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Resistance spot welding of AISI 430 ferritic stainless steel: Phase transformations and mechanical properties

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ABSTRACT

The paper aims at investigating the process–microstructure–performance relationship in resistance spot welding of AISI 430 ferritic stainless steel. The phase transformations which occur during weld thermal cycle were analyzed in details, based on the physical metallurgy of welding of the ferritic stainless steels. It was found that the microstructure of the fusion zone and the heat affected zone is influenced by different phenomena including grain growth, martensite formation and carbide precipitation. The effects of welding cycle on the mechanical properties of the spot welds in terms of peak load, energy absorption and failure mode are discussed.

1. Introduction

Nowadays, ferritic stainless steels (FSSs) are widely accepted for the use in structural frameworks and body paneling of buses and coaches [1]. The microstructure of FSSs can be either fully ferritic or a mixture of ferrite and martensite where martensite sits at the grain boundaries [2]. The fully ferritic microstructure can be achieved by suppressing the austenite formation at elevated temperatures. Grain boundary martensite can be formed either by austenite solid state transformation or during the last stage of solidification. The austenite solid state transformation is the common path in AISI 430 FSS [2]. The physical metallurgy and microstructure of this steel can be explained using the pseudo-binary diagram at 17% Cr shown in Fig. 1. Accordingly, δ-ferrite is the first phase to solidify followed by some transformation from δ-ferrite to austenite during cooling. Under equilibrium cooling condition this austenite phase will transform to α-ferrite and $Cr_{23}C_6$ carbides; however, non-equilibrium cooling condition (such as welding processes) results in the formation of martensite phase [2].

Fusion welding of ferritic stainless steels (FSSs) is accompanied by undesirable grain growth and precipitation of derogatory secondary phases particularly sigma phase in the heat affected zone and the fusion zone of the weldment, which results in the low toughness and ductility [2,3]. Grain growth and formation of the sigma phase can be controlled by applying processes which involve low heat input including laser beam welding, pulsed current gas tungsten arc welding and solid state welding processes [3,4]. Lakshminarayanan and Balasubramanian [5] reported the formation of fine dendritic and equiaxed grains in the weld metal of 409 M FSS during laser beam welding showing a higher tensile strength and impact toughness of weld metal compared to the base metal. According to Bilgin and Meran [3], friction stir welding of AISI 430 FSS results in an decrease in the grain size in the weld metal by a factor of 4.

Resistance spot welding (RSW) is the main joining process in automotive industry. This welding method is a low heat input process in which the heat is produced by resistance of the parts being welded, as well as the interfaces, to the flow of localized current [6]. The cooling rates of RSW are extremely high (in the order of 1000–10,000 °C/s) [7]; therefore, it can be used as a suitable welding method for decreasing grain growth and preventing the formation of derogatory secondary phases which makes it a promising candidate for welding of FSSs.

Automobile structural assemblies contain a few thousand of spot welds. Therefore, the quality, performance and the failure characteristics of resistance spot welds are important for determining the durability and safety design of the vehicles, as they transfer the load through the structure during a crash [8,9]. Therefore, the aim of the present research is investigating the metallurgical and mechanical properties of resistance spot welded AISI 430 FSS.

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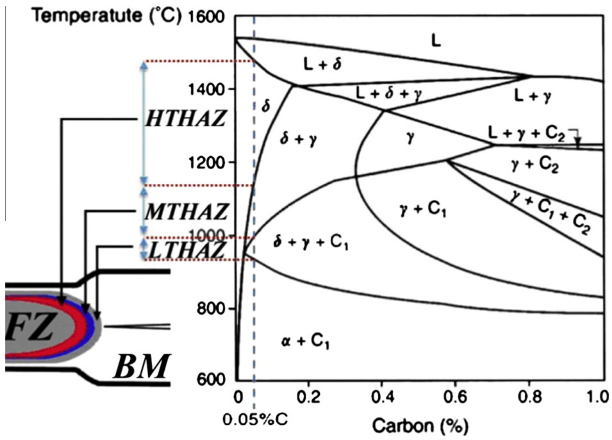

Fig. 1. Fe–Cr–C pseudo-binary diagram at 17% Cr [2].

Table 1
Chemical composition and mechanical properties of the investigated AISI 430 ferritic stainless steel.

Chemical composition (wt.%)								Mechanical properties		
C	Mn	Si	Cr	Ni	Mo	Al	Fe	YS (MPa)	UTS (MPa)	EL (%)
0.05	0.48	0.28	16.9	0.16	0.2	0.011	Base	330	490	33

YS, yield strength; UTS, ultimate tensile strength; EL, elongation.

