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Comparative analysis of electrode, preheat, and interpass combination in dissimilar GMAW welding of bisalloy 400 steel and SM490YA material on hardness and micro structure

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Abstract

A construction company produced a side-dump type trailer used to transport coal, but it suffered damage in the form of cracks in the welding joints on the floor. The weld joint uses two different materials, Bissalloy 400 and SM490YA steel. This study aims to analyze the damage and repair it using appropriate electrodes, preheating, and interpass temperature, which affect the hardness and microstructure of both materials. The hardness test results showed that the highest value reached 385 HVN. Increasing the preheat and interpass temperatures was found to decrease the material's hardness. Microstructure analysis revealed phase changes in the weld metal, including mixing of martensite phase, ferrite phase, and pearlite phase. The use of a buffer layer between dissimilar materials proved effective in reducing the risk of cracking and deformation. This research confirms the importance of selecting appropriate welding parameters to improve joint quality in materials with significant carbon equivalent differences.

1. Introduction

The case is the presence of defects in the welding joint in the form of cold cracks on the floor side of the dump trailer, which is the result of welding between different materials, namely Bisalloy 400 and SM490YA. Further research was conducted to analyze the variation of preheat and interpass temperatures, as well as the combination of electrodes used in welding these different materials, with the aim of creating welding parameters that can overcome these problems. In addition, the welding process does not have qualifications and preparation methods that are used as a reference in the construction of side dump trailers.

In the previously discussed case, the welding process used was GMAW with ER70S-6 filler metal. Because of the lower tensile strength of the filler metal compared to the base metal, the filler metal was replaced with ER80S-G. The selection of ER80S-G filler metal is based on its higher tensile strength than the base metal. Bisalloy 400 steel has a carbon equivalent (CE) content higher than 0.4%, which is 0.499%, so special treatment is required to improve weldability. Meanwhile, SM490YA has a lower CE of 0.37%. This significant difference in CE necessitates the use of a buffer layer as a shield between the two materials. Such CE differences can cause variations in thermal properties, such as cooling rate and thermal expansion, which in turn can lead to residual stresses.

The buffer layer serves to absorb and distribute stress, thereby minimizing the risk of cracking or deformation. In addition, the buffer layer also plays a role in gradually reducing the difference in chemical composition between the two materials. This helps create a more homogeneous weld joint and reduces the likelihood of problems such as cracks or incomplete fusion. By understanding the chemical composition of the structures, we can evaluate the effect of selecting ER80S-G and E309L electrodes, as well as the changes in hardness and microstructure due to the preheat and interpass.

2. Research Methods

In this study, welding was carried out using Bisalloy 400 steel material which was connected to HSLA SM490YA steel measuring 400x250x20 mm. The welding process uses the Gas Metal Arc Welding (GMAW) method with variations in preheat and interpass temperature parameters, as well as electrode combinations. Overall, there will be 6 specimens for testing. Details of the specimens and welding parameters shown in Table 1.

Table 1. Welding Parameters

No.	Filler Metal	Preheat	Interpass	Position
1.	ER80S-G	30°C	250°C	1G
2.		75°C	175°C	
3.		75°C	250°C	
4.	ER80S-G + E309L	30°C	250°C	
5.		75°C	175°C	
6.		75°C	250°C	

The materials are joined using a single V groove type joint with a 60° angle. The filler metal used is ER80S-G, while the filler for the buffer layer uses E309L. After the welding process is complete, the test coupon will be cut according to the AWS D1.1 code and then used as a specimen for testing. The tests carried out are hardness and microstructure tests.

3. Results and Discussion

Hardness testing is one type of destructive testing that aims to determine the level of material hardness due to welding or other treatment processes, as well as to check other mechanical properties. Hardness testing is carried out using the Vickers (HVN) method using a load of 2 kgf and a loading time of 10 seconds. Micro-etching tests were conducted to observe the shape of the microstructure after the welding process. In addition, micro testing also aims to see the microstructure of the material formed due to phase changes during the welding process.

3.1 Hardness Test Results

The hardness points shown in Fig. 1. were taken as many as 51 points in 3 variations, namely 6 points in the upper base metal area, 6 points in the middle base metal area, 6 points in the lower base metal area, 5 points in the upper weld metal area, 5 points in the middle weld metal area, 5 points in the lower weld metal area, 6 points in the upper HAZ area, 6 points in the middle HAZ area, and 6 points in the lower HAZ area. For the next variation, 57 hardness points were taken in 3 variations, namely 6 points in the upper base metal area, 6 points in the middle base metal area, 6 points in the lower base metal area, 5 points in the upper weld metal area, 5 points in the middle weld metal area, 5 points in the lower weld metal area, 6 points in the upper HAZ area, 6 points in the middle HAZ area, 6 points in the lower HAZ area, 2 points in the upper buffer layer area, 2 points in the middle buffer layer area, 2 points in the lower buffer layer area.

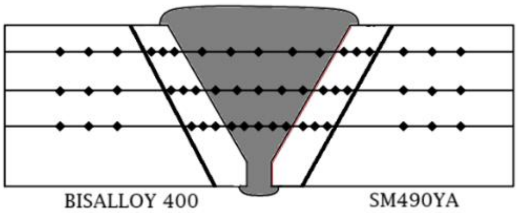


Fig.1. Indentation Point of Hardness

3.1.1 Hardness Testing Variation 80A

The 80A variation specimen using the ER80S-G electrode, as well as the preheat variation of 30°C and interpass of 250°C, showed the hardness values listed in Table 2 and Fig. 2.

