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The Effect of Shielding Gases on the Microstructure and Thoughness of Stainless Steels Weldments by FCAW

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Abstract

In this study AISI 316 types of austenitic stainless steels were welded by FCAW (flux cored arc welding) using ER 316L flux cored filler metal under various shielding gas compositions such as Ar + 12% CO_2, Ar + 20% CO_2, Ar + 50% CO_2 and 100% CO_2 gases. The aim of the current study is that effects of shielding gas compositions on the microstructure and toughness of AISI 316L austenitic stainless steels weldments were investigated. Charpy V notch impact tests were carried out at 0^oC temperature. The results were indicated that the shielding gas compositions have an influence on toughness values. The study showed that variation of those values depended on δ-ferrite content in the weld metal. δ-ferrite content decrease with increasing CO_2 percentages in the shielding gas. Decreasing δ-ferrite rate in the weld metal have negative effects on the toughness values of the weldments.

Keywords: *Austenitic stainless steel, AISI 316, impact toughness, FCAW, microstructure, shielding gas,*

1. Introduction

The austenitic stainless steels (Fe-Cr-Ni) have excellent mechanical properties and corrosion resistance [1-3]. Due to having combine properties, their usage in various applications such as storage tanks, pipe, and pressures vessel valves, pumps, distiller etc have been increasing. Better strength, toughness and formability are required for this kind of applications mentioned above [4]. 300 serious austenitic stainless steels are most popular steels and their most important and conspicuous properties are their excellent toughness and corrosion resistance [1-4]. Due to austenitic stainless steels having fcc structure, they have higher toughness values. A higher notch toughness values and it is almost independent from temperature, thus brittle structure does not occur like low carbon steels having bcc structure, and is strongly temperature dependent. Austenitic stainless steels maintain their higher notch toughness even at cryogenic temperature (5-8). The mechanical properties of austenitic stainless steels provide an excellent combination of better strength, ductility and toughness over a broad temperature range compare with notch impact toughness of low carbon steels (4-6).

AISI 316L grades austenitic stainless steels also retain their strength advantage over the AISI 304 grades at elevated temperatures. AISI 316L austenitic stainless steels contain molybdenum and make it resistant to a wide range of corrosive environments. Most of the austenitic stainless steels grades lie in the 300 serious. Some alloying elements modified grades to provide special properties required for certain industrial applications. AISI 316L grades austenitic stainless steels contain 2-3% molybdenum, which is added to increases corrosion resistance and allow usage of this materials at high temperatures (1, 2).

The gas-shielded arc welding methods are generally classified in to two methods such as solid wires and flux-cored wires (FCAW). Usage of FCAW is increasing year by year because of its workability and efficiency. FCAW method is suitable for mechanization and robotization and easy for applying, thus provide efficiency and speedy during welding process of the sheets having high thickness (6, 9-12).

FCAW method have received great attention from welders and contractors recently compare to conventional GMAW because flux cored wire have a lot of advantages such as outstanding productivity, deep penetration, spatter reduced welding behavior, higher deposition rates and high welding speed (11, 12). In the welding process, a shielding gas is used to protect molten metal from negative affection of atmospheric nitrogen and oxygen as the weld pool is being formed. The shielding gas also provides a stable arc and uniform metal transfer during welding process. In addition to that the quality, deposition rates, productivity, surface appearance and efficiency of the welding are strongly dependant to shielding gas used (13-16). Microstructure and mechanical properties have been influenced by composition of shielding gases used during welding process. CO_2 is most frequently used in the FCAW process as the shielding gas (6). CO_2 and argon in various mixtures is also used. The selection of the shielding gas is crucial for obtaining optimal properties of the weldment. Therefore, number investigations have been performed regarding the affection of the shielding gas composition on mechanical properties of austenitic stainless steel weldments (5, 6, 13-16). Nevertheless, just a few studies about gas composition on microstructure and mechanical properties of weldment by FCAW are available in the literature.

Determination of mechanical properties such as hardness variation, impact toughness and tensile strength and fatigue etc. of the construction made from austenitic stainless steel weldments is crucial for safety using. Those constructions can be exposed dynamic load during working in various applications, therefore, impact toughness behavior become more important under different working condition such as temperature and environment.
The present study investigates the influence of shielding gas composition on the notch impact toughness of AISI 316L austenitic stainless steels. Four different gas compositions were used. Optical and scanning electron microscopy studies and hardness measurement were also carried out.

