Materials Science & Engineering A 608 (2014) 35–45

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Study on microstructure and mechanical characteristics of low-carbon steel and ferritic stainless steel joints

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ARTICLE INFO

Article history:
Received 13 December 2013
Received in revised form
10 April 2014
Accepted 15 April 2014
Available online 26 April 2014

Keywords:
Ferritic stainless steel
Dissimilar weld
Microstructure
Mechanical properties
Gas tungsten arc welding

ABSTRACT

In this work, examinations on the microstructure and mechanical properties of plain carbon steel and AISI 430 ferritic stainless steel dissimilar welds are carried out. Welding is conducted in both autogenous and using ER309L austenitic filler rod conditions through gas tungsten arc welding process. The results indicate that fully-ferritic and duplex ferritic–martensitic microstructures are formed for autogenous and filler-added welds, respectively. Carbide precipitation and formation of martensite at ferrite grain boundaries (intergranular martensite) as well as grain growth occur in the heat affected zone (HAZ) of AISI 430 steel. It is found that weld heat input can strongly affect grain growth phenomenon along with the amount and the composition of carbides and intergranular martensite. Acquired mechanical characteristics of weld in the case of using filler metal are significantly higher than those of autogenous one. Accordingly, ultimate tensile strength (UTS), hardness, and absorbed energy during tensile test of weld metal are increased from 662 MPa to 910 MPa, 140 Hv to 385 Hv, and 53.6 J m^{-3} to 79 J m^{-3}, respectively by filler metal addition. From fracture surfaces, predominantly ductile fracture is observed in the specimen welded with filler metal while mainly cleavage fracture occurs in the autogenous weld metal.

1. Introduction

Over the past few years, dissimilar metal welding (DMW) has attracted growing attention for saving costs and material consumption [1]. Moreover, DMW can be utilized to join different alloys together to provide wide variety of property requirements [2]. Dissimilar joints usually experience various service conditions, especially temperature changes, affecting their performance [3]. Therefore, welded metals should have a relatively good compatibility in their properties depending on the necessity of the service condition such as heat transfer characterization, oxidation and corrosion resistance, and also high temperature mechanical properties [4]. DMW is generally more challenging than similar metal welding due to the differences in the physical, mechanical and metallurgical properties of the parent materials [5]. These variations may even make the selection of compatible filler metal more complicated with both of the base metals [6].

Ferritic stainless steels have a ferrite-base microstructure and possess suitable resistance to stress corrosion cracking, pitting and crevice corrosion. In addition to the better corrosion resistance and relatively lower price of these alloys with respect to austenitic stainless steels [7], ferritic stainless steels have relatively higher thermal conductivities and lower thermal expansions [8,9]. The latter makes them more attractive than austenitic steels in applications where thermal cycling is present. Ferritic stainless steels have slightly higher yield strength than austenitic ones; however, they exhibit lower elongation during tensile loadings [10,11].

Considering the fact that ferritic stainless steels possess lower weldability, they are not used extensively with respect to the austenitic ones [7]. Ferritic stainless steels have useful properties in the wrought condition. Fusion welding causes to decrease in their toughness, ductility and corrosion resistance due to the grain coarsening, carbides precipitation and martensite formation occurred in their microstructure [12]. This is responsible for their limited weldability. Moreover, ferritic stainless steels are susceptible to intergranular corrosion due to the sensitization phenomena as a result of thermal cycles experienced during welding or post-weld heat treatment. Hence, the application of this group of alloys is limited in specific environments after welding [13]. Carbide precipitation also occurs much faster in ferritic stainless steels than that in austenitic ones due to the higher carbon contents and much lower solubility of carbon in the ferritic matrix [14].

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http://dx.doi.org/10.1016/j.msea.2014.04.065
0921-5093/

Table 1
Chemical compositions of base and filler metals.

Alloy	Composition (wt%)										
	C	Si	Mn	Cr	Ni	P	S	Mo	Co	Cu	Fe
AISI 430 steel	0.046	0.6	0.586	17.13	0.132	0.022	0.001	0.019	0.044	0.121	81.1
Plain carbon steel	0.021	0.005	0.22	0.011	0.035	0.012	0.009	0.005	0.01	0.046	99.6
ER309L	0.08	1.0	2.0	23	12	0.045	0.03	–	–	–	61.8

Table 2
Examined mechanical properties of base metals.

Alloy	Elongation (%)	Ultimate tensile strength (MPa)	Hardness (Hv)	Absorbed energy (J m^{-3})
AISI 430 steel	31.3	516	171	144
Plain carbon steel	35.2	334	124	109

Table 3
Physical properties of base metals.