Table 2. Hardness Test Value 80A Variation

Results of Hardness Value Collection						
Number of Points		WM	BM BIS	BM SM	HAZ BIS	HAZ SM
A	1	194,8	381,1	170,6	179,1	190,3
	2	167,5	380,7	146,3	184,1	174,5
	3	162,2	313,3	132,4	193,8	179,2
	4	171,9	-	-	-	-
	5	175,7	-	-	-	-
B	1	185,9	325,2	144,7	176,9	176,4
	2	169,1	347,6	145,4	176,8	166,7
	3	168,8	292,3	162	181,4	169,3
	4	168,4	-	-	-	-
	5	169,1	-	-	-	-
C	1	185	353,4	157	189	182,1
	2	181	339	146,2	199,8	163,1
	3	176,4	317,4	158,4	207,3	160,9
	4	163,5	-	-	-	-
	5	165,7	-	-	-	-

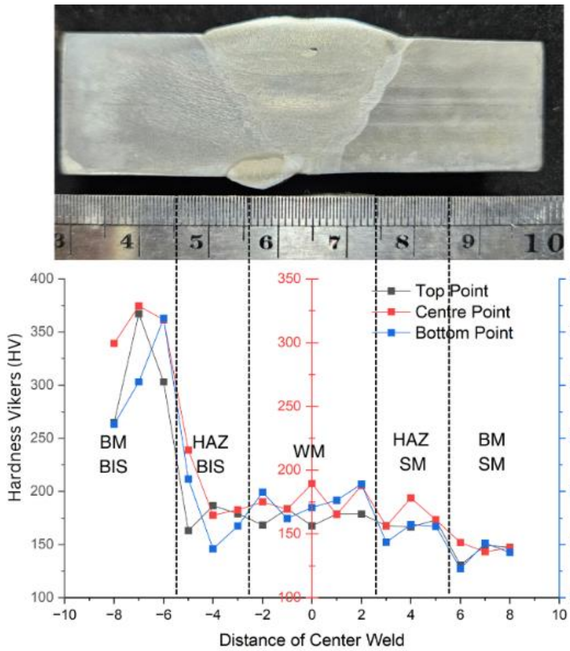


Fig. 2. Hardness Value Chart of Specimen 80A

In the 80A variation specimen, it is known that the highest hardness value is found in the Bisalloy 400 base metal (BM BIS) with a value of 381.1 HVN, while the lowest hardness is found in the SM490YA base metal (BM SM) with a value of 132.4 HVN. The hardness in the HAZ and weld metal areas showed almost similar values. In addition, the hardness of specimens that do not use buffer layer is also relatively the same.

3.1.2 Hardness Testing Variation 80B

Specimen Variation 80B with the use of ER80S-G electrodes and variations of 75°C preheat and 175°C interpass, has a hardness value presented in the form of Table 3 and Fig. 3.

Table 3. Hardness Test Value 80B Variation

Results of Hardness Value Collection						
Number of Points		WM	BM BIS	BM SM	HAZ BIS	HAZ SM
A	1	168,4	265	130,6	163,1	167,9
	2	183,6	367,2	149,4	186,6	166,6
	3	167,7	303,2	147,5	179,1	173,2
	4	178,9	-	-	-	-
	5	178,9	-	-	-	-
B	1	175,2	299,4	143,3	215,8	156,2
	2	169,4	328,9	136,1	164,8	178,2
	3	189,5	318	139,3	168,9	161,1
	4	165,3	-	-	-	-
	5	187,9	-	-	-	-
C	1	199,4	263,2	127,4	211,6	152,2
	2	174,5	303,2	151,3	146	168,9
	3	185	362,9	142,6	167,5	167,1
	4	191,7	-	-	-	-
	5	207	-	-	-	-

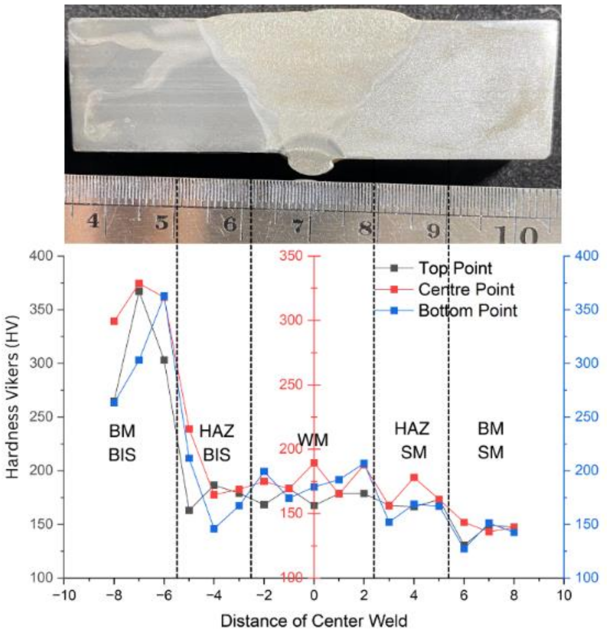


Fig. 3. Hardness Value Chart of Specimen 80B

Fig. 3. shown the highest hardness value is found in the Bisalloy 400 base metal (BM BIS) with a value of 367.2 HVN, while the lowest hardness value is found in the SM490YA base metal (BM SM) with a value of 127.4 HVN. The hardness values in the HAZ and weld metal areas are on average the same.

3.1.3 Hardness Testing Variation 80C

Variation 80C specimens with the use of ER80S-G electrodes and variations of 75°C preheat and 250°C interpass, hardness values presented in the Table 4 and Fig. 4.