2. Experimental Procedure

AISI 316L grades austenitic stainless steels were used in this study. E316LT1-1/4 flux cored wire with diameter of 1.2 mm was used grades austenitic stainless steels as a filler material. The chemical composition of base materials and filler materials were given in Table 1. Those AISI 316L grades austenitic stainless steels plates were prepared for joining of FCAW with dimension of 400 (l) x150 (w)x 10 (t) mm^3. V shaped grove were used and three passes of FCAW were performed using ceramic substrate as well. Butt joint configuration was used.

Table 1. Chemical compositions of base and filler material used

Elements	Base Metarial wt(%)	Consumable wt(%)
C	0.015	0.028
Si	0.460	0.60
Mn	1417	1.50
P	0.038	0.021
S	0.006	0.008
Cr	18.01	18.35
Ni	9.66	12.65
Mo	2076	2.68
Cu	0.433	-
Nb	0.018	-
Creq	20.10	21.93
Nieq	12.49	14.24

The plates were joined firstly in the root pass later second pass and then third cover pass, respectively. A schematic diagram of welded plate is shown in Figure 1. Welding process were carried out under four different shielding gases such as 12% CO_2 + 88% Ar (C1), 20% CO_2 + 80% Ar (C2), 50% CO_2 +50% Ar (C3) and 100% CO_2 (C4) with gas flow rate of 20 lt/min. Interpasses temperature keeps below 150^{o}C due to lower thermal conductivity of austenitic stainless steels.

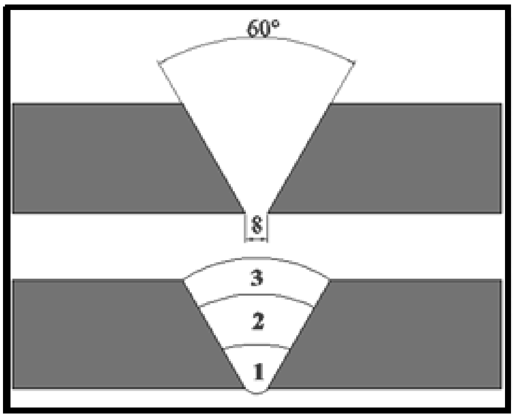


Figure 1. Scheme of joint preparation of FCAW weld, V shaped grove design and number of welding passes

The welding parameters were shown in Table 2. The welding parameters used were selected according to suggestions of product catalogue prepared by flux cored wire consumable producer and experiences obtained earlier. As seen from the table, welding current and voltage were between 185-222 and 24-26 volt respectively. Oscillation was also applied during welding as welding equipment photographically shown in Figure 2. This welding system provides the same welding condition during welding process of all the weldments.

Table 2. Welding conditions and parameters used

Passes	Current (A)	Voltage (V)	Gas flow rate (l/min)	Oscillation (cm)	Welding speed (cm/min)	Heat input (kJ/cm)
1	185-205	26,4 - 26,6		0,8	12,4	21,1
2	189-205	25,4 - 25,6	20	1,2	16,1	15,6
3	216-222	25,7 - 26		1,9	15,6	17,7

The specimens for impact test and microstructural examination were extracted from the welded plates. The specimens for Charpy test were taken as perpendicular to weld direction. The tests were performed at the temperature of 0^{o}C. Microhardness measurements were carried out across the weld metal and base metal and 300 g load was used during measurements. Microstructural examination was carried out on cross section of the weldments. The specimens were mounted later flatted and then grounded using SiC abrasive paper with grit ranges from 180 to 1200. Then the sample were then lightly polished using 1 μm alumina slurry. Samples were then washed, cleaned by alcohol and then dried, followed by electrolytic etching in 10 % oxalic acid at 9v for 30 s. Optical examination samples were performed using a Nikon Elipse L 150 model optical microscopy. Scanning electron microscopy (SEM) was used for examination of fracture surface after impact test. Chemical composition of weld metal was determined by using Faundry Master Spektrometre. Ferrite numbers of the weld metal were measured using ferrite-scope equipment.

