Effect of welding parameters on the mechanical properties of GMA-welded HY-80 steels

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Article Information

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In this publication, investigations of HY-80 steels joined by gas metal arc welding by using different welding parameters are described. Different samples obtained from the welded joints were subjected to mechanical testing by means of tensile, hardness and impact toughness tests. The tensile test results showed that the strength of weld metal and heat affected zone were higher than of base metal. Similar Charpy impact toughness test results were obtained for weld metal and heat affected zone. Weld metal hardness was almost similar to the base metal hardness, nevertheless, the heat affected zone indicated higher values. The base metal has ferritic-perlitic structure with fine grains. Martensite needles and bainite are seen in the heat affected zone. Weld metal has martensite needles, partial bainite and residual austenite.

Exceptional combination of high strength and high impact toughness is a crucial need for thick steel plates used for the manufacturing of pressure vessels, ship hulls, line pipes and various other strategic defense applications [1].

HSLA (high strength low alloyed) steels which are produced using the microalloying technique [2], present excellent balance between strength, toughness, ductility, formability and weldability [3-4].

Due to these advantages, HSLA steels have been widely used in the construction of buildings, pipelines [5], automotive industry [6], transport equipment, storage tanks, excavator buckets, high-rise buildings and induced draft fans [7], high pressure vessels or pipelines [8], lifting cranes and high speed ships [9-10].

Microalloyed HSLA steels are essentially low carbon low-alloy, structural steels [11-12]. The excellent properties are basically due to small additions of microalloying elements: Ti, Nb, V and B (0.001-0.1 wt.-%) [13] and controlled rolling [14].

Microalloy carbides, nitrides and carbonitrides are important in the control of austenite recrystallization and grain growth during steel processing and welding leading to a desirable grain refinement. Moreover, microalloying, controlled rolling and accelerated cooling lead to the formation of non-polygonal or acicular ferrite as well as bainite which further contribute to strengthening [15]. Especially, titanium has frequently been added to HSLA steels to enhance the control of austenite grain size during welding or reheating process [16-17].

Welding of HSLA steels involves usage of low, even and high strength filler materials (electrodes) compared to the parent material depending on the application of the welded structures and the availability of the filler materials [18].

HY-80 is a high yield strength (minimum of 80 ksi or 550 MPa), low carbon and low alloyed steel with nickel, molybdenum and chromium. It has excellent weldability and notch toughness along with good ductility even in welded sections. HY-80 steel is readily machined when it is in the quenched and tempered condition. HY-80 may be simply cold or hot formed by conventional bending or forming processes. Weldments of HY-80 are known for good ductility, notch toughness and strength [19

Gas shielded arc welding (MIG/MAG welding) process in which additional metal is brought into by a roll of wire line and is molten by Joule effect and an electric arc [20], belongs to the fusion welding processes, which are the most applied processes in modern manufacturing industries [21-22].

An inert gas, generally argon based gas (MIG welding), or active gas, generally CO_2 based gas (MAG welding) is used as plasma for electric arc outbreak and as protective atmosphere for metal at high temperature, avoiding contamination of the metal by oxygen and nitrogen [20].

Notwithstanding, HSLA steels have fine grains and good mechanical properties with the balance of strength and toughness. The excellent toughness of a structural steel can be upset during welding procedures since toughness values are very sensitive to microstructural change within heat affected zone (HAZ). In general, the coarsed-grained HAZ adjacent to the fusion line is known to have the lowest toughness among the various regions within a HAZ because of unfavorable microstructure [23-25]. In these steels, drastic embrittlement can still be encountered [26]. Because of that, welding joints of HSLA are the weakest part of the whole welding structure under fatigue conditions [27].

Experimental procedure

The base material used in this study was HY-80 steel with thicknesses of 23 and 14 mm, respectively. Chemical composition data and mechanical properties obtained by steel manufacturer are given in Table 1.

Six types of gas metal arc welded (MAG) joints (Hy-1, Hy-2, Hy-3, Hy-4, Hy-5, Hy-6) of Hy-80 steel with different thicknesses, shielding gases and welding grooves were manufactured. Hy-7 test sample is the base material in order to compare the results. For Hy-1, Hy-2, Hy-4, Hy-5, The base material consisted of a X-groove with an opening angle of 50°(±5). HY-3 was manufactured with V-groove with an opening angle 50°(±5). According to thickness and welding groove, the welds were completed, supported by submerged arc flux. Welding details of the joints are given in Table 2. Welding positions were applied according to EN ISO 6947 in the ASME section.

