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Microstructure and Mechanical Properties of Weld Metals of 950 MPa Class High-strength Steel†

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Abstract

Gas metal arc weld metals of the 950 MPa class high-strength steel were prepared in shielding gases with different CO_2 contents, and effect of CO_2 on the mechanical properties and microstructure of the weld metal was investigated. Vickers hardness and Charpy impact absorbed energy decreased with an increase of CO_2 content in the shielding gas. With the pure Ar shielding gas the weld metal showed lath martensite microstructure With an increase in the CO_2 content in the shielding gas the microstructure became bainitic, and with the 25%CO_2-Ar shielding gas a granular bainite structure was found. These changes were caused by the decrease in the hardenability of the weld metal with the decrease of alloy elements by the oxidation during the welding.

KEY WORDS: (high-strength steel) (gas-metal-arc welding) (microstructure) (martensite) (bainite) (mechanical property)

1. Introduction

Welding of 950 MPa class high-strength steel is strongly demanded in the construction of large steel structures. There are significant literatures on the microstructure and mechanical properties of the heat-affected zone in welds of high-strength steels[1-3], but available reports that concentrate on the weld metal are limited[4,5]. The microstructure and properties of weld metals are depend out on their chemical compositions and thermal histories. It is known that the addition of CO_2 to argon based shielding gas is effective for improvement of productivity in gas metal arc (GMA) welding of steel. Through the chemical reaction in the welding arc, CO_2 in the shielding gas can affect the chemical composition of the weld metal, and its microstructure. The aim of this study is to obtain more knowledge about the effect of the CO_2 content in the shielding gas on the microstructure and mechanical properties of GMA weld metal of 950 MPa class high strength steel.

2. Experimental

In **Table 1** are shown the chemical compositions of the base metal and filler wire of the 950 MPa class high strength steel. Welding coupons, 12x120x200 mm, were prepared from the base metal. A groove was cut at the center of the coupon. The groove angle was 65° and the groove depth was 9 mm. A flat face 3 mm wide was made at the root of the groove. Weld metals were deposited on the grooves by single pass GMA welding. Shielding gases of 5 different compositions, Pure Ar, 10%CO_2-Ar, 15%CO_2-Ar, 20%CO_2-Ar and 25%CO_2-Ar, were used. Heat inputs were ~3 kJ/mm. Chemical compositions of the obtained weld metals were measured. To estimate mechanical properties of the weld metals, Vickers hardness and Charpy impact tests were utilized. Observations of microstructure were carried out by transmission electron microscopy (TEM).

Table 1 Chemical composition of high strength steel base metal and filler metal (mass%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Al	N
Base metal	0.12	0.17	0.74	0.001	0.004	0.24	3.13	0.56	0.65	0.003	0.053	0.004
Filler wire	0.07	0.49	1.49	0.003	0.001	0.15	3.12	0.58	0.91	-	0.032	-

Fe: barance

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Table 2 Chemical compositions of GMA weld metals of 950 MPa class steel (mass%).

Shielding Gas	C	Si	Mn	Cu	Ni	Cr	Mo	Ti	V	Al	Nb	O	N	C_{eq}
Pure Ar	.089	.36	1.26	.22	3.13	.59	.83	.025	.015	.031	.006	.0024	.011	0.80
10%CO_2	.092	.25	1.00	.21	3.11	.58	.82	.010	.015	.023	.006	.025	.0034	0.76
15%CO_2	.089	.21	0.94	.22	3.12	.57	.83	.010	.013	.016	.006	.027	.0033	0.75
20%CO_2	.094	.20	0.89	.22	3.12	.57	.82	.010	.013	.016	.006	.029	.0032	0.74
25%CO_2	.092	.16	0.80	.21	3.12	.57	.81	.008	.013	.014	.006	.031	.0034	0.72

S and P were 0.001 and 0.0043%, respectively. C_{eq}= C+Mn/6+(Cu+Ni)/15+(Cr+Mo+V)/5.