Figure 2. The assembly of welding equipments, preparation and performing of the welding

3. Results and discussion

It is not observed any spatters generated under all gas composition except the gas of 100% CO_2 which generates few little spatters. This indicates that a stable arc is obtained under all the gas composition. Better weld bead appearance were obtained after FCAW process as seen in Figure 3 which is pointed out that FCAW process provides better appearance and weld quality. As mentioned in earlier investigation by Liao and Chen (5, 6), the spatter rates increase with increasing CO_2 content in the shielding gas composition. Higher CO_2 content causes formation larger and numbers of spatter particles. Actually the spatter rate is increased by oxygen potential of shielding gas. Of course, an increase of CO_2 content in the shielding gas naturally resulted from increasing oxygen potential of the gas. This study also show that FCAW method provide better welding and less spatter rates compared with the other methods such as gas metal arc welding (GMAW) using solid wire (5, 6). The reason why lower spatter rate obtained during FCAW welding process is that cored wire included slag made powder and flux provide formation of little and less drops by changing metal transfer mode during the welding process. Welding current during FCAW process with flux cored wire has lower values than that of GMAW process with solid wire (17). The difference between the values is about 20A that is also support little and less spatter occurrences. The ferrite numbers in the weld metal were measured. The effect of CO_2 content in the shielding gas on ferrite is shown in Figure 4. The ferrite content in the weld metal is decreased by increasing the amount of CO_2 in the shielding gas. Carbon is austenite stabilized elements and widened austenitic area in the weld metal [1]. The increase of CO_2 content in the shielding gas resulted in increasing amount of carbon in the deposited metal. Thus the ferrite number decreases, which provides larger austenitic area in the weld metal due to increasing of Ni equivalent value.

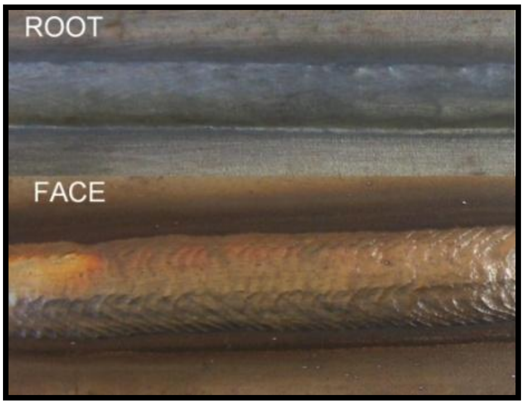


Figure 3. Appearance of the weldment by FCAW methods

Higher percentage of CO_2 resulted in higher oxygen potential therefore, consumption of Cr and Si increase due to oxidation, which causes lowering Cr equivalent value and narrowing ferrite area in the weld metal. The results obtained in this study are consisted with earlier literature (5, 6). The amount of delta-ferrite was estimated using Cr and Ni equivalent of the weld metal. δ-ferrite is solidified firstly and decrease crack sensation during cooling. The percentage of δ-ferrite in the weld metal was determined by Cr and Ni ratios. The other elements are also effective during cooling (18). According to earlier studies, about 2% and 3% volume ferrite prevents the weld metal from solidification cracking (7).

Table 3. Chemical compositions of the weldment and Cr and Ni equivalents

Elements	Wt(%)			
	C1	**C2**	**C3**	**C4**
	12%CO_2 88%Ar	**20%CO_2 80%Ar**	**50%CO_2 50%Ar**	**100%CO_2**
C	0,0221	0,0238	0,0246	0,0263
Si	0.638	0.599	0.568	0.544
Mn	1.33	1.35	1.24	1.16
P	0.023	0.021	0.022	0.025
S	0.0086	0.0086	0.0086	0.0086
Cr	18.24	18.14	18.04	17.55
Ni	12,03	12,27	12,54	12,78
Mo	2.82	2.75	2.69	2.65
Cu	0.109	0.0981	0.099	0.151
Nb	0.020	0.0176	0.0196	0.0153
Creq	21.074	20.902	20.744	20.211
Nieq	13,09	13,56	13,82	14,03

On the other hand, ferrite number of 4 is preferable for preventing hot cracking during the cooling of the weld metal. Sometimes, cracks may be seen in deep and narrow of weld metal during usage of the welding methods having higher heat input (16). The measured chemical composition of the weld metal is listed in Table 3.

