, post weld heat treatment

1. INTRODUCTION

Ferritic stainless steel (FSS) is distinguished for their ferrite phase with BCC structure. This steel remains stable from room temperature till it reaches melting temperature [1]. FSS is iron based alloy with 10.5% to 30% chromium along with small amount of alloying elements. FSS has attained a new milestone in the last few decades by covering 30% of total market share[2]. This increased popularity is due to its low price and stress corrosion resistance properties in chloride and caustic environment. This steel gave considerable cost saving benefit over austenitic steel. Its applications can be found in wide variety of areas such as muffler and catalytic convertor of automobile exhaust system, different parts of railway wagons, drums of washing machine, frames of busses etc.

Though ferritic stainless steel has been used in wide applications, still its use is restricted due to its low weldability[3]. It suffers from severe grain growth in the region exposed to weld heat. This grain coarsening prompts adverse effects on its mechanical and microstructural properties [4]. Amuda and Mrida [5] confirmed that high heat input with slow cooling rate, during welding, gave more time to grains for elongation which elongated the grains, hence promotes grain coarsening. Mohandas et al. [6] compared the 3mm thick ferritic steel weld joints made by the gas tungsten arc welding and shielded metal arc welding process of ferritic steel. Authors concluded that welds made by gas tungsten arc process gave higher strength and ductility due to less heat input than shielding gas arc process. Lakshminarayanan et al. [7] used 3 types of arc welding process to weld 4 mm thick rolled AISI 409M plate and made a comparison between them. It was observed that pulsed arc welding process exhibits higher mechanical properties owing to its lower heat input which eventually resulted in fine grains diameter and high weld zone hardness.

Taban et al. [8] used plasma arc welding process to weld 12 mm thick ferritic plate. Authors concluded that grain coarsening occurred at weld zone and heat affected zone which reduced the impact toughness in comparison with the base metal. Mukherjee et al. [9] concluded that pulsed mode welding process reduced the amount of dilution and enhanced the weld zone grain structure. The hardness of weld metal was higher than the heat affected zone. It was also concluded that pulsed mode always gave better properties than spray mode, whatever may be the heat input. Taban et al. [3] investigated the mechanical and microstructural properties of 12 mm thick plate welded with laser beam welding. Authors mentioned that defect free joint is possible with laser beam. Grain coarsening has no effect on the tensile and bend properties, but it reduced the impact toughness. Further, PWHT improves the impact toughness of weld joint to acceptable value. Lakshminarayanan et al. [10]used low heat input electron beam welding process to weld 4mm AISI 409M thick plate. Owing to the low heat input, the fine equiaxed grains were formed in the weld zone. Tensile properties and micro-hardness values were found higher than the base metal whereas impact toughness values were retained. Pryds and Huang [11] investigated the role of cooling rate on the microstructure of weld zone. The grain size was found to be decreased with the increase in cooling rate. Precipitations on the boundaries were also observed and were found increased with decrease in cooling rate.

The advancement in research and development in technology has given a new face to ferritic stainless steel [12][13]. Unconventional welding process viz. laser beam welding process and electron beam welding process were found more advantageous owing to its low heat input than the unconventional welding process. Literature studies on ferritic stainless steel also revealed that grain coarsening can be controlled up to certain limits by proper selection of welding process and welding parameters (current input). But for welding thick plate, the requirement of multi pass ruins the purpose of low heat input. In the present study attempts have been made to weld 18mm thick AISI 409 ferritic steel plate with single pass weld. Low heat electron beam welding was used to fabricate the butt joint. Macro-structural analysis, micro-structural analysis, microhardness measurements and tensile test were carried to evaluate the weld and weldability of electron beam process. Further the influences of post weld heat treatment at 550°C for 75 min, on microstructural and mechanical properties, were studied and compared with as-welded joint properties.

