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Metallurgy and mechanical properties variation with heat input,during dissimilar metal welding between stainless and carbon steel

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Abstract. The present research focus on the metallurgy and mechanical aspect of dissimilar metal welding.One of the common parameters that significantly contribute to the metallurgical aspect on the metal during welding is heat input. Regarding this point, in the present research, voltage, current and the welding speed has been varied in order to observe the effect of heat input on the metallurgical and mechanical aspect of both welded metals. Welding was conducted by Gas Metal Arc Welding (GMAW) on stainless and carbon steel with filler metal of ER 309. After welding, hardness test (micro-Vickers), tensile test, macro and micro-structure characterization and Energy Dispersive Spectroscopy (EDS) characterization were performed. It was observed no brittle martensite observed at HAZ of carbon steel, whereas sensitization was observed at the HAZ of stainless steel for all heat input variation at the present research. Generally, both HAZ at carbon steel and stainless steel did not affect tensile test result, however the formation of chromium carbide at the grain boundary of HAZ structure (sensitization) of stainless steel, indicate that better process and control of welding is required for dissimilar metal welding, especially to overcome this issue.

1. Introduction

Dissimilar metal welding can be found in various industries, such as automotive industry, air craft, electric generator, oil and gas, etc. Practically, dissimilar metal welding involving various metals such as between carbon steel and stainless steel [1], TWIP and TRIP steel [3], steel with high strength to weight ratio [6], aluminum and stainless steel [7], duplex and austenitic stainless steel [11], etc.

Apart of its wide applications, there are several remaining problems that need to be solved. Among these problems including unmixed composition at the fusion boundary [1], different microstructure characteristic at the weld interface of different metal [2], brittleness [3], macro segregation [8], corrosion [11], etc. Therefore several works need to be performed such as study on fluid flow of metal melting and element transport process during dissimilar metal welding [1,10]. Other matters that

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become concern are mixing characteristic of two different metals during welding including microstructure, composition, hardness at the fusion [1,2,3,10], tensile strength [3], corrosion [11], effect of heat treatment before and after welding [6], and heat input [2,3,4,12].

Regarding heat input, welding parameter that related with this value is current, voltage, welding speed [3] and applied current mode [4]. For the case of welding on stainless steel, variation on heat input might affect the thickness of carbide layer on the weld interface [2]. Heat input also can influence microstructure and the size of welding nugget and therefore influence the mechanical properties of the weld. Based on the above facts the present paper describes several characteristics on dissimilar metal welding between carbon steel and stainless steel using gas metal arc welding (GMAW) method, with heat input as the variable parameter.

2. Experimental Method

Carbon steel and stainless steel used as the based metals in the present research are ASTM A53 and AISI 304 respectively, whereas weld/filler metal used is AISI 308. Before the process, based metals were prepared by cleaning, grinding and polishing, therefore homogeneous surface can be obtained before the process.

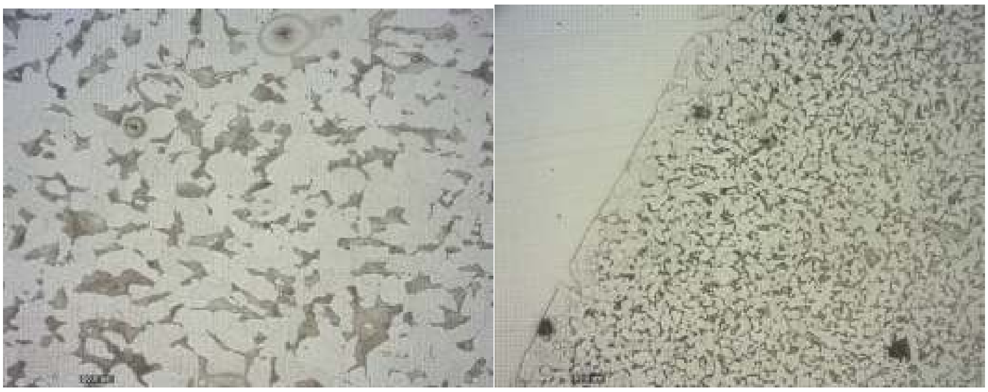
Welding processes were performed by gas metal arc welding (GMAW) method. In order to establish variation on heat input, welding current and voltage were varied at 105-190A and 18.5-25V respectively. The welding speed was also varied at around 0.4mm/s up to around 1mm/s. This variation resulted in the variation of heat input from around 0.4 kj/mm up to 1kj/mm.