Table 4. Hardness Test Value 80C Variation

Results of Hardness Value Collection						
Number of Points		WM	BM BIS	BM SM	HAZ BIS	HAZ SM
A	1	178,1	319,5	164,4	168,4	173,1
	2	183,4	274,9	151	165,4	168,8
	3	175,4	252,5	151,7	168,9	174,4
	4	183,7	-	-	-	-
	5	169,2	-	-	-	-
B	1	162,3	301,6	141,9	159,2	171,8
	2	161,2	278	147,9	182,5	163,1
	3	149,7	234,2	152,5	182,9	152
	4	167,7	-	-	-	-
	5	159,1	-	-	-	-
C	1	168,3	299,7	150,4	164,7	175,2
	2	157,5	286,4	137,1	178,7	185,5
	3	168,5	252,3	153	180,4	178,7
	4	158,7	-	-	-	-
	5	168,9	-	-	-	-

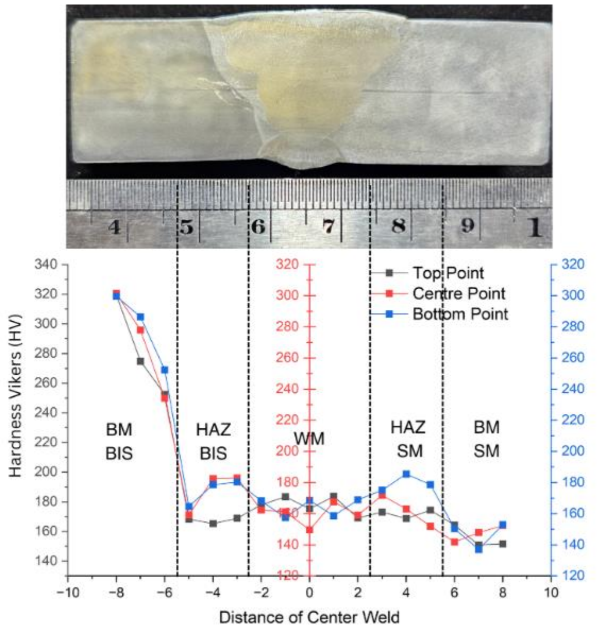


Fig. 4. Hardness Value Chart of Specimen 80C

Fig. 3. shown the highest hardness value was found in the Bisalloy 400 base metal (BM BIS) with a value of 319.5 HVN, while the lowest hardness was in the SM490YA base metal (BM SM) with a value of 137.1 HVN. The hardness in the HAZ region is generally higher than the previous two specimens, with an increase in hardness seen at the midpoint and bottom point of the HAZ region. In the weld metal region, the average hardness value remains consistent.

3.1.4 Hardness Testing Variation BFA

The BFA Variation specimens with the use of ER80S-G + E309L electrodes and 30°C preheat variation and 250°C interpass, hardness values presented in the Table 5 and Fig. 5.

Table 5. Hardness Test Value BFA Variation

Results of Hardness Value Collection							
Number of Points		WM	BM BIS	BM SM	HAZ BIS	HAZ SM	BF
A	1	296,2	354,1	152,4	193,4	177,5	223,9
	2	297,8	364,3	154	180,2	172	205,3
	3	273,3	385	163,9	173,4	162	-
	4	268	-	-	-	-	-
	5	240,6	-	-	-	-	-
B	1	265,9	342,6	145,1	148	166,8	236,2
	2	251,2	352,7	148,5	176,9	174,1	240,1
	3	257,6	319,8	153,8	143,1	168,4	-
	4	261,7	-	-	-	-	-
	5	245,4	-	-	-	-	-
C	1	292	320,4	146,9	178,4	169,3	298,6
	2	258	360,7	153,3	204,3	171,8	283,9
	3	285,6	376,5	156,8	166,7	170,7	-
	4	254,6	-	-	-	-	-
	5	255,2	-	-	-	-	-

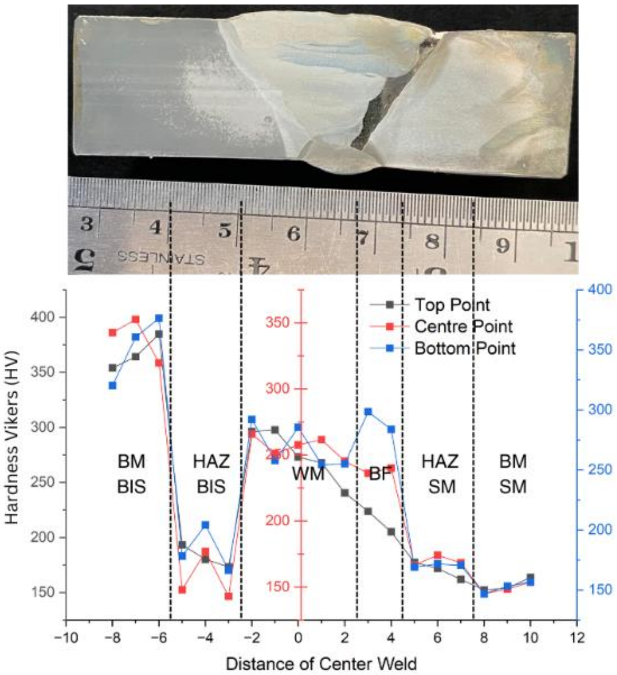


Fig. 5. Hardness Value Chart of Specimen BFA

Fig. 5. shown the highest hardness value was found in the base metal Bisalloy 400 (BM BIS) with a value of 385 HVN, while the lowest hardness value was in the HAZ (HAZ BIS) with a value of 143.1 HVN. The graph shows a significant increase in the weld metal (WM) and HAZ (HAZ SM) sections, where the average hardness value is similar to the HAZ BIS region. The largest increase occurred in HAZ SM, especially at the bottom point hardness measurement. In the HAZ BIS region, the hardness values tend to be similar to the BM SM.

