

Title	Mechanical Properties of High Manganese Non-magnetic Steel and Carbon Steel Welded Butt Joints : Investigation for Applying Dissimilar Materials to Steel Structures (Repot I) (Mechanics, Strength & Structure Design)
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Citation	Transactions of JWRI. 1998, 27(2), p. 115-118
Version Type	VoR
URL	https://doi.org/10.18910/6946
rights	
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Mechanical Properties of High Manganese Non-magnetic Steel and Carbon Steel Welded Butt Joints †

- Investigation for Applying Dissimilar Materials to Steel Structures (Report I) -

Eiji NAKAJI*, Souichi IKEDA**, You Chul KIM*** and Kohsuke HORIKAWA****

Abstract

Mechanical properties of the dissimilar materials welded butt joints between high manganese non-magnetic steel and carbon steel (referred to as DMW joints) were investigated for applying to steel structures. SS400 is used as carbon steel.

The DMW joints, in which weld defects such as incomplete penetration, blowhole and crack were not found, were shown to be of good quality. Tensile strength in the DMW joints was 10(%) higher than in carbon steel. In the bend tests, the DMW joints showed good ductility, without cracks. Charpy absorbed energy at 0 (°C) of the DMW joints was over 120(J) at the bond where it seems to be the lowest. Significant hardening or softening was not detected in the heat affected zone.

KEY WORDS: (Dissimilar materials welded joints) (Mechanical property) (Tensile strength) (Ductility) (Weldability) (Charpy absorbed energy) (Weld defect) (High manganese non-magnetic steel)

1. Introduction

As the research and development of nuclear fusion reactors, magnetic levitation vehicle systems (linear motor car), etc. utilizing magnetic technology progress from the stage of basic studies to studies for practical use in recent years, structural non-magnetic steel comes to be required in large quantities. Non-magnetic steel comprises austenitic stainless steel and high manganese non-magnetic steel (hereinafter referred to as high Mn steel).

High Mn steel is superior in strength, stability of magnetic permeability and cost compared with austenitic stainless steel. While high Mn steel is essentially a high work hardening material, it is meager machinability especially in drilling. As a new type of high Mn steel with improved machinability has been developed in recent years, it becomes attractive as a structural non-magnetic steel. However, since high Mn steel is rather expensive compared with carbon steel, particular consideration to reduce the fabrication cost in design must be required when high Mn steel is applied to the structures.

Paying attention to steel structures for magnetic levitation vehicle systems, the distance requiring non-

magnetic properties is considered to be within about 1.5(m) from the super-conductive magnet¹⁾. So, it is considered that a composite structure in which high Mn steel is partially adopted for the portion which really requires non-magnetic properties and carbon steel is adopted for the other portions. In such cases, dissimilar material welded butt joints of high Mn steel/carbon steel (hereafter referred to as DMW joints) are indispensable. Before applying the DMW joints to steel structures, it is necessary to confirm the mechanical properties of the joints.

In this paper, the DMW joints of high Mn steel with improved machinability are prepared and the mechanical properties of the dissimilar materials welded joints are investigated.

2. Experiment

2.1 Materials

Table 1 shows the chemical composition and mechanical properties of the base metals used in these experiments. The high Mn steel has a chemical composition with 0.25% C and 25% Mn. This steel is produced by reducing the C down to 0.25% to alleviate hardening in the drilling, and by adding 25% Mn to

† Received on December 4, 1998

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Transactions of JWRI is published by Joining and Welding Research Institute of Osaka University, Ibaraki, Osaka 567-0047, Japan.

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Table 1 Chemical composition and mechanical properties of base metals.

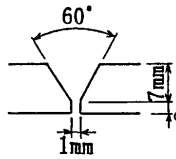
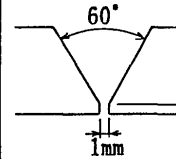
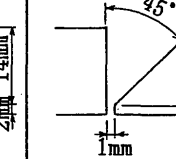
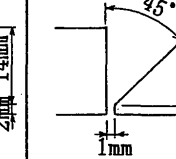
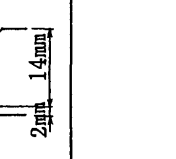

Designation	Plate thickness(mm)	Chemical composition (mass%)					Mechanical properties			
		C (%)	Si (%)	Mn (%)	P (%)	S (%)	YP (Mpa)	TS (Mpa)	EI (%)	vEo (J)
High Mn steel (0.25%C-25%Mn)	9	0.27	0.29	24.89	0.022	0.002	415 ^{*)}	829	53	—
	16	0.25	0.27	25.02	0.019	0.001	303 ^{*)}	774	61	216
Carbon steel (SS400)	9	0.12	0.23	1.02	0.015	0.003	291	434	31	—
	16	0.12	0.23	1.02	0.015	0.003	298	441	33	143

^{*)} 0.2%YS

Table 2 Chemical composition of filler wire.

