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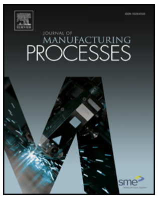

Effect of welding heat-input on tensile strength and fracture location in upset resistance weld of martensitic stainless steel to duplex stainless steel rods

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ABSTRACT

Effect of welding current (2–4 kA) was investigated on the microstructure evolution and mechanical properties of the upset resistance dissimilar welds of Martensitic Stainless Steel (MSS) to Duplex Stainless Steel (DSS) rods. While in MSS side of the welds, no martensite was formed at lower welding currents (2–3 kA), small values of martensite was formed at the higher welding currents (3.5–4 kA). In DSS side of the welds, hotspot formation and change in the phase balance between ferrite and austenite phase were the most important phenomena. Strength of welds first increased and then decreased with welding current. Increase of strength was related to superior plastic deformation and stronger metallurgical bonds with the solid state mechanism. For high welding currents, decline in the tensile strength was mainly due to '*hotspot*' formation. Fracture occurred in the heat affected zone of the martensitic steel rod rather than the weld interface at the optimum welding current (3.5 kA).

1. Introduction

Martensitic stainless steels (MSSs) are the cheapest grade of the stainless steels due to low content of alloying elements. Because of high strength and hardness as well as good atmospheric corrosion resistance, MSSs are widely used in turbine blades, cutlery and piping industry. MSSs have high hardenability and except at very low cooling rates, their microstructure mostly consists of martensite. However, because of high yield strength and low formability, MSSs are usually produced with ferritic microstructure. After forming or other manufacturing processes like welding, their microstructure will be turned into martensite by an appropriate heat treatment. Fusion welding processes face multiple challenges when used for MSSs such as formation of very hard martensite phase and hydrogen embrittlement [1–3]. In contrast, duplex stainless steels (DSSs) are among the most expensive grades of steels, not only due to high content of alloying elements, but also because of the thermomechanical process needed to produce their particular microstructure. Nevertheless, higher strength and better corrosion resistance in chlorine environments compared to austenitic stainless steels (ASSs) resulted in the replacement of ASSs and even some Nickel-based alloys with DSSs specially in piping industry. The exceptional properties of DSSs are mainly related to the equal content of ferrite and austenite phases in their microstructure. Thus, the main challenges in joining DSSs using fusion welding processes are formation of an unbalanced microstructure (with more ferrite in most cases) which no longer possesses the required properties [1,4–6].

Upset Resistance Welding is a solid state welding process which uses electrical current and mechanical pressure to join various metallic parts, from wheel rims in automotive industry to pipes and rods used in petrochemical industry. Heat is produced as a result of electrical current passage through the workpieces in accordance to Joule's law, i.e. $Q = RI^2t$, where Q is the produced heat and R, I and t are electrical resistance, electrical current and time of current passage, respectively. Since the electrical resistance is the highest at the interface of the workpieces (called as contact resistance), most of the heat is generated at the interface and temperature rises up to hot working or even melting temperature of the workpieces [7–10].

Dissimilar joints of martensitic to duplex stainless steels have some applications specially in critical joints of piping industry, where both corrosion resistance and high yield strength are needed. A literature review shows that several researches have been conducted on the welding of MSS to DSS using GTAW process [11,12]. To the best knowledge of the authors, no attempt has been made so far to weld martensitic to duplex stainless steels by upset resistance welding. However, there is no limitation for URW process in dissimilar welding of martensitic to duplex stainless steels. Indeed, URW may be used to weld martensitic to duplex stainless steels according to the geometry and size of the parts. In this work, the effects of the welding current on

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Table 1
Chemical composition and mechanical and physical properties of the base metals.