3.1.5 Hardness Testing Variation BFB

BFB Variation specimens with the use of ER80S-G + E309L electrodes and variations of 75°C preheat and 175°C interpass, hardness values presented in the Table 6 and Fig. 6.

Table 6. Hardness Test Value BFB Variation

Results of Hardness Value Collection							
Number of Points		WM	BM BIS	BM SM	HAZ BIS	HAZ SM	BF
A	1	251,2	328,9	162	175,8	147,6	232,5
	2	259,1	260,2	160,5	182,9	148,2	221,5
	3	323,4	257,8	160,7	183,2	163,8	-
	4	380,7	-	-	-	-	-
	5	383,8	-	-	-	-	-
B	1	328,9	285,4	160,1	183	189	227,1
	2	358,6	351	150,2	175,3	169,6	226,1
	3	349,6	351	145,6	175,9	180,6	-
	4	349,3	-	-	-	-	-
	5	348,9	-	-	-	-	-
C	1	329,5	306,5	147,1	180,4	197,8	245
	2	327,6	307,6	145,4	183,7	161,6	241,2
	3	328,2	309,9	146,4	181,3	161,7	-
	4	325,2	-	-	-	-	-
	5	329,5	-	-	-	-	-

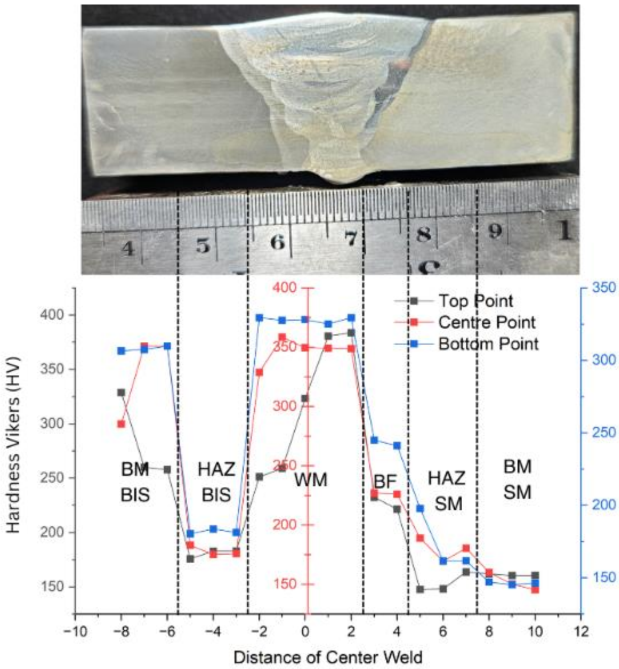


Fig. 6. Hardness Value Chart of Specimen BFB

Fig. 6. shown the highest hardness value was found in the weld metal (WM) with 383.8 HVN, while the lowest hardness was found in the HAZ SM with 147.6 HVN. The graph shows a significant increase in the weld metal (WM), which exceeds the hardness of the base metal Bisalloy 400 (BM BIS). Meanwhile, the hardness of base metal SM490YA (BM SM) and base metal Bisalloy 400 (BM BIS) is relatively consistent with the previous specimen results. For the BIS HAZ region, the hardness values are almost the same at all points (top, middle, and bottom), while in the SM HAZ, the lowest hardness value is found at the top point.

3.1.6 Hardness Testing Variation BFC

BFC Variation specimens with the use of ER80S-G + E309L electrodes and 75°C preheat variation and 250°C interpass, hardness values presented in the Table 7 and Fig. 7.

Table 7. Hardness Test Value BFC Variation

Results of Hardness Value Collection							
Number of Points		WM	BM BIS	BM SM	HAZ BIS	HAZ SM	BF
A	1	240,4	294,6	148,4	282,9	182,5	266,6
	2	238,9	280,2	150,7	287,4	189,1	268
	3	239,9	308,2	158,7	284,9	192,1	-
	4	237,4	-	-	-	-	-
	5	235,5	-	-	-	-	-
B	1	276,1	304,6	158,9	177,4	170,7	223,2
	2	273,7	294,1	160,6	176,9	172,6	223,6
	3	256,3	309,3	162,5	176,4	171,5	-
	4	255,4	-	-	-	-	-
	5	258,9	-	-	-	-	-
C	1	287,4	304,6	153,4	299,4	183,9	246
	2	222,7	294,1	153	307,1	175,1	254
	3	292	309,3	153,1	284,4	183,4	-
	4	218,6	-	-	-	-	-
	5	258,4	-	-	-	-	-

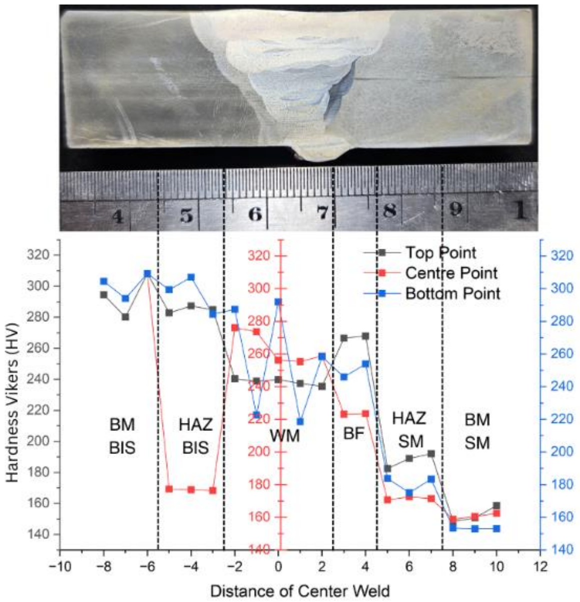


Fig. 7. Hardness Value Chart of Specimen BFC

Fig. 7. shown the highest hardness value was found in the base metal Bisalloy 400 (BM BIS) with a value of 308.2 HVN, while the lowest hardness was found in the HAZ SM with a value of 148.4 HVN. The graph shows a significant increase in the BIS HAZ, both at the top and bottom points, but the hardness value at the midpoint of the BIS HAZ tends to be low. In the weld metal (WM) region, the hardness at the middle and upper points is relatively stable, while at the lower points there are significant fluctuations. For the SM HAZ, the highest hardness value is at the top point, while the middle and bottom points have almost the same hardness value. In the SM490YA base metal, the hardness values tend to be evenly distributed.