Alloy	Density (g cm^{-3})	Heat conduction coefficient (W m^{-1} K^{-1}) at 100 °C	Specific heat (J kg^{-1} K^{-1})	Melting point (°C)
AISI 430	7.80	26.1	460	1425–1510
Carbon steel	7.85	51.5	486	1450–1500

Table 4
The welding parameters during GTAW process to achieve complete penetrating joints.

Parameter	Welding with ER309L filler rod	Autogenous welding
Welding current (A)	85	130
Arc voltage (V)	12	12
Welding speed (mm s^{-1})	2	4.27
Gas flow rate (l min^{-1})	12	12
Arc gap (mm)	< 2	1

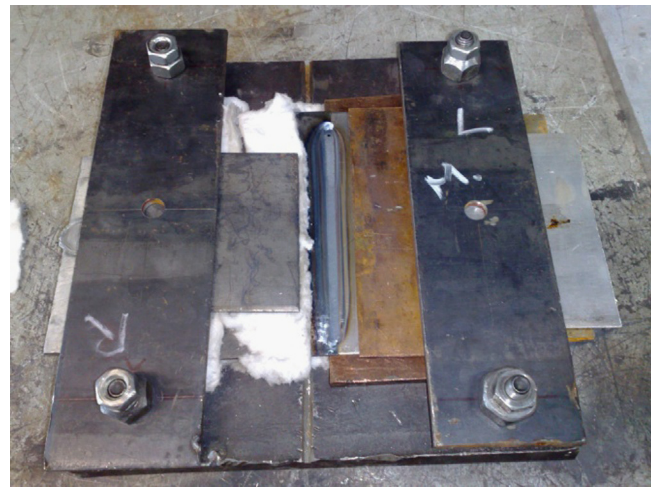

Fig. 1. Configuration of welding fixture.

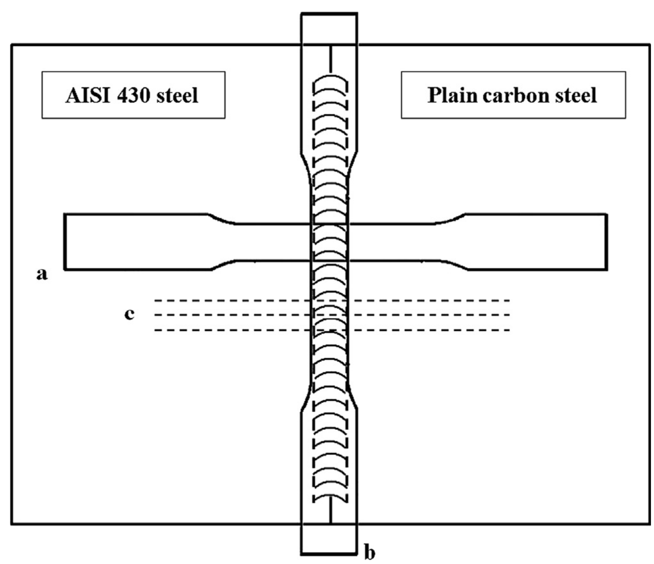

Fig. 2. Schematic of weld sample showing configuration of regions from which specimens were prepared for transverse tensile test (a), longitudinal tensile test (b) and hardness measurement (c).

Standard grades of ferritic stainless steels have nominal chromium (Cr) contents of 12, 17, and 27 wt% equivalent to AISI 405, 430, and 446 alloys, respectively. Steels with high chromium contents, such as AISI 446, are used at high temperature applications where their resistance to sulphurous flue gases are an advantage [10,15]. AISI 430 steel containing 17 wt% chromium is the most common type of ferritic stainless steels and is known as the head of this grade [16]. Therefore, investigation of dissimilar weld properties of this type of steel will provide a general insight for future study and research in DMW of other types of ferritic stainless steels.

Plain carbon steel is widely welded due to its appropriate weldability and various kinds of applications. It is almost welded by all conventional processes depending on its thickness, expected joint quality and the cost of weldment [17]. In addition to the weight and cost savings, one of the direct applications of alloy AISI 430 to plain carbon steel dissimilar joint is in some components of low temperature area in heat recovery steam generators of power plants. Also, it has been reported that dissimilar joint between ferritic stainless steel and carbon steel could be used in automotive exhaust systems [18]. To the best knowledge of the authors, despite the importance of dissimilar welding of ferritic stainless steels to other types of steels, no attempt has been made so far to examine such dissimilar joints comprehensively.

The aim of present study is to weld AISI 430 ferritic stainless steel to plain carbon steel by using gas tungsten arc welding (GTAW) process in both conditions of autogenous and using ER309L austenitic filler metal. The microstructure and mechanical properties of welded specimens as well as the influence of using filler metal on the weld metal and HAZ properties are discussed in detail.