After welding, evaluation on the microstructure, macrostructure, composition profile at HAZ and fusion area, hardness and tensile strength were performed. Comparison of microstructure resulted at HAZ and fusion area at both different metals were performed based on these data.

3. Results and Discussion

Figure 1 shows typical microstructure of base metal carbon steel and its HAZ. It can be seen both figure showing pearlite structure, a structure in steel containing ferite (white feature) and cementite (dark feature) phases. However for the case of HAZ structure shows finer structure than the base metals. This fact also shows that the present welding processes did not create martensite phase, which normally induce in the brittleness at this area as well as corrosion problem. The HAZ area for carbon steel in the present research reaching more than 1.5 mm in width as can be seen in the Figure 2. Based on these data, it can be expected that HAZ of carbon steel were not negatively affected by the welding process.

On the other hand Figure 3 (a) shows typical microstructure obtained at the base of stainless steel and its HAZ area. It can be seen the base area showing austenite phases with twinning structures, typical microstructure for austenitic stainless steel. In addition Figure 3(b) shows typical HAZ microstructrure of stainless steel obtained in the present research and it was observed that sensitization occur on this steel. The appearance of this microstructure is due to the formation of chromium carbide at the grain boundary of austenite at temperature between 500-850^{o}C, leaving the area around the grain boundary poor with chromium and therefore susceptible to corrosion attack. This microstructure is appeared as darker grain boundary as compared with common austenite phase as can be seen in the figure. The area of sensitization at HAZ area of stainless steel reaching within 100-150μm. Therefore the HAZ area is significantly narrower than carbon steel, however for the carbon steel with no appearance of harmfull phase, whereas for the case of stainless steel with the appearance of sensitization.



(a) (b)

Figure 1 Microstructure of Based metal carbon steel (a) HAZ of carbon steel (b)

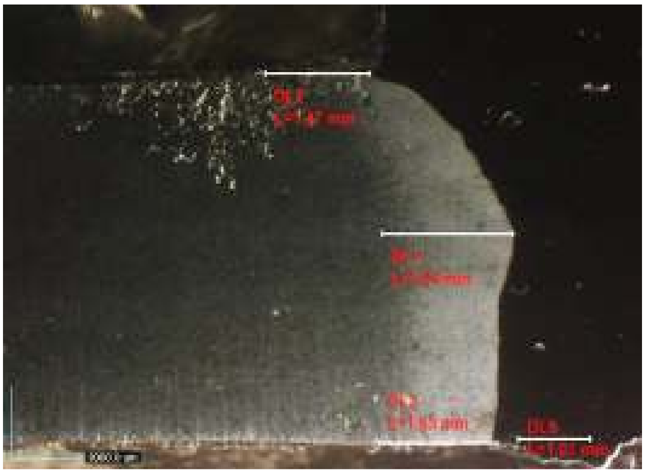
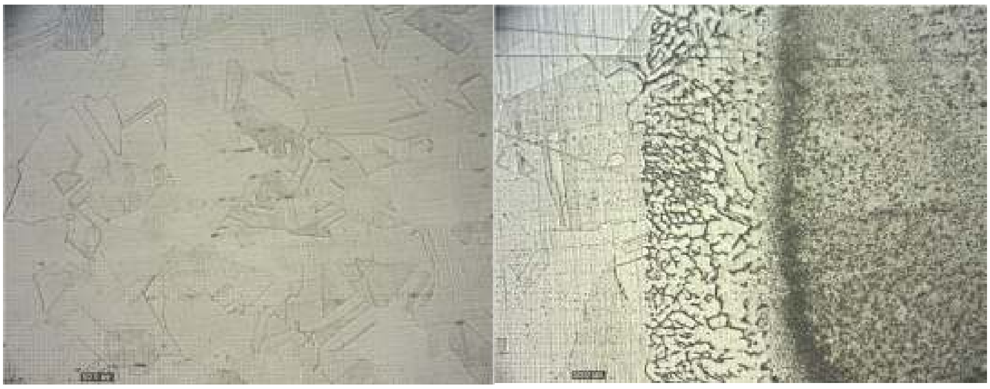