The specimen test results show that the hardness values in the base metal, HAZ, and buffer layer are relatively similar, but significantly different in the weld metal region. The hardness in the weld metal region for variations 80A, 80B, and 80C tends to be low, while variations BFA, BFB, and BFC show higher hardness. During the welding process of specimens that use buffers, the cooling temperature after welding occurs faster than specimens that do not use buffers. This is in line with the function of the buffer, which is to regulate thermal conditions during the welding process.

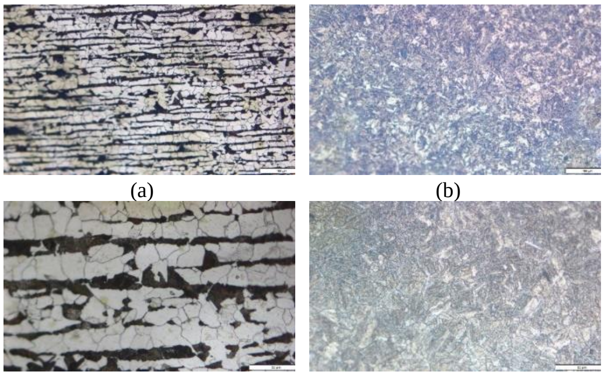
The highest hardness is found in the Bisalloy 400 base metal which contains the martensite phase, while the lowest hardness is found in the SM490YA base metal which is not affected by the preheat temperature. The 250°C interpass temperature has a slower cooling rate than the 175°C interpass temperature. The higher preheat temperature gives more time for the specimen to cool to the temperature required for the next weld. High preheat and interpass temperatures tend to reduce the hardness of the material.

3.2 Micro Structure

Micro etching testing aims to observe the microstructure of the material after the welding process. In addition, this test is also carried out to see changes in microstructure due to phase changes caused by the welding process. Microstructure observations were made in the base metal, fusion line, HAZ, buffer layer, and weld metal areas with 200x and 500x magnification to study in more detail the microstructure of the six specimen variations tested. The following are the results of microstructure observations of each specimen:

3.2.1 Microstructure Testing on Base Metal

The results of micro testing on the base metal Bisalloy 400 and SM490YA shown in Fig. 8.



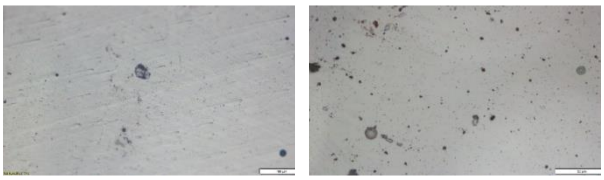
(a) (b) (c) (d)

Fig. 8 Microstructure of Base Metal
(a) SM490YA 200X Magnification; (b) Bisalloy 400 200X Magnification; (c) SM490YA 500X Magnification; (d) Bisalloy 400 500X Magnification

Fig. 8. shown the microstructure of the SM490YA base metal consists of ferrite and pearlite phases. Ferrite (α iron) is a metal composition with a maximum carbon solubility limit of 0.025% at 723°C, has a BCC (Body Centered Cubic) crystal structure, and at room temperature its solubility reaches 0.008% carbon. Pearlite is a eutectoid mixture of ferrite and cementite (α+Fe_3C) that forms at 723°C and contains 0.8% carbon. Meanwhile, the microstructure of Bisalloy 400 consists of martensite and ferrite phases. Martensite is usually formed in steel that has gone through a heat treatment process in the form of quenching, has a BCT (Body Centered Tetragonal) crystal structure, and is very hard and brittle.

3.2.2 Microstructure Testing on Buffer Layer

The results of micro testing on the buffer layer using E309L electrodes shown in Fig. 9.



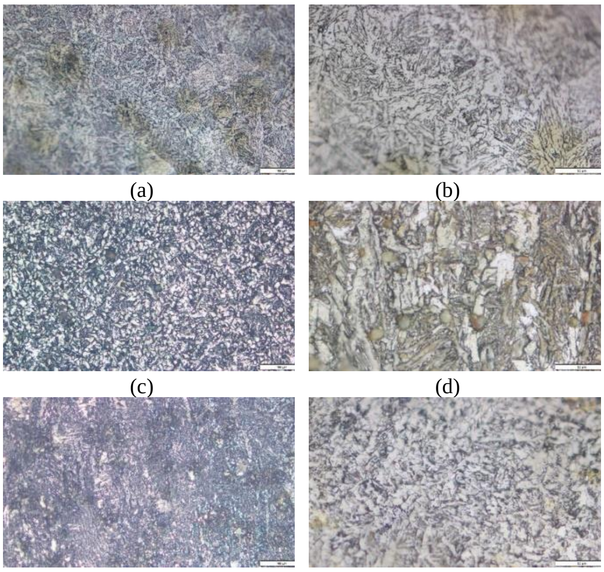
(a) (b)

Fig. 9 Microstructure of Buffer Layer
(a) 200X Magnification; (b) 500X Magnification

Fig. 9 shown the microstructure formed in the buffer layer area is the austenite phase. The presence of austenite phase is due to the use of E309L electrode. The austenite phase generally has softer and more ductile properties than martensite, making it more resistant to deformation before cracking. Austenite is a solid solution that has a maximum solubility limit of carbon of 2.11% at 1148°C, with an FCC (Face Centered Cubic) crystal structure.