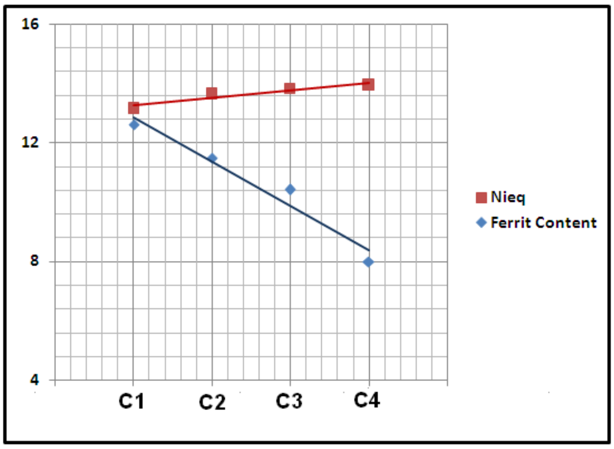


Figure 4. The affection of CO_2 in the gas composition on Nieq ve delta-ferrite values

As seen from the table, carbon and nickel content in the weld metal increase with increasing of the CO_2 content in the shielding gas. It is well known that nickel and carbon are strong austenite stabilize elements. Therefore, the effect of CO_2 increase resulted in decreasing $Cr_{eq.}$ on the other hand, increasing of Ni_{eq}. In addition to that, an increase of CO_2 percentage in the gas increases consumption of Cr, Si and Mn (4).

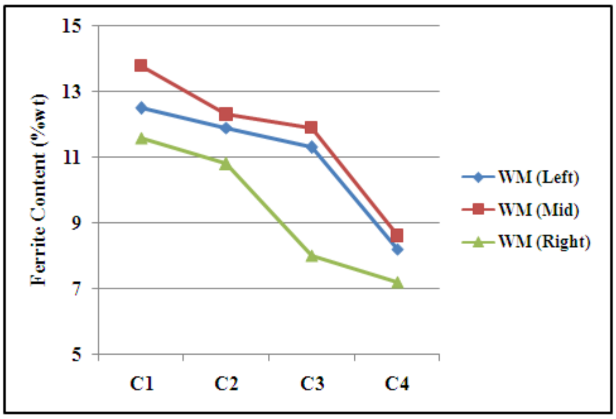


Figure 5. Variation of % wt content of ferrite in the weld metal

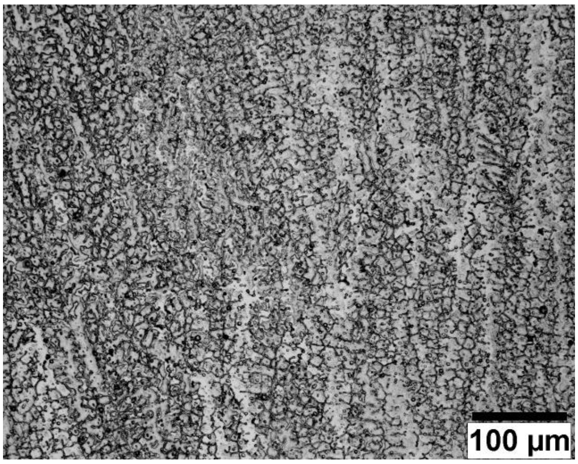
The amount of δ-ferrite in the weld metal is calculated using the composition of base and filler metal according to Cr_{eq} and Ni_{eq} WRC-92 diagram. The calculation of δ-ferrite ratio is arrange from 4,2 % to 9,5 % however, those are estimated values. Ferrite-scope apparatus were used for measurement of ferrite content in the weld metal. The amount of δ-ferrite was measured in every single pass of the weldments.

Table 4. %wt ferrite amount of the weld metal obtained by ferrite-scope measurements.

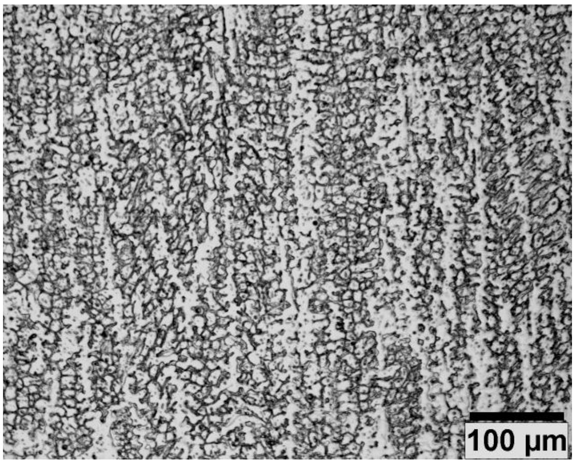
	Ferrite Content			
Shielding Gases	WM (Left)			
	1. pass	2. pass	3. pass	Av.
C1	12,5	12,3	12,7	12,5
C2	11,7	12,1	11,9	11,9
C3	10,9	11,2	11,7	11,3
C4	6,7	9,0	8,8	8,2
	WM (Mid)			
	1. pass	2. pass	3. pass	Av.
C1	14,2	12,1	15,1	13,8
C2	12,0	12,3	12,7	12,3
C3	11,6	12,4	11,8	11,9
C4	6,1	8,5	11,3	8,6
	WM (Right)			
	1. pass	2. pass	3. pass	Av.
C1	10,9	10,6	13,2	11,6
C2	10,5	10,9	11,0	10,8
C3	7,1	8,2	8,8	8,0
C4	6,2	7,6	7,8	7,2