2. Experimental procedure

The 1.2 mm thick AISI 430 FSS sheets were used as the base metal. The chemical composition of the base metal was determined using a standard spark emission spectrometer (quantometer). The tensile properties of the base metal were determined using a standard tensile test in accordance to ASTM: E8M. Table 1 shows the chemical composition and tensile properties of the base metal. Welding process was performed by a 120 kVA ac pedestal type resistance spot welding machine, controlled by a Programmable Logic Controller (PLC). Welding was conducted at the constant electrode pressure of 4 bar using a 45° truncated cone Resistance Welding Manufacturing Alliance (RWMA) Class two electrodes having the face diameter of 8 mm. The welding current was increased from 7 to 11 kA with an increment of 0.5 kA. Throughout the process, squeeze time, welding time and holding time were kept constant at 40, 12 and 20 cycles, respectively.

Tensile-shear test samples were prepared according to ANSI/AWS/SAE/D8.9-97 standard [10] and tested using an Instron universal testing machine at a cross head of 2 mm/min. Microstructure characterization of the fusion zone and heat affected zone was conducted by performing standard metallography procedure and the specimens were etched by Kalling's No. 1 (33 ml H_2O, 1.5 g $CuCl_2$, 33 ml HCl, 33 ml Ethanol). The fusion zone size was measured on the metallographic cross sections. Fracture surface of the samples were studied by scanning electron microscopy (SEM). Vickers microhardness test was performed 100 μm above

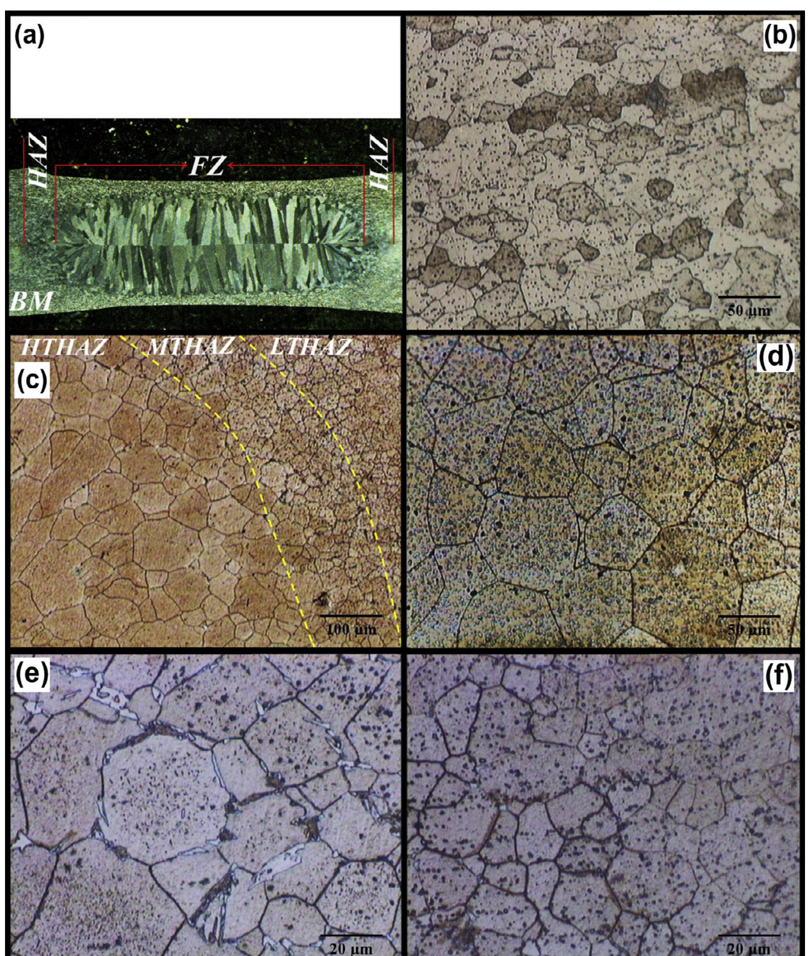

Fig. 2. (a) Typical macrostructure of AISI 430 resistance spot welds. (b) Base metal microstructure. (c) HAZ microstructure. (d) MTHAZ microstructure. (e) LTHAZ microstructure. (f) Dispersion of precipitates in HTHAZ.