2. MATERIAL AND METHOD

Standard cold rolled AISI 409 ferritic steel was used as a base metal in this research work. The chemical composition as presented in Table 1was obtained using spectro analysis. The plates were prepared to the size 200 x 75 x 18 mm by machining and the edges were made accurately at 90° to obtain high-quality butt joint. The plates were thoroughly cleaned and washed with ethanol prior to welding.

Table 1: Composition of base metal AISI 409

Material/ Chemical Composition	C	Si	Mn	P	S	Cr	Ni	Mo	Nb	Ti	Al	V	Fe
SS-409	0.014	0.39	0.582	0.02	0.007	11.43	0.33	0.023	0.015	0.18	0	0.017	Bal

To evade the outflow of weld pool at the bottom, backing plate was used; and to optimize the welding parameters, trial runs were carried out until full penetration was achieved in single pass. The final optimized parameters are shown in Table 2. Plates were rigidly fixed on the EBW bed and proper care was taken while welding to avoid distortion. Single pass full penetrated weld joint was obtained in autogeneous mode without the filler metal. The photograph of weld joint is shown in Figure 1. After welding, the soundness of the joint was inspected through liquid penetrant and ultrasonic testing technique.

Figure 1: Fabricated AISI 409 joint with electron beam process

Table 2: Optimized parameters for welding

Parameters	Voltage	Current	Speed	Heat Input	Vacuum
	kV	mA	mm/min	kJ/mm	mbar
Value	150	90	600	1.2528	$5x10^6$

Specimens for macro-structure analysis, micro-structure analysis, microhardness measurements, tensile test and impact test were extracted in two sets using wire cut EDM. One set of specimen was used for testing in as-welded condition and other set was used for testing following post weld heat treatment at 550ºC for 75 min.

Metallographic samples perpendicular to weld joint were extracted and prepared according to ASTM E3-11[14] (ref Figure 2). Specimen preparations involved grinding and polishing with emery paper up to 2500 grit size. Final polishing was done with diamond paste. Microstructure was revealed by etching with 5ml HCL+1g picric acid+100 ml ethanol (vilella reagent)[15]. Macro-structure and micro-structure analyses were done using optical microscope. Microhardness measurements were done using Vicker's microhardness testing machine at a load of 1000 g for 30 sec. Readings were taken along the weld bead and across the weld bead at a gap of 0.5 mm.

Figure 2: Extracted sample for macro-structure, micro-structure and microhardness analysis

Transverse tensile samples were extracted as per ASTM standard E8[16] (Figure 3). Testing was done at room temperature using Tinius Olsen machine with capacity of 50kN. Ultimate tensile, yield strength and percentage elongation were evaluated. Charpy impact test was performed by pendulum type testing machine at room temperature. V-notch was precisely cut along the weld center to determine the notch impact property. Samples were prepared as per standard ASTM E23 – 12C[17] as shown in Figure 5.

Figure 3: Extracted specimen for tensile testing before and after testing

Figure 4: Tensile testing machine

Figure 5: Extracted specimen before and after impact test

Figure 6: Impact testing Machine

3. RESULTS AND DISCUSSIONS

— Macrostructure analysis

The cross-sectional view of EBW AISI 409 weld joint is shown in Figure 7. The macrostructure of the weld joint can be divided into weld zone, heat affected zone and base metal. Dagger shape with wide upper region and narrow bottom region of the weld zone was obtained. The weld is fully penetrated throughout the thickness with acceptable fusion and with no defect which makes it clear that 18mm thick AISI 409 plate can be welded in single pass and its behavior related to microstructure characteristics and mechanical properties are discussed in proceeding sections.