Longitudinal sections were prepared perpendicular to the plate surface for tensile test and notch impact test (see Figure 1). 25 mm of welded part was eliminated from begin and end due to weld defects. Welded joints were cross-sectioned perpendicular to the welding direction for hardness tests 10 × 55 mm. Specimens for microstructural analyses were prepared, polished and etched with Nital 5. Notch impact test samples were extracted transverse to the weld with notches positioned at the weld metal (WM) center and the HAZ 2 mm away from the WI (WI + 2 mm) [28]. Hardness test results and microstructures are important for giving information regarding material structure. Vickers hardness measurements under 1 kg load were carried out over the weld cross-sections (base metal, weld metal, heat affected zone at 2 mm intervals). The hardness measurements were obtained from 16 different points (see Figure 2).

Results and discussion

All test samples were broken off the base metal. All breaks were ductile. The yield strength (R_e) values obtained were higher than the minimum value of the base material. It was seen that ultimate tensile strength (R_m) results were near to base metal values (see Figure 3). Due to the increase of welding speed, weld seam and penetration caused the decrease of UTS results. Nevertheless, breaks of tensile samples occured on the base metal. Comparing with X welding groove, V type groove caused the decreasing of UTS. As a result, the tensile test results showed that the strength of weld metal and heat affected zone were higher than of base metal.

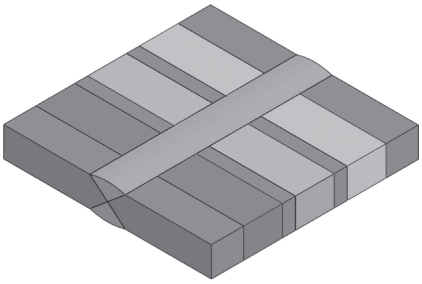

Figure 1: Test parts for tensile, hardness and notch effect test

C	Si	Mn	P	S	Cr	Mo
0.16	0.21	0.27	0.006	0.001	1.68	0.47
Ni	Cu	Sn	V	As	Ti	Sb
2.95	0.06	0.010	<0.01	0.005	<0.002	<0.0030
Yield strength (MPa)		Ultimate tensile strength (MPa)			Strain at fracture (%)	
657 (550-685)		778			25.9	

Table 1: Chemical composition and tensile properties of the base material (wt.-%)

Weldjoint	Welding position	Type of consumable	Protection	Plate preparation	Backing material	Welding parameters (V/A)	Welding speed (cm × min^{-1})	Heat input max. (kJ × cm^{-1})	Preheat temp. (°C)	Interpass temp. max. (°C)
Hy-1	PA(1G)	E90T5-GM H4	80 % Ar - 20 % CO_2	X/50°±5 t=23 mm	F7A8-EH12K	24-26 ~ 180 A	~ 9/1	22	55	150
Hy-2	PA(1G)	E90T5-GM H4	80 % Ar - 20 % CO_2	X/50°±5 t=23 mm	F7A8-EH12K	24-26 ~ 180 A	~ 10.5/1	22	55	150
Hy-3	PA(1G)	E90T5-GM H4	80 % Ar - 20 % CO_2	V/50°±5 t=23mm	F7A8-EH12K	24-26 ~ 180 A	~ 9/1	22	55	150
Hy-4	PA(1G)	E80C-Ni2H4	80 % Ar - 20 % CO_2	X/50°±5 t=23 mm	F7A8-EH12K	24-26 ~ 180 A	~ 12/1	22	55	150
Hy-5	PA(1G)	E90T5-GM H4	100 % Ar	X/50°±5 t=23 mm	F7A8-EH12K	24-26 ~ 180 A	~ 9/1	22	55	150
Hy-6	PA(1G)	E90T5-GM H4	100 % Ar	X/50°±5 t=14 mm	F7A8-EH12K	24-26 ~ 180 A	9/1	22	55	150
Hy-7	–	–	–	–	–	–	–	–	–	–

Table 2: Welding details for MAG joining the 23-14 mm (X-V) thick base materials

Investigating the obtained results, the welded samples showed that the impact energy levels were between 60-90 J (see Figure 4). The applications of various welding parameters affected impact toughness. The increasing of welding speed, V welding groove instead of X welding groove, filler metal changing and the decreasing of CO_2 shielding gas rate decreased the impact energy according to the reference welding parameters. Although the impact toughness tests which were carried out at room temperature were lower according to base metal, it was calculated to be normal for such welded structures. In general, the similar Charpy impact toughness test results were obtained for weld metal and heat affected zone.