Figure 2. Macro figure of base metal and HAZ of carbon steel



(a) (b)

Figure 3 Microstructure of based metal (a) stainless steel (b) and HAZ area

Figure 4 shows the effect of heat input on the tensile strength of welded samples. It can be seen that initially there is an increasing of tensile strength with increasing of heat input, however after heat input reaching around 1kJ/mm it tends to be stable. Another point to be noted is, none of the sample fracture at the weld or HAZ area, indicating that the samples have been well welded and microstructure resulted at the HAZ area did not cause in early or catasthropic failure during the test. From the microstructure of HAZ of stainless steel it was observed the appearance of sensitized structure. However eventhough this structure might create brittleness as well as susceptible to corrosion, data from tensile test show that it did not significantly affect on the strength of the welded sample.

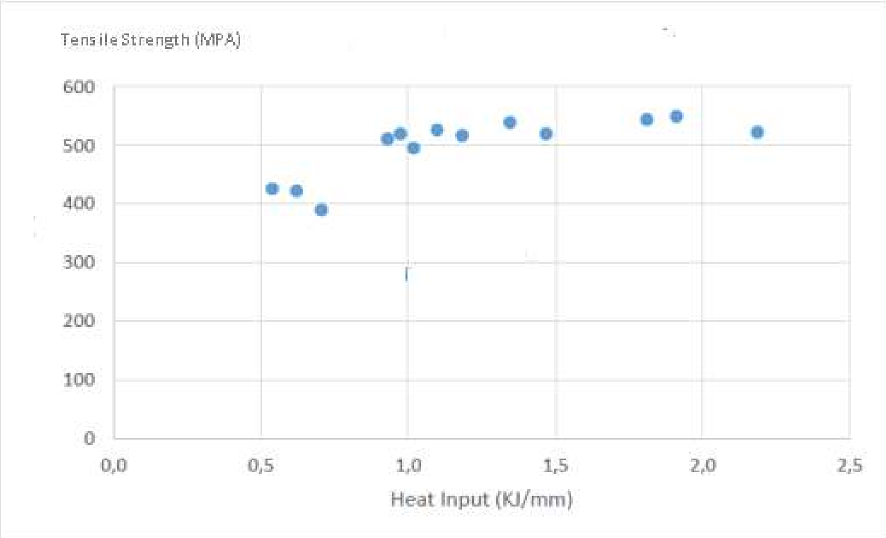


Figure 4 Effect of heat input on the tensile strength

Figure 5 shows hardness of various samples with different heat input. For each samples it can be seen that welded area showing the highest hardness, which is considered more due to different steel grade. Higher hardnesses were found at both HAZ of carbon steel and stainless steel as compared with their based area for all samples. For the case of carbon steel, eventhoughmartensite structures were not resulted at the HAZ area, however finer pearlite structure as can be seen in the Figure 1 causing higher hardness as compared with the based area. On the other hand, for stainless steel, higher hardness at the HAZ area are resulted from the finer structure as well as due to the formation chromium carbide at this area.