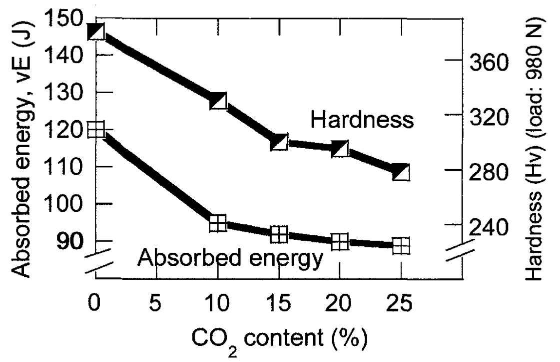

Fig. 1 Hardness and absorbed energy of the weld metals as a function of CO_2 content in the shielding gas

3. Results and Discussions

Chemical compositions of the weld metals are listed in **Table 2**. With an increase of CO_2 content in the shielding gas, O content in the weld metal increased, and at the same time the contents of alloy elements, Mn, Si, Al, and Ti decreased. It was suggested that these elements were reduced by the oxidation during the welding. With the decrease of these alloy elements, the IIW carbon equivalent for hardenability (C_{eq}) also decreased.

As shown in **Fig. 1**, both the hardness and Charpy impact absorbed energy of the weld metals decreased with an increase of CO_2 content in the shielding gas.

The microstructures of the weld metals are shown in **Fig. 2**. Fine lath structures with high density of dislocations were found in the weld metal produced with the Pure Ar shielding gas (Fig. 2(a)). These characteristics strongly suggested lath martensite. Elongated laths were found in the weld metal produced in the 10%CO_2-Ar shielding gas (Fig. 2(b)). This structure suggested lower bainite, but carbide was not found in this weld metal. In the weld metal produced in the 25%CO_2-Ar shielding gas (Fig. 2(c)) lath structures were found, and there were non-lath areas with martensite-austenite constituents (marked by '**A**' in Fig. 2(C)). Characteristics of this structure corresponded to that of the granular bainite, the structure that is found in the low-carbon steel receiving continuous cooling. It was thought that the decrease in hardenability of the weld metal with the increase in the CO_2 content caused the changes in microstructure observed by TEM, and the decrease of the hardness and Charpy impact absorbed energy.

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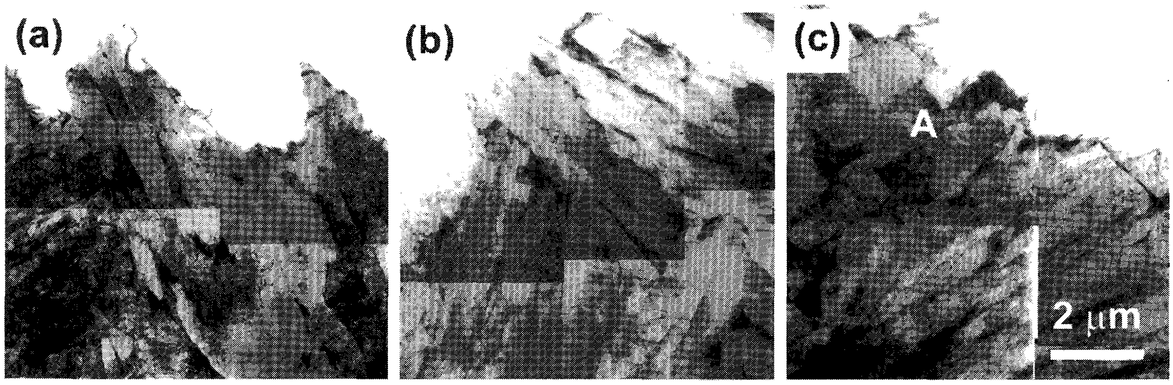

Fig. 2 Microstructure of the weld metal of the 950 MPa class steel by the Pure Ar shielding gas (a), 10%CO_2-Ar shielding gas (b), 25%CO_2-Ar shielding gas (c).