Hardness measurements were carried out under 1 kg load over the weld cross-sections (base metal, weld metal, heat affected zone at 2 mm intervals) of 23 mm- and 14 mm-thick MAG welded material with X- and V-groove. The hardness measurements were obtained from 16 different points. The hardness distribution is given in Figure 5. As shown in the diagram, the hardness values of HAZ are higher than that of the base material. This zone presents a transition zone for material quality, and is the most appropriate zone where microcracks can occur. By applying of appropriate tempering pass technique, high hardness can be prevented, and also values similar to base material hardness can be achieved. Weld metal hardness was almost alike to the base metal hardness, however, using the related to different welding parameters, HAZ showed higher values. Various welding parameters were seen to affect the macro- and microstructure. As a general rule, hardening in the weld joint is determined by the maximum in HAZ. According to the IIW IX commission report, HAZ hardness shall not exceed 350 HV, otherwise additional precautions must be taken. At hardness testing, reference welding parameters exposed HAZ hardness similar to standard values, respectively. Nonetheless, by changing of welding parameters, lower hardness was obtained.

For microstructural investigation, the metallographic samples from the joints and Nital 5 for etching were used. The base metal has ferritic-perlitic structure with fine grains. In the sample welded using reference welding parameters, martensite needles and bainite are seen at HAZ. Weld metal has martensite needles,