Welding process	Diameter (mm)	Chemical composition (mass%)						
		C	Si	Mn	P	S	Ni	Cr
MAG	1.6	0.40	0.59	13.30	0.007	0.007	9.14	2.72

Table 3 Welding conditions.

Welding process	MAG					
Plate thickness (mm)	9			16		
Shape of groove						
	Carbon steel	High Mn steel	Carbon steel	High Mn steel	Carbon steel	High Mn steel
	Single V			Single V		
	Single V			Single bevel		
Heat input (kJ/cm)	21.6~24.7 (270A , 28~35V , 21~23 cm/min)					
Shielding gas	Ar + 20%CO ₂ (25l/min)					
Preheating	None					
Interpass temp.(°C)	≤ 150					

stabilize the austenitic phase and confer non-magnetic properties. SS400 is used as carbon steel.

Table 2 shows the chemical composition of the weld wire for high Mn steel.

2.2 Welding conditions

MAG butt welding is performed with single V and single bevel grooves without pre-heating and post-heating. For the specimen with a plate thickness of 9 (mm), the welding sequence is such that the 1st layer is welded from the surface, and after back chipping, the 2nd layer is welded from the back face. Moreover, for the specimen with a plate thickness of 16 (mm), with both single V and single bevel grooves, the 1st to the 3rd layers are welded from the surface, and after back chipping, the 4th and 5th layers are welded from the back face.

The welding conditions are summarized in Table 3.

2.3 Tests and specimen

For the welded joints, surface color check, radiographic (X-ray) inspection and macrostructure observation are performed. The test pieces for tensile and bending tests are taken perpendicular to the weld line from the specimens of single V groove, and those for impact test are taken perpendicular to the weld line from the specimens of single bevel groove respectively. The notch on the impact test pieces is made at three positions i.e. ① center of the weld metal, ② at the bond of the weld metal and carbon steel and ③ at the boundary of the heat affected zone on the carbon steel side. Moreover, the concentration changes of chemical compositions of the weld metal by dilution are investigated using EPMA line analysis.

3. Results and Discussions

3.1 Mechanical properties

The welded joints were submitted to surface color check and radiographic inspection, but weld defects such as incomplete penetration, blowhole, crack etc. were not found. Figure 1 shows an example of the macrographic photo of the cross section taken from the specimen of single V groove. The weld defects were not found in the macrostructure observation.

Figure 2 shows the stress-strain curve of high Mn steel and carbon steel (SS400).

Table 4 shows the results of tensile and bending tests. The fracture position in the tensile test is the base metal of carbon steel of lower strength compared with that of high Mn steel. The tensile strength of 498 (MPa) is more than 10% higher than the value 441 (MPa) of the carbon steel base metal.

In the bending test, excellent bending ductility is demonstrated without cracks in face bending, root bending and side bending. Figure 3 shows an example of the bending test results.

Figure 4 shows the results of impact tests. Charpy absorbed energy at 0(°C) is over 120(J) even at the bond where it seems to be the lowest.

3.2 Dilution of chemical compositions at welded joints

Figure 5 shows the results of EPMA line analysis performed from the bond to weld metal. The compositions change from the bond toward the direction of weld metal, and in this transition zone, martensitic texture having low impact resistance is produced. However, the width of the transition zone forming martensitic texture is very narrow, at no more than 10(μ m). The reason why Charpy absorbed energy at the bond has the value of 120(J) without indicating any remarkable drop seems to be because of the extreme narrowness of the martensitic texture area.

On the other hand, near the center of the weld metal, the concentration of composition is sufficiently uniform, showing values close to chemical compositions of weld wire.

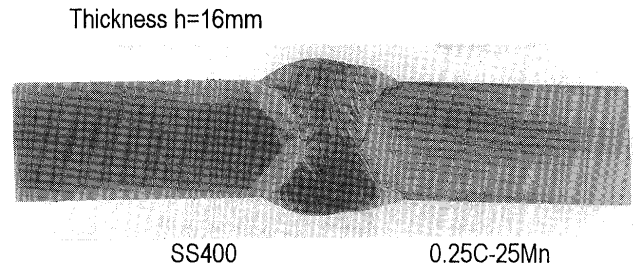


Fig.1 Macrostructure of welded joints (Single V groove).

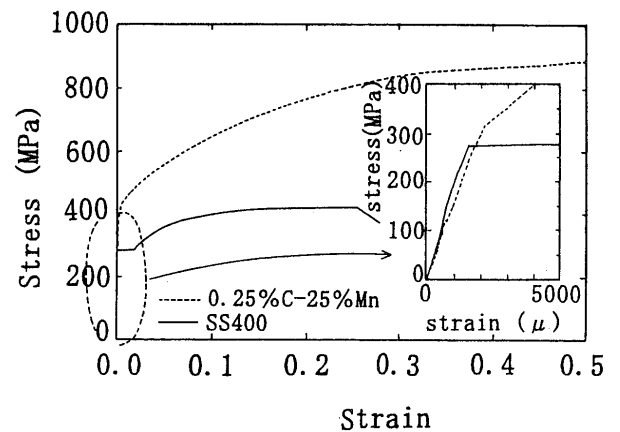


Fig.2 Stress-strain curve of high Mn steel and carbon steel.