3.2.3 Microstructure Testing on Weld Metal

Microstructure testing on the weld metal was carried out on each specimen. Based on the observation results, in specimens that only use the GMAW welding process with ER80S-G electrodes, three phases are formed, namely martensite, ferrite, and pearlite. The SM490YA material produces a microstructure in the weld metal in the form of ferrite and pearlite phases because the temperature when welding reaches around 250°C. Martensite is a very hard and brittle phase, usually in the form of thin plates or needles scattered in the metal matrix. The higher the carbon content, the harder the martensite. The ferrite phase looks bright white and is soft, ductile, and magnetic up to a certain temperature, with low carbon solubility compared to the austenite phase. Meanwhile, pearlite is a lamellar mixture of ferrite and cementite, with a harder structure than ferrite. The results of micro testing on weld metal without the addition of buffer shown in Fig. 10.

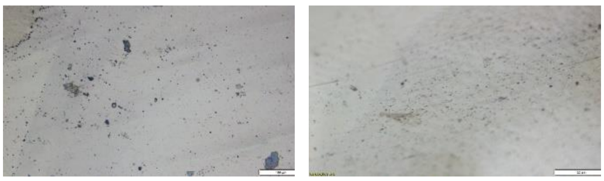


(a) (b) (c) (d) (e) (f)

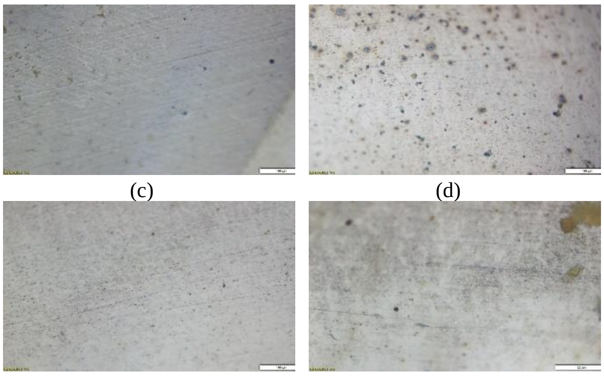
Fig. 10. Structure Micro Weld Metal

(a) 200X Magnification; (b) 500X Magnification; (c) 200X Magnification; (d) 500X Magnification; (e) 200X Magnification; (f) 500X Magnification

Microstructure testing of the weld metal was carried out on specimens using the GMAW and SMAW welding processes with ER80S-G and E309L electrodes, which produced an austenite phase in the weld metal. This is due to the mixing of the electrodes. The main microstructure of the weld metal produced by the E309L electrode is austenite with an FCC (Face Centered Cubic) crystal structure. This austenite phase dominates due to the high chromium and nickel content. The results of the micro test on the weld metal with additional buffer shown in Fig. 11.



(a) (b)



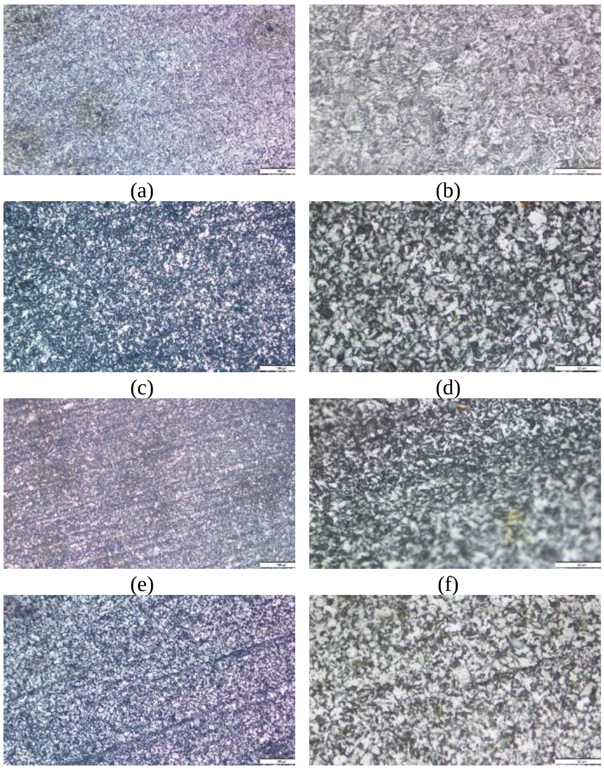
(c) (d) (e) (f)

Fig. 11. Structure Micro Weld Metal

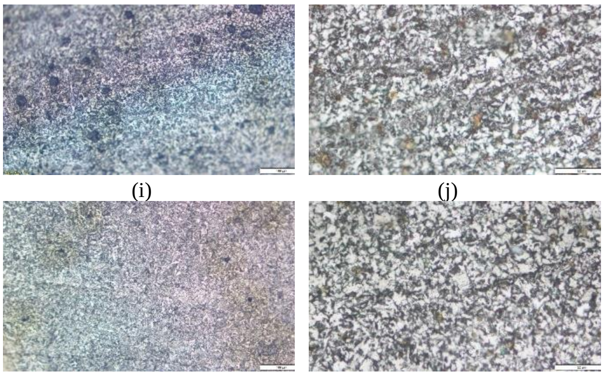
(a) 200X Magnification; (b) 500X Magnification; (c) 200X Magnification; (d) 500X Magnification; (e) 200X Magnification; (f) 500X Magnification

3.2.4 Microstructure Testing on HAZ

Microstructure testing in the HAZ region was carried out on HAZ specimens of Bisalloy 400 material. Based on microstructure observations, ferrite and martensite phases are seen, where the size of the ferrite phase in the HAZ is larger than in the base metal area. This is due to the heat input during the welding process that affects the base metal. Preheat before welding on martensitic materials also has a significant effect on the microstructure. This influence shown in the changes in phase transformation, carbide distribution, and mechanical properties of the material after welding. Heat input slows down the cooling rate, resulting in a finer grain size in the martensite structure. In addition, heat input also reduces the tendency for highly brittle martensite to form, thereby lowering the risk of cracking. After welding, the microstructure of the material becomes more homogeneous with a balance between martensite and ferrite phases, depending on the welding conditions and alloy composition of the material. The results of microstructure testing in the HAZ of Bisalloy material shown in Fig. 12.