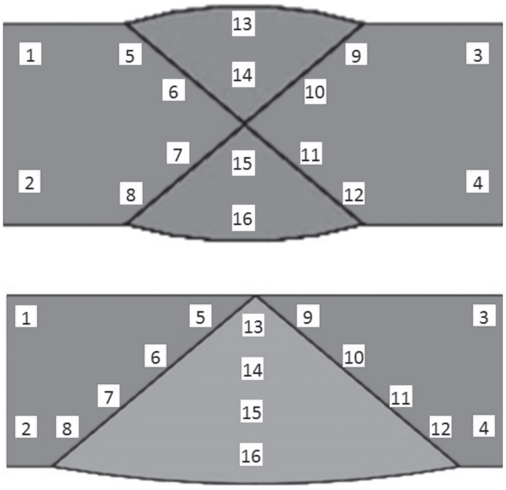

Figure 2: Hardness measurement test points for X and V in the welding groove

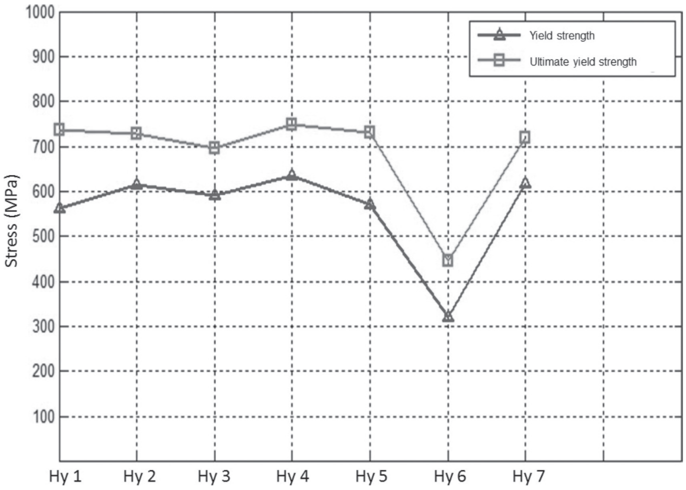

Figure 3: Tensile test results

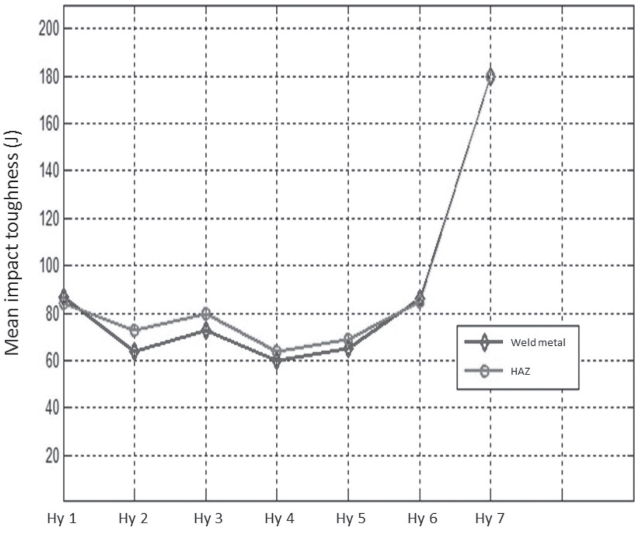

Figure 4: Notch impact test results

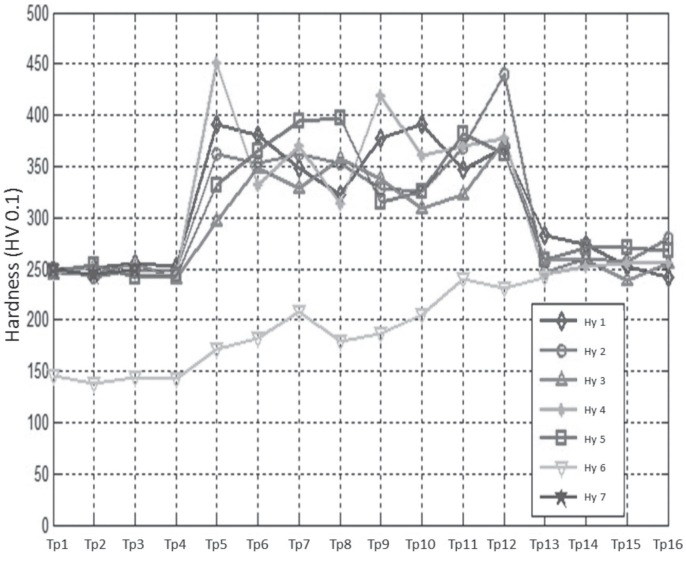

Figure 5: Hardness test results

partial bainite and residual austenite (see Figure 6).

In the other welded test samples (see Figures 7 to 11), the base metal structures have strips. It is determined as deformation texture. With the effect of heat, this effect was eliminated in HAZ. HAZ has martensite needles.

Conclusions

The following conclusions of this study concerning the effect of the welding param-