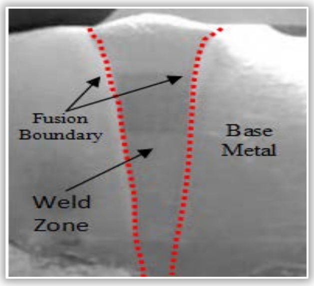

Figure 7: Macrostructure of weld joint

— Microstructural analysis

Optical microstructures of 18mm thick AISI 409 were carried out at base metal, weld zone and fusion zone. The micro graphs in as welded condition and after post weld heat treatment are displayed in "Figure 8", Figure 9 and Figure 10. AISI 409 ferritic stainless steel possesses fully ferritic structure with coarse ferrite grains as can be seen in Figure 8(a). Post weld heat treatment at 550°C for 75 min increased the martensite at the grain boundaries (Figure 8b). The weld zone consists of enlarged columnar grains. The enlarged grains are due to the effect of heat induced during welding and size depends upon the time period they remain heated[18]. The direction of heat flow is normal to the weld center line owing to thermal gradient which exists between the base plate and weld zone, that tends to grow the grains in columnar shape (Figure 9a). Lakshminarayanan et al. and Taban et al. [3], [19] reported similar microstructure of weld zone after welding with low heat input process. Further, post weld heat treatment improved the grain structure as can be seen in Figure 9(b). The enlarged columnar grains were converted into fine equiaxed grains.