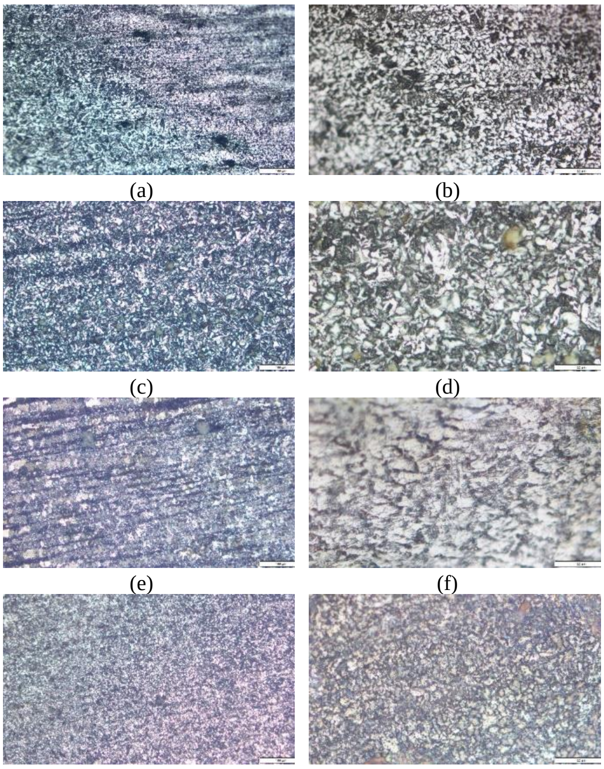
(a) (b) (c) (d) (e) (f) (g) (h)



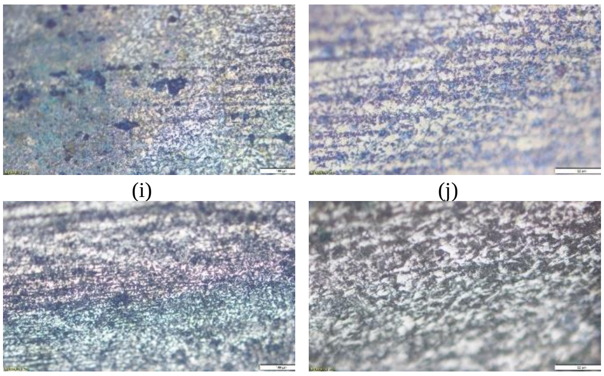
(i) (j) (k) (l)

Fig. 12. Microstructure of HAZ
(a) 200X Magnification; (b) 500X Magnification; (c) 200X Magnification; (d) 500X Magnification; (e) 200X Magnification; (f) 500X Magnification; (g) 200X Magnification; (h) 500X Magnification; (i) 200X Magnification; (j) 500X Magnification; (k) 200X Magnification; (l) 500X Magnification

Microstructure testing in the HAZ region was carried out on specimens of the HAZ section for SM490YA material. Based on observations, it shown that ferrite and pearlite phases are formed, where the size of these phases is smaller than the base metal region. This is due to the influence of heat during the welding process which reduces the cooling rate in the HAZ zone. The HAZ is the area most prone to the formation of hard and brittle microstructures. The preheat process helps to keep the microstructure in the HAZ smooth, with more stable ferrite and pearlite phases, thus improving toughness and reducing the risk of cracking. The microstructure in the HAZ is dominated by ferrites and pearls which are softer and more ductile. The HAZ micro test results for SM490YA shown in Fig. 13.



(a) (b) (c) (d) (e) (f) (g) (h)

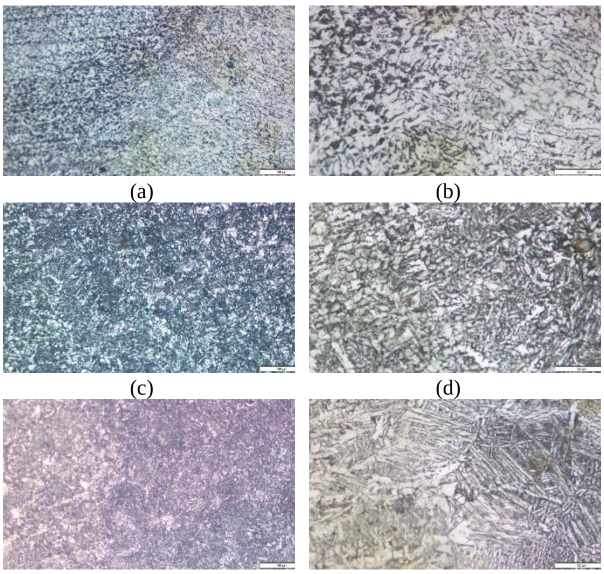


(i) (j) (k) (l)

Fig. 13. Microstructure of HAZ
(a) 200X Magnification; (b) 500X Magnification; (c) 200X Magnification; (d) 500X Magnification; (e) 200X Magnification; (f) 500X Magnification; (g) 200X Magnification; (h) 500X Magnification; (i) 200X Magnification; (j) 500X Magnification; (k) 200X Magnification; (l) 500X Magnification

3.2.5 Microstructure Testing of The Fusion Line

Microstructure testing at the fusion line was conducted for each specimen. From the observations, it was found that specimens using only the GMAW welding process with ER80S-G electrodes showed the formation of several phases. At the fusion line of the Bisalloy 400 region, martensite and ferrite phases were formed. While in the SM490YA area, ferrite and pearlite phases are formed. The striking difference in structure at the Bisalloy 400 fusion line is due to the higher carbon content, which leads to the formation of martensite near the fusion line. The micro test results at the fusion line for the Bisalloy 400 region shown in Fig. 14.