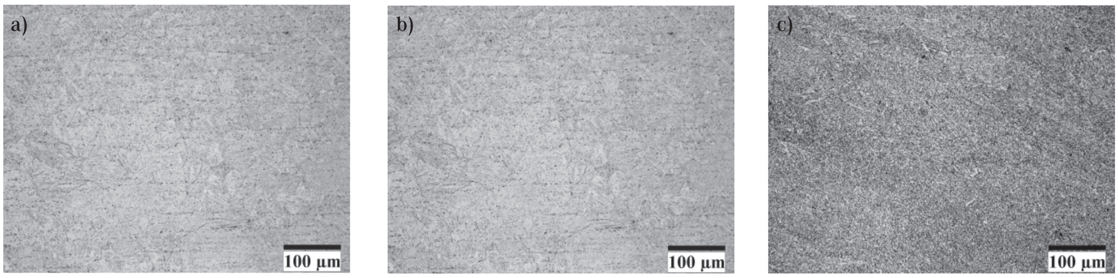

Figure 6: Microstructure of Hy-1, a) base material, b) HAZ, c) weld metal

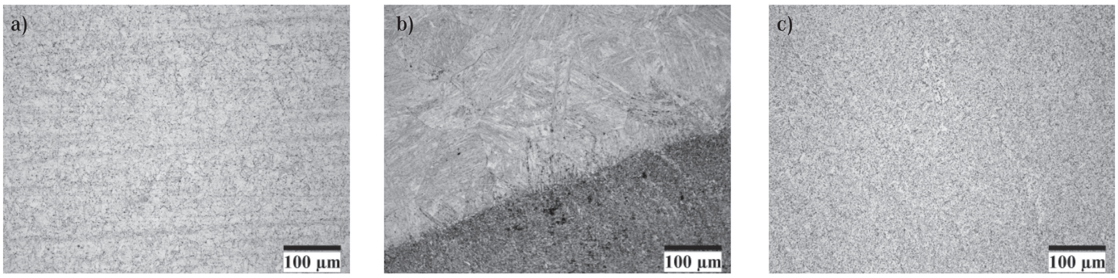

Figure 7: Microstructure of Hy-2, a) base material, b) HAZ, c) weld metal

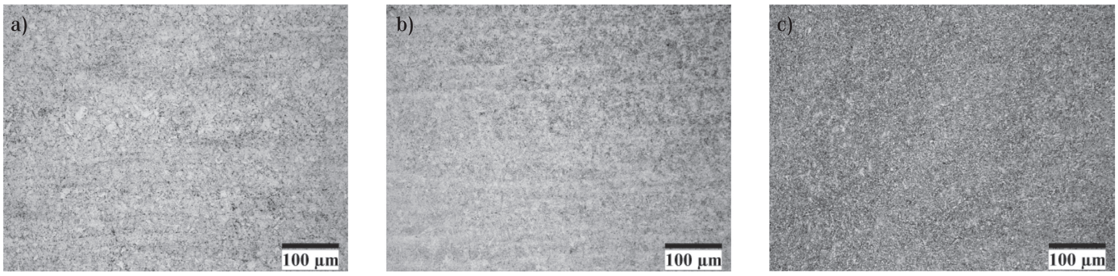

Figure 8: Microstructure of Hy-3, a) base material, b) HAZ, c) weld metal

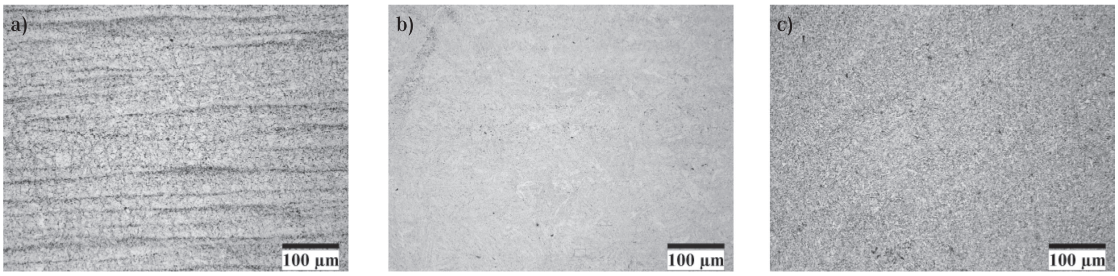

Figure 9: Microstructure of Hy-4, a) base material, b) HAZ, c) weld metal

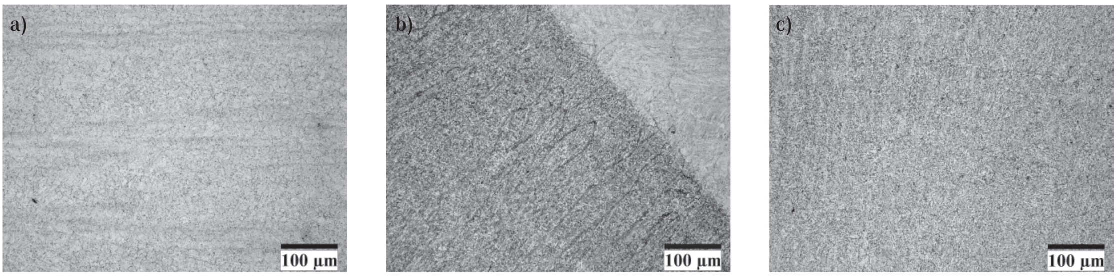

Figure 10: Microstructure of Hy-5, a) base material, b) HAZ, c) weld metal

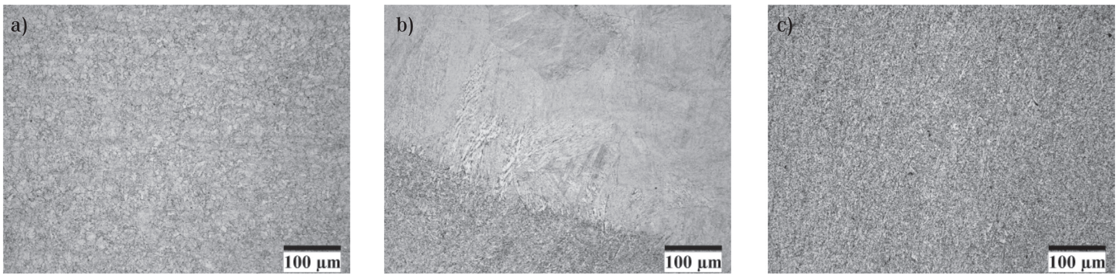

Figure 11: Microstructure of Hy-6, a) base material, b) HAZ, c) weld metal

eters on mechanical properties of gas metal arc welded HY-80 steels can be drawn:

1. The experimental results obtained were satisfying in comparison with the results of literature related to HY-80 steels. In tensile test, all sample parts fractured in the base material. All fractures were ductile. This indicates that the deformation capabilities of structures welded from these materials can be sufficient. At the same time, it was found out that the strength of both, weld metal and HAZ, was higher than that of the base material.
2. In the Charpy V-notch test, the effect of notch was investigated and the data of toughness of joints were measured. The results of impact toughness test realized at room temperature were lower compared to them of the base metal, nonetheless, it is normal for such a type of welded steel.
3. The HY-80 steels show a good weldability when using appropriate welding parameters without the need of heat treatment. In all tensile tests of welded samples, breakings were from the base material. This result must be taken into account with respect to welding design when a weld metal having a higher yield strength than the base material is needed.