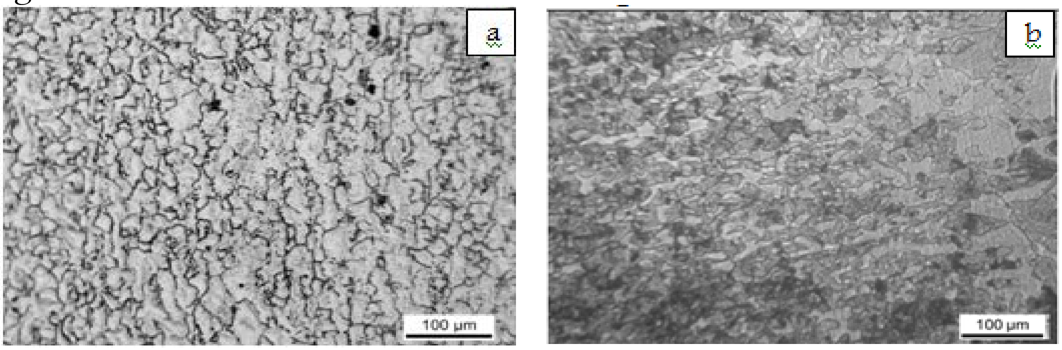

Figure 8 : Microstructure of AISI 409 (a) Base metal (b) Base metal after PWHT

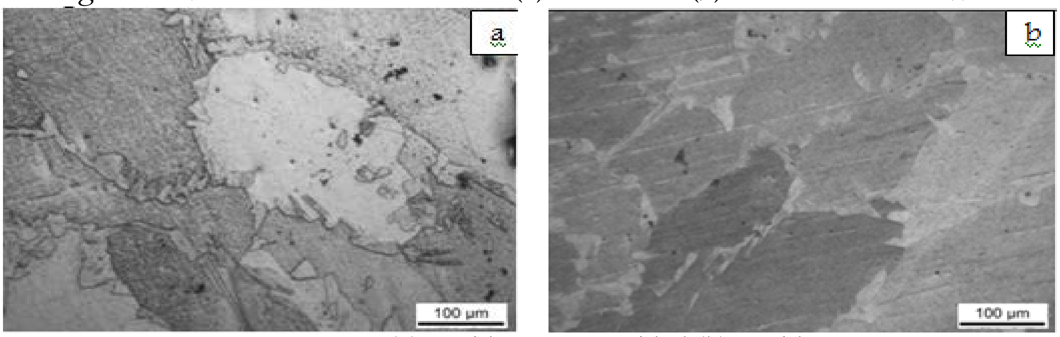

Figure 9: Microstructure of (a) Weld zone as-welded (b) Weld zone after PWHT

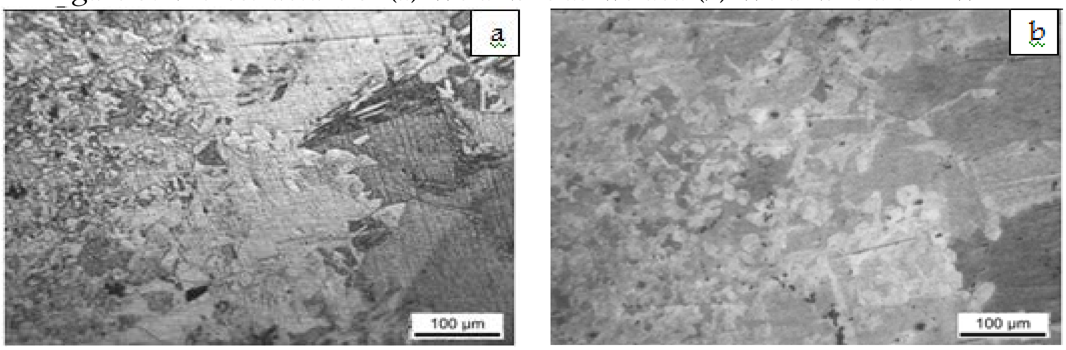

Figure 10: Microstructure of (a) fusion zone as-welded (b) fusion zone after PWHT

— Microhardness measurements

The Vicker's microhardness readings were recorded across the weld bead at a gap of 0.5 mm. The average results of microhardness are shown in Figure 11. The microhardness of weld zone and heat affected zone were found higher than the base metal, which may be due to grain coarsening effect. Further, the microhardness of heat affected zone was 19% higher than the weld zone. The application of post weld heat treatment reduced the microhardness by 10% (approx). This reduction in microhardness was found correlated with the microstructure. The grains after PWHT were refined which led to reduction in the microhardness. The microhardness of base metal after PWHT was found increased; this may be due to formation of martensite structure which makes the metal brittle.

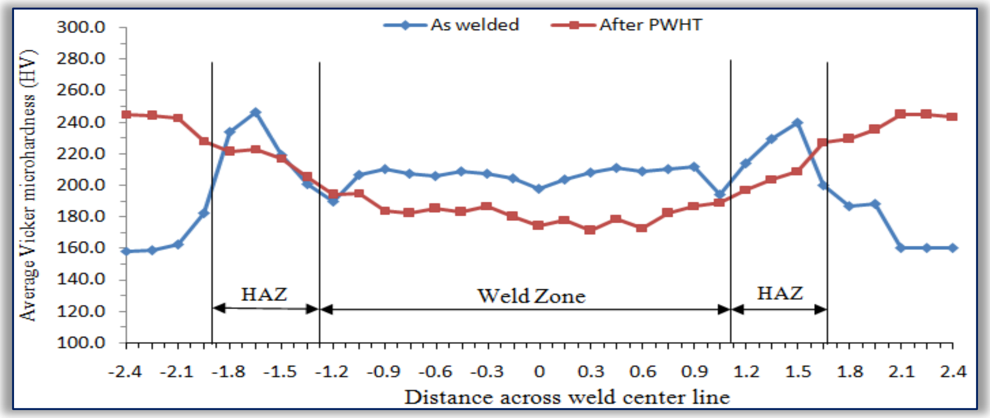

Figure 11: Average value of microhardness across the weld bead

— **Tensile strength**

Transverse tensile properties such as ultimate tensile strength (UTS), yield strength (YS) were evaluated from the welded joint in as welded condition and after post weld heat treatment. The average of results obtained is shown in Figure 12. The tensile strength and yield strength of the weld joint was found higher than the base metal as the entire specimen fractured at the base metal. Similar types of results are reported by Vidyarthy et al.[20] and Deleu et al.[12] The UTS and YS recorded from as welded specimens were 475 MPa and 333 MPa. Microhardness results were also in agreement with the tensile results. The microhardness of the weld zone was also higher than the base metal. Further, post weld heat treatment resulted by improved UTS and YS.