	Chemical composition (wt.%)							Mechanical Properties		Physical Properties [13]	
	C	**Mn**	**Si**	**Cr**	**Ni**	**N**	Mo	Tensile Strength (MPa)	El. (%)	Thermal Conductivity (W/m K)	Electrical Resistivity (Ω. mm^2/m)
AISI 410	0.02	0.46	0.31	13.31	0.28	–	0.03	675	10	24.9	0.57
ER 2209	0.02	1.31	0.36	22.62	8.01	0.08	3.08	989	17	16	0.80

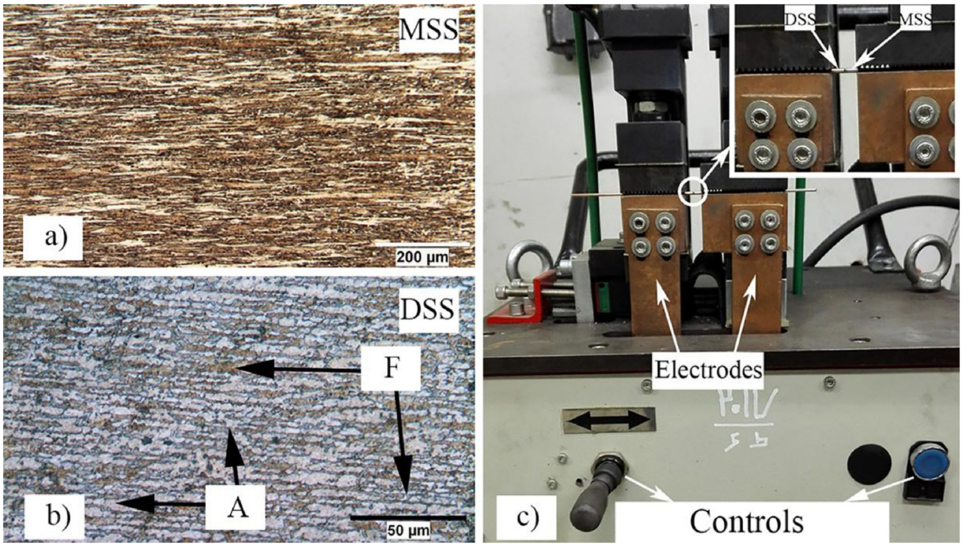

Fig. 1. Microstructure of a) MSS and b) DSS base metals and c) URW machine used for welding the samples.

the microstructure and mechanical properties of the upset resistance welds of MSS to DSS rods are investigated. Determining the optimal welding current in order to achieve the highest strength is the main purpose of this paper.

2. Experimental procedure

Rods with 2.4 mm diameter from AISI 410 MSS and 2209 DSS were used as the base materials. Chemical composition and mechanical and physical properties of the base materials are given in Table 1. Fig. 1 shows the microstructures of the base materials, both with the worked-elongated grains. AISI 410 and 2209 steels consisted mostly of ferrite, and relatively equal amount of austenite and ferrite phases, respectively. As mentioned before, MSSs are usually produced with initial microstructure of ferrite due to high yield strength and low formability limiting forming of these alloys to wire and sheet.

For welding, samples were first cut 90 mm in length, then grinded by 240 grit abrasive paper to promote intimate contact between faying surfaces. Afterward, samples were welded using an URW machine (Fig. 1-c) manufactured by Novin Sazan Company (Tehran, Iran). Important resistance welding parameters such as pre-squeeze time, upset force, welding time and holding time were determined by primary experiments, and were set to 60 cycles (each cycle is equal to 0.02 s approximately), 1.1 kN, 8 cycles and 60 cycles, respectively.

Five levels of welding current, from 2 to 4 kA (2, 2.5, 3, 3.5 and 4 kA) were used to weld the samples. Three samples were welded with each welding current, two of them were used for tensile test and the other one for microstructural studies and microhardness test.

Tensile tests were conducted using Hounsfield tension/compression machine, with the gauge length of 50 mm (25 mm from each side of the joint) and tensile rate of 2 mm/min. Vickers microhardness test was done along the centerline of the joint cross section with a load of 100 gf applied for 15 s.

Vilella's (100 ml ethanol, 5 ml HCl, 1 g Picric acid) and Kalling's No. 2 (100 ml ethanol, 100 ml HCl, 5 g $CuCl_2$) reagents were used for etching MSS and DSS, respectively. Field-Emission Scanning Electron Microscope (FESEM) was used for investigation of the fracture surfaces and presence of discontinuities and voids at the weld interface.

3. Results and discussion

3.1. Microstructural studies

3.1.1. Weld interface

Fig. 2 shows the microstructure of the weld interface. No signs for formation of a reaction or transition layer between the base metals were seen at the weld interface of all samples. Variation of the welding current resulted in two main differences between the weld zone of the samples:

(i) Formation of defects at the weld interface
(ii) Size of the flash formed at the weld interface