4. The welding parameters have an evident effect on the toughness and hardness of the welds. The hardness of the welded joints by using various welding parameters (welding speed, filler metal, welding groove, shielding gas mixture rate and material thickness) were lower than that of the reference material. Nonetheless, welding of samples with standard and equal parameters revealed a high ultimate tensile strength. A hardness with higher values than the base material was measured in HAZ. HAZ creates a transition zone for the material quality and represents also a critical zone at which microcracks can occur. An appropriate tempering pass technique can prevent an increased hardness in this zone.
5. As a general rule, hardening in the weld joint is determined by the maximum in HAZ. According to the IIW IX commission report, HAZ hardness shall not exceed 350 HV, otherwise additional precautions must be taken. The hardness data measured in this research are seen to be near to this measurement.
6. Microstructural investigations exhibited that the base metal has a ferritic-perlitic structure with fine grains. Martensite needles and bainite have been observed in the HAZ. The weld metal shows martensite needles, partial bainite and residual austenite.

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11 B. K. Show, R. Veerababu, R. Balamuralikrishnan, G. Malakondaiah: Effect of vanadium and titanium modification

Abstract

Auswirkungen der Schweißparameter auf die mechanischen Eigenschaften von MAG-geschweißten HY-80-Stählen. In dem vorliegenden Beitrag werden Untersuchungen von HY-80-Stählen beschrieben, die mittels Schutzgasschweißens unter Verwendung verschiedener Schweißparameter verbunden wurden. Hierzu wurden verschiedene Proben aus den Schweißverbindungen mechanischen Prüfungen, wie Zugversuchen, Härtemessungen und Kerbschlagprüfungen, unterworfen. Die Ergebnisse der Zugversuche zeigten, dass die Festigkeit des Schweißgutes und der Wärmeeinflusszone höher als die des Grundwerkstoffes war. Für das Schweißgut und die Wärmeeinflusszone wurden ähnliche Ergebnisse in den Charpy-Versuchen erzielt. Die Härte des Schweißgutes war nahezu gleich hoch wie im Grundwerkstoff, aber die Wärmeeinflusszone wies höhere Werte auf. Der Grundwerkstoff hatte eine feinkörnige ferritisch-perlitische Mikrostruktur. In der Wärmeeinflusszone wurden Martensitnadeln und Bainit ermittelt. Das Schweißgut weist Martensitnadeln, teilweise Bainit und Restaustenit auf.

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