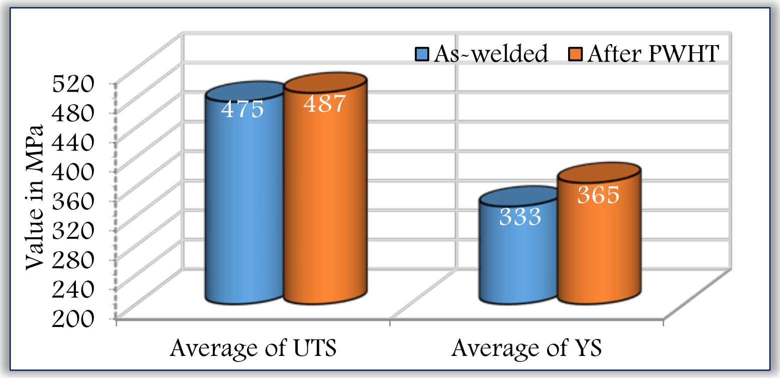

Figure 12: Average ultimate tensile strength and yield strength of as welded and after PWHT specimens

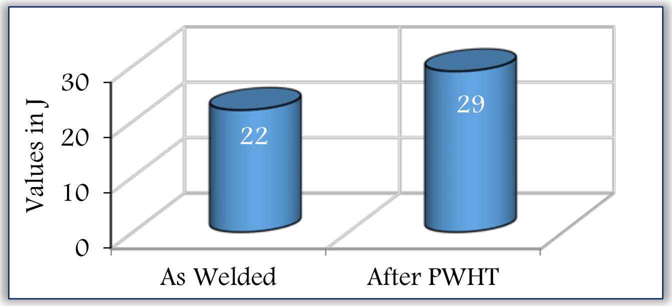

Figure 13: Average impact toughness

— **Impact toughness**

Charpy impact toughness of the weld joint in as welded and after post weld heat treatment was evaluated and is presented in Figure 13. The notch impact toughness of the weld joint was found promising even after grain elongation. The grain elongation directly affects the toughness of the joint[21]. The average impact toughness of as welded sample was recorded 22 J. Further post weld heat treatment enhanced the toughness properties. The toughness was in correlation with the microstructure and microhardness.

4. CONCLUSIONS

The following conclusions have been drawn related to weldability of 18 mm thick AISI 409 ferritic stainless steel:

— AISI 409 ferritic steel plate of 18mm thickness can be successfully welded in single pass with electron beam welding process without any defect.
— Low heat input during welding resulted in fine columnar grain structure with no effect on tensile properties.
— The microhardness of the fusion zone and heat affected zone was found superior than the base metal, which may be due to rapid solidification of weld pool.
— Impact toughness of AISI 409 electron beam joint was in acceptable range.
— Post weld heat treatment at 550°C for 75 min improved the grain structure, tensile properties and impact toughness.