The results are listed in Table 4. Figure 5 also shows that delta-ferrite percentage in the weld metal changes depending on the content of carbon in the shielding gas.

Optical microscopy studies were shown in Fig 6 (a-d). These micrographs were taken from the weld metals. It is clearly seen that δ-ferrite rates decreases with the increasing of CO_2 content in the shielding gas. This situation was discussed earlier. Both dentiritic and laty ferrite morphology is present in the microstructure. As mentioned by Liao (5, 6), dentiritic ferrite can occur due to peritectic solidification wile laty ferrite can occur because of dissolution of ferrite during cooling.



a)



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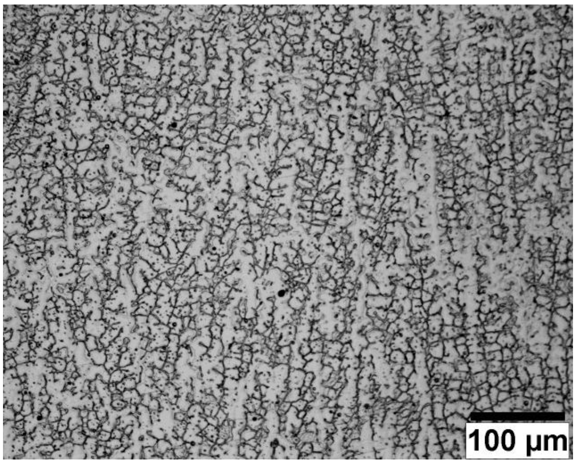

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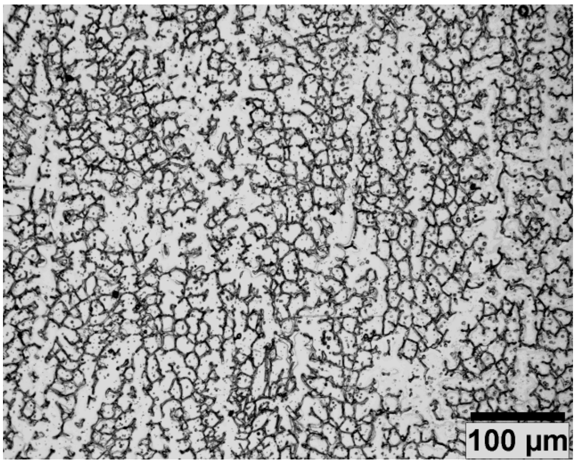

d)

Figure 6. Optical micrographs of the weld metal of AISI 316L weldment under a) 12%CO_2 + 88%Ar, (C1) b) 20%CO_2 +80%Ar, (C2), c) 50%CO_2 + 50%Ar, (C3) d) 100%CO_2, (C4)

Impact test were performed at 0 ^{o}C in order to see the affection of carbon content on the toughness behavior. Obtained results are given in Figure 7. The impact energies are decreased with increasing CO_2 content in the shielding gas. It is consisted with earlier finding (5, 6).