From what has been described above, it has been demonstrated that the DMW joints using weld wire for high Mn steel have excellent joint performances.

4. Conclusions

In this study, the mechanical properties of the dissimilar materials welded butt joints of high manganese non-magnetic steel and carbon steel joints (DMW joints) are investigated for applying the DMW joints to steel structures.

Table 4 Tensile and bending properties of welded joints.

Groove	Tensile test		Bending test (R=1.5t , 180°)		
	TS (MPa)	Fracture location	Face bend test	Root bend test	Side bend test
Single V groove	498	Carbon steel	good	good	good
	499	Carbon steel	good	good	good

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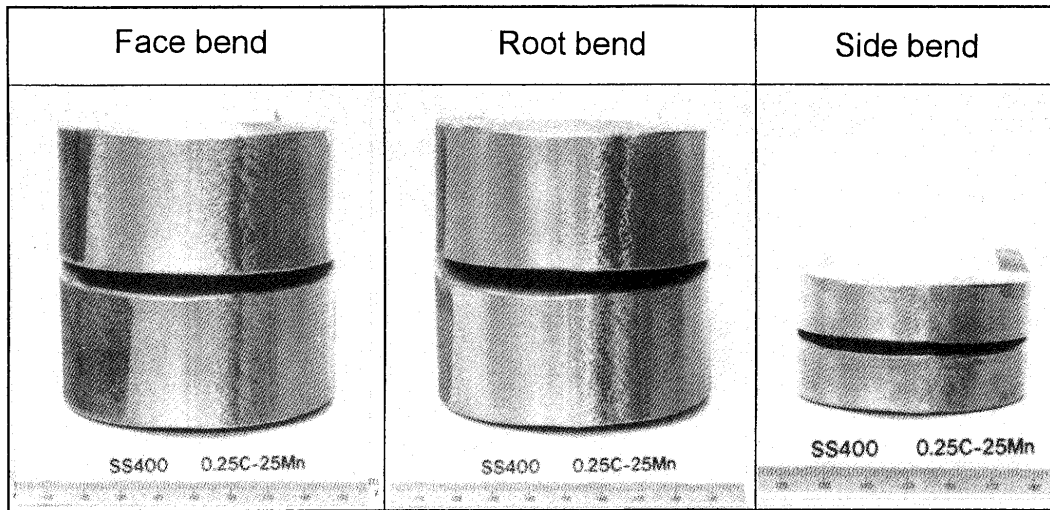


Fig.3 Appearance after bending test.

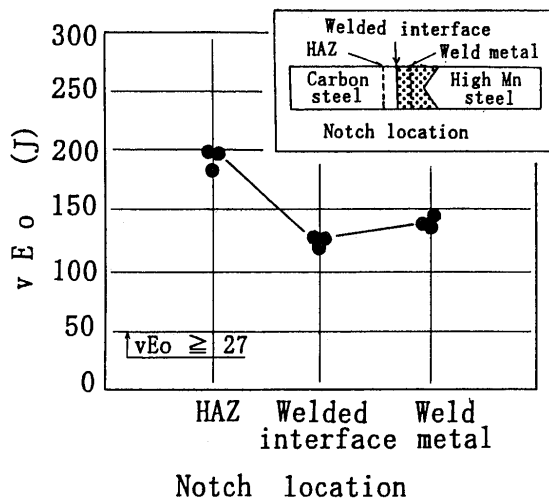


Fig.4 Charpy V-notch impact properties of welded joints.

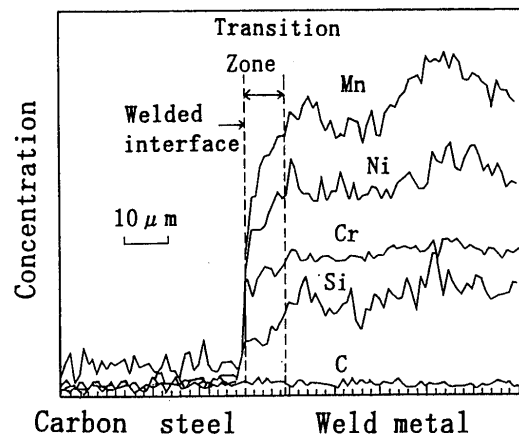


Fig.5 Dilution of chemical compositions by EPMA line analysis.

The results can be summarised as follows:

- (1) The DMW joints show excellent penetration without weld defects such as incomplete penetration, blowhole and crack.
- (2) The tensile strength of the DMW joints is more than 10(%) higher than that of the carbon steel base metal.
- (3) Excellent bending ductility is demonstrated without cracks in face bending, root bending and side bending.

- (4) Charpy absorbed energy at 0(°C) indicates a good value of 120(J) or higher, even at the bond where it seems to be the lowest.

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