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REFERENCES

[1] J. B. S. Robert G. Nooning, "Effect of Stabilizing Elements on the Precipitation Behavior and Phase Stability of Type 409 Ferritic Stainless Steel," 2002.
[2] J. Charles, J. D. Mithieux, P. O. Santacreu, and L. Peguet, "The ferritic stainless family: The appropriate answer to nickel volatility?," Rev. Metall. Cah. D'Informations Tech., vol. 106, no. 3, pp. 124–139, 2009.
[3] E. Taban, E. Deleu, A. Dhooge, and E. Kaluc, "Laser welding of modified 12% Cr stainless steel: Strength, fatigue, toughness, microstructure and corrosion properties," Mater. Des., vol. 30, no. 4, pp. 1193–1200, 2009.
[4] D. H. Kah and D. W. Dickinson, "Weldability of Ferritic Stainless Steels.," Weld. J., vol. 60, no. 8, 1981.
[5] M. O. H. O. H. Amuda and S. Mridha, "Grain Refinement in Ferritic Stainless Steel Welds : The Journey so Far," Adv. Mater. Res., vol. 86, pp. 1165–1172, 2010.
[6] T. Mohandas, G. Madhusudhan Reddy, and M. Naveed, "Comparative evaluation of gas tungsten and shielded metal arc welds of a `ferritic' stainless steel," J. Mater. Process. Technol., vol. 94, no. 2, pp. 133–140, 1999.
[7] A. K. Lakshminarayanan, K. Shanmugam, and V. Balasubramanian, "Effect of Autogenous Arc Welding Processes on Tensile and Impact Properties of Ferritic Stainless Steel Joints," J. Iron Steel Res. Int., vol. 16, no. 1, p. 16,62-68, 2009.
[8] E. Taban, A. Dhooge, and E. Kaluc, "Plasma arc welding of modified 12% Cr stainless steel," Mater. Manuf. Process., vol. 24, no. 6, pp. 649–656, 2009.
[9] M. Mukherjee, A. Dutta, P. Kanjilal, T. K. Pal, and S. Sisodia, "Enhancement of microstructural and mechanical properties by pulse mode of metal transfer in welded modified ferritic stainless steel," ISIJ Int., vol. 55, no. 7, pp. 1439–1447, 2015.
[10] A. K. Lakshminarayanan and V. B. & G. M. Reddy., "Microstructure and mechanical properties of electron beam-welded AISI 409M-grade ferritic stainless steel," Int. J. Adv. Manuf. Technol., vol. 1, pp. 153–162, 2011.
[11] N. H. Pryds, X. Huang, and I. Introduction, "The Effect of Cooling Rate on the Microstructures Formed during Solidification of Ferritic Steel," vol. 31, no. DECEMBER, 2000.
[12] E. Deleu, A. Dhooge, E. Taban, and E. Kaluç, "Possibilities and limitations to improve the weldability of low carbon 12Cr Ferritic stainless steel for expanded industrial applications," Weld. World, vol. 53, no. 9–10, pp. 198–208, 2009.
[13] W. Gordon and A. Van Bennekom, "Review and stablisation of ferretic stainless steel," vol. 12, no. February, pp. 126–131, 1996.
[14] ASTM E3-11, "Standard Practice for Preparation of Metallographic Specimens," ASTM Int., vol. 82, no. C, pp. 1–15, 2016.
[15] A. Standard, "E407-99: Standard Practice for Microetching Metals and Alloys," ASTM Int. West Conshohocken, PA, pp. 1–21, 2012.
[16] ASTM Standard E8, ""Standard Test Methods for Tension Testing of Metallic Materials,"" ASTM Int., vol. i, pp. 1–27, 2013.
[17] ASTM E 23-12c, "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials," Standards, vol. i, pp. 1–25, 2013.
[18] M. Z. K. Sanjay Kumar Gupta, Avinash Ravi Raja, Meghanshu Vashista and Yusufzai, "Effect of heat input on microstructure and mechanical properties in gas metal arc welding of ferritic stainless steel," Mater. Res. Express, pp. 1–46, 2018.
[19] A. K. Lakshminarayanan, V. Balasubramanian, P. Taylor, A. K. Lakshminarayanan, and V. Balasubramanian, "Comparison of Electron Beam and Friction Stir Weldments of Modified 12 wt % Ferritic Stainless Steel Comparison of Electron Beam and Friction Stir Weldments of Modified 12 wt % Ferritic Stainless Steel," no. October 2014, pp. 37–41, 2011.
[20] R. S. Vidyarthy, D. K. Dwivedi, and M. Vasudevan, "Influence of M-TIG and A-TIG Welding Process on Microstructure and Mechanical Behavior of 409 Ferritic Stainless Steel," J. Mater. Eng. Perform., vol. 26, no. 3, pp. 1391–1403, 2017.
[21] C. J. Van Niekerk, M. Du Toit, M. W. Erwee, C. J. Van Niekerk, M. Du Toit, and M. W. Erwee, "Sensitization of aisi 409 ferritic stainless steel during low heat input arc welding," Weld. World, vol. 56, no. 5–6, pp. 54–64, 2012.

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