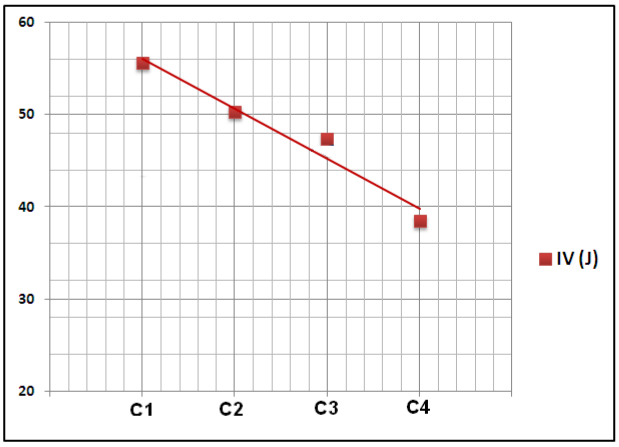

Figure 7. Variation of the notch impact energy values depending on CO_2 content in the shielding gas

It is thought that impact energy values are connected with delta-ferrite content in the weld metal. Higher delta-ferrite percentages increase the strength of the weldment. Therefore, it is also increase the impact energy values. It is also thought that the impact energy values obtained at 0^{o}C is lower than the values of obtained at higher temperatures. It is known that the has a fcc structure and delta-ferrite has bcc structures. Fcc structure has higher toughness values and temperature independence (5-8). On the other hand, bcc structure has lower toughness and strongly temperature dependence. Therefore, brittle fracture is seen at low test temperature. Figure 8 shows the fracture morphology of the sample welded using 100% CO_2 shielding gas. It shows ductile rapture. Impurities occurred in the microstructure due to increasing CO_2 percentages in the shielding gas may be resulted in reduction of the toughness values (5).

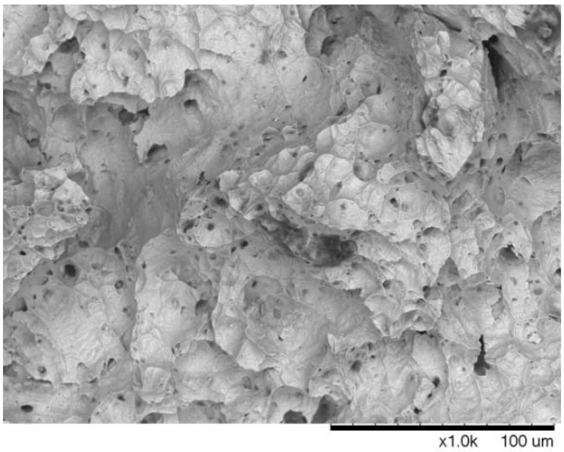

Figure 8. Fracture morphology of SEM images of the samples welded under 100%CO_2 shielding gas

The hardness variation across the weld and base metal of the weldments were shown in Figure 9. The result of hardness measurements approve the results obtained from impact tests and microstructure studies.

Microhardness values increases with increasing δ-ferrite content in the weld metal. Consequently, increase in CO_2

content in the gases resulted in lowering hardness values of the weld metals.

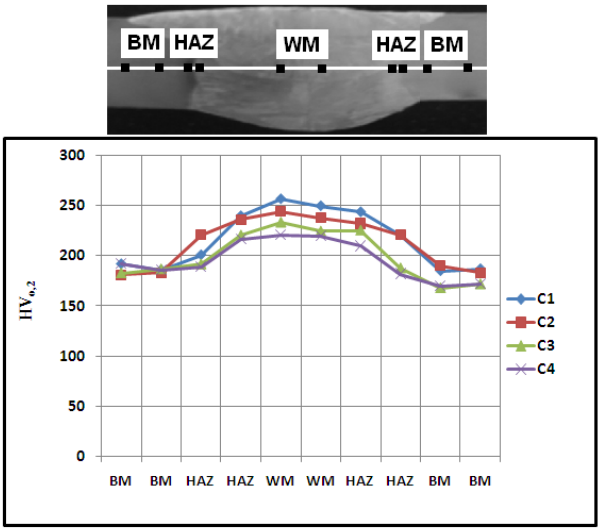

Figure 9. Microhardness variation across the weldments

4. Conclusions

In this study, AISI 316L austenitic stainless steels were welded by FCAW. The following conclusions can be drawn from the experimental results:

1. AISI 316L austenitic stainless steels were welded by FCAW using various gas composition. Any spatter problems were not meet during the welding process.
2. Carbon percentage in the weld metal increases with increasing of CO_2 content of the shielding gas, which causes a decrease of ferrite amount and an increase in austenite area.
3. Usage of various gas compositions during FCAW process resulted in difference in hardness values of the weld metals. It is attributed to ferrite content in the weld metal.
4. Spectroscopy analysis shows that difference in gas composition have a great influence on changing chemical composition of the weld metal. Some elements such as Cr, Si and Mn may be decreased depending on CO_2 content in the gas composition due to oxidation of those elements.

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