(a) (b) (c) (d) (e) (f)

Fig. 14. Structure Micro Fusion Line
(a) 200X Magnification; (b) 500X Magnification; (c) 200X Magnification; (d) 500X Magnification; (e) 200X Magnification; (f) 500X Magnification

At the fusion line area of SM490YA, two phases are formed, namely ferrite and pearlite phases. This ferrite and pearlite phase structure is maintained around the fusion line, with more ductile characteristics. The micro test results at the fusion line for the SM490YA region shown in Fig. 15.

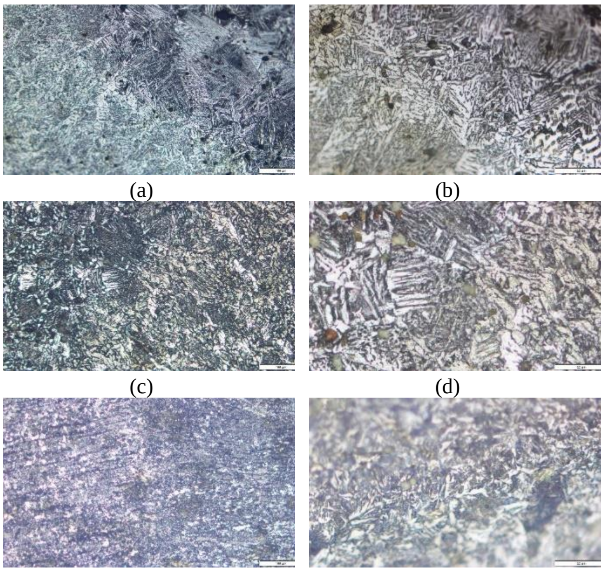


Fig. 15. Structure Micro Fusion Line
(a) 200X Magnification; (b) 500X Magnification; (c) 200X Magnification; (d) 500X Magnification; (e) 200X Magnification; (f) 500X Magnification

Microstructure testing on the fusion line was carried out on specimens using the GMAW and SMAW welding processes with ER80S-G and E309L electrodes, producing austenite phase, ferrite phase, and pearlite phase. The results of micro testing on the fusion line with additional buffer shown in Fig. 16.

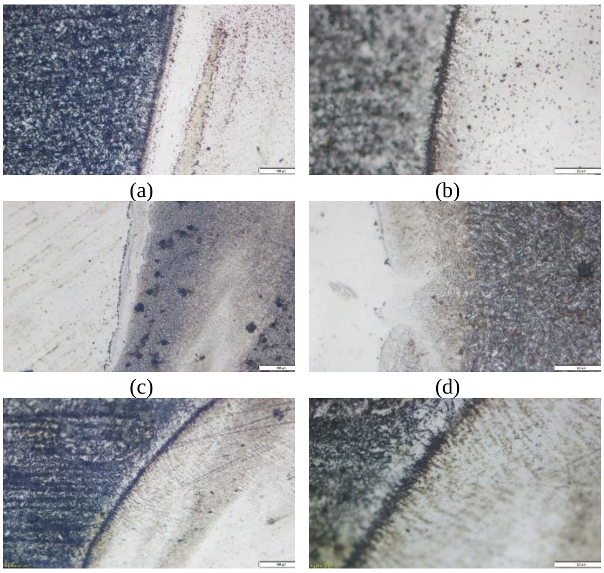


Fig. 16 Structure Micro Fusion Line
(a) 200X Magnification; (b) 500X Magnification; (c) 200X Magnification; (d) 500X Magnification; (e) 200X Magnification; (f) 500X Magnification

Variations in electrode combinations, preheat, and interpass affect the microstructure. In the weld metal area, phase mixing occurs, including ferrite, pearlite, and martensite phases. In the HAZ area of Bisalloy 400, there is a change in microstructure where the martensite and ferrite phases change, with the ferrite phase becoming more dominant. Meanwhile, in the HAZ area of SM490YA, the proportion of ferrite and pearlite phases is reduced compared to the microstructure in the base metal.

4. Conclusions

From the research results it can be concluded that the results of the comparative analysis of the combination of electrodes, preheat, and interpass in the hardness test show that higher preheat and interpass temperatures tend to reduce the hardness value of the material. Hardness testing provides hardness value results for BFA variation specimens of 385 HVN, BFB variation specimens of 383.8 HVN, 80A variation specimens of 381.1 HVN, 80B variation specimens of 367.2 HVN, 80C variation specimens of 319.5 HVN, and BFC variation specimens of 308.2 HVN. Analysis of the comparison of electrode combinations, preheat, and interpass to metallographic tests that the results of micro testing occur phase changes in the weld metal area. In the SM490YA base metal area consists of ferrite phase and pearlite phase. Bisalloy 400 base metal area consists of ferrite phase and martensite phase. The fusion line area is a transition area that has a mixed structure between base metal and weld metal. For variations that use a buffer layer, there is an austenite phase. The weld metal region consists of ferrite phase, pearlite phase, and martensite phase.

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