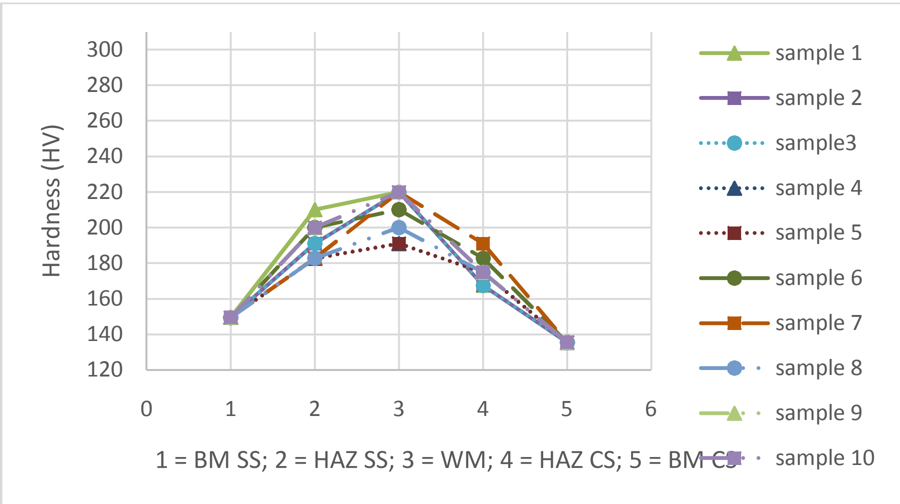
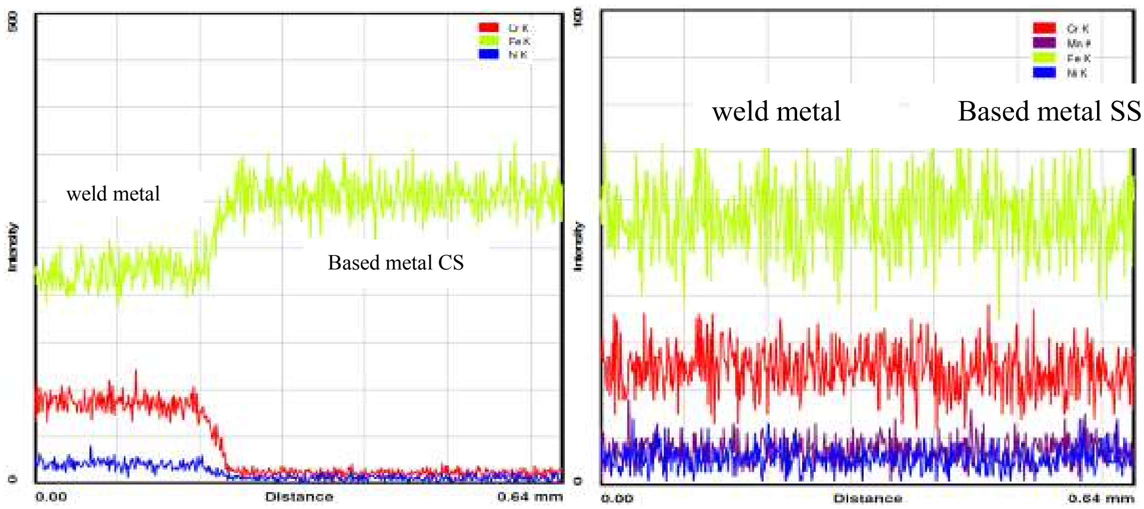


Figure 5 Hardness at based metal (BM), HAZ of stainless steel(SS) and carbon steel (CS), and weld metal (WM)

In addition Figure 6 shows common composition line data by energy dispersive spectroscopy (EDS) characterization method, obtained in the present research. It can be seen from Figure 6(a) gradation of elemental composition of Fe, Ni and Cr from the weld to the based metal of carbon steel. Since Ni and Cr were not observed in the single based metal characterization, therefore it can be concluded that there is significant diffusion of Ni and Cr from the weld to the carbon steel based metal. On the other hand, no significant diffusion was observed from based metal of stainless steel to the weld area and vice versa.



(a) (b)

Figure 6 Line EDS data of CS and weld area (a) ; SS and weld area (b)

4. Conclusions

Several characterizations have been performed on the dissimilar welding sample between carbon steel and stainless steel. Generally finer pearlite structure was obtained at the HAZ of carbon steel with no appearance of martensite phases, whereas sensitization was observed at the HAZ of stainless steel. Due to these structure both HAZ of carbon steel and stainless steel show higher hardness than their based metals. From tensile test data it was obtained that no negative effect from the HAZ and weld structure on the tensile test results. From the present resulted, it can be concluded that controlling welding process to avoid sensitization in the HAZ of stainless steel is more difficult than martensitic transformation in the HAZ of carbon steel. Therefore this condition still be remaining challenge to be solved for further research.

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