Influence of Parameters of Gas Metal Arc Welding on Macrostructures and Mechanical Properties of Austenitic Stainless Steels

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Abstract: -The Influences of parameters of Gas Metal Arc Welding Process on its microstructures and mechanical properties were investigated in this paper by using Austenitic stainless steel 304 with Factorial Design experiment. The parameters used in this study have Welding current, welding speed, Welding speed, Shielding gas on microstructures, Ultimate tensile strength, Yield strength, Elongation and Hardness. The results of this process revealed that 1) current parameters, welding speed, shielding gas effected on the ultimate tensile strength, yield strength, elongation and hardness by using Welding current about 90Amp, welding speed 500 mm/min and shielding gas of Ar+5%O_2, after welding test was found that the ultimate tensile strength values is 940.68 MPa. At welding current about 900A, welding speed 300 mm/min and shielding gas of Ar+3%N_2, after welding test was found that the yield strength values is 648.34 MPa. At welding current about 100Amp, welding speed 400 mm/min and shielding gas of Ar+5%H_2, after welding test was found that the elongation values are 20 % and at welding current about 90Amp, welding speed 300 mm/min and Shielding gas of Ar+5%H_2, after welding test was found that the hardness values is 278.33 HV, respectively. 2) The analysis results of microstructures of the specimens on ultimate tensile strength which are higher and lower strength values were found that microstructures of columnar dendrite and the growth of grains on the heat-affected zone are more differences, that is the area of columnar dendrite is smaller than the specimens on higher ultimate tensile strength and the growth of grains on the heat-affected zone are The chromium carbide ($Cr_{23}C_6$) can be occurred on both of all conditions.

Key-Words: - Welding parameters / GMAW / Gas shield/ Austenitic stainless steel / Mechanical properties / Factorials Design experiment

1 Introduction

Since the past to the present Austenitic stainless steel is the most widely used alloy group in the process industry, which has many advantages such as a used excellent in high temperature welding and a high withstanding in corrosion resistance properties [1,2] therefore stainless steel is used in forming and welding processes especially Austenitic stainless steel welding is often used in welding of manufacturing industrial. Then completion of the weld in Welding especially on weld zone and heat-affected zone is the most important in completion of the weld. It is likely that The Influences of welding parameters can cause of changing on microstructures and mechanical properties of weld zone thereby, in welding procedure would be necessary to consider the various conditions that may occur such as: (a) segregation during solidification; (b) distribution of elements during phase changes; and (c) precipitation of secondary phase particles [3, 4, 5 and 6]. The welding process was chosen to be used in welding of Austenitic stainless steel is Gas Metal Arc Welding or GMAW due to be able for given an efficiency on completion of the weld. However, in welding operation, because it can have a change during the welding procedure, especially in the chemical compositions of weld metal while fusion welding. This condition has an effect on the stability of passivity layer and also effect on the ability of corrosion resistance [7, 8] therefore, when there is a difference in chemical compositions will have influence on a difference in chemistry especially due to the microstructures of welding on weld zone and heat-affected zone, which also be resulted in mechanical properties of welding. [9, 10] Due to the foregoing description, can revealed that the parameters of Gas Metal Arc Welding Process on Austenitic stainless welding and also has an important influence on qualities and completion of the weld joint. From these reason, the researcher has been interested in the parameters of Gas Metal Arc Welding Process on Austenitic stainless welding which the purpose of this research is The Influences of parameters of Gas Metal Arc Welding Process on its microstructures and mechanical properties of Austenitic stainless steel type 304. The parameters used in this study have Welding current, welding speed, Welding speed, Shielding gas on microstructures, Ultimate tensile strength, Yield strength, Elongation and Hardness.

2 Research Methodology

2.1 Materials and welding conditions

This research is the welding of Austenitic stainless steel grade304 which has the chemical composition is shown in Table 1. and has the dimension as Fig.1 which was made on Gas Metal Arc Welding at the flat position 1G with Stainless Steel wire electrodes ER-308L Si as size as 0.8 mm of diameter. The parameters used in this study under the welding current with 3 levels are 90, 100 and 110Amp, the welding speed with 3 levels are 300, 400 and 500mm/min and the shielding gas with 3 compositions are Ar+5%O2, Ar+5%H2 and Ar+3%N2. This test can be made on the following sequence:

i) Set Up the welding parameters such as welding current, welding speed, wire feed speed, torch angle, arc length and gas flow rate at 15 lit/min

ii) Clean the parent plate on bevel zone for clearing out the dirtiness such as oil stain, fat and the other dirtiness with alcohol.

iii) Put the parent plate in the flat position 1G as Fig.2 onto the backing strip. Hold the work pieces by the welding jig and copper plate depositing the parent plate onto the upper surface.

iv) Open gas flow over the back surface of the test plate at 15 lit/min.

v) Beginning the welding operation on the surface of jig and fixture relative to the end on opposite side by using welding technique on forward welding.

vi) When the welding run was finished, removed the parent plate from jig and fixture after it is cooled in the air.

vii) Welding operation on another parent plates, when welding was finished, allowed parent plates to cool in the air. Continuous welding operation until were wholly finished of 54 pieces.

viii) When changing welding parameters, the operation set up of the welding parameters is repeatedly.

Welding operation used for collecting data is the experiment by random selection then cut the parent metal which was passed welding process into small pieces as Fig.3 for checking the microstructure, weld zone and heat-affected zone and mechanical properties test were Ultimate Tensile Strength, Yield Point, Hardness and Elongation

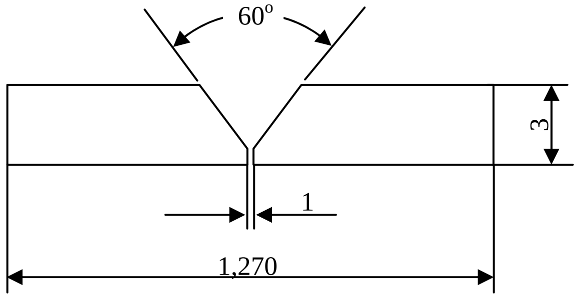

Figure 1 Dimension of specimen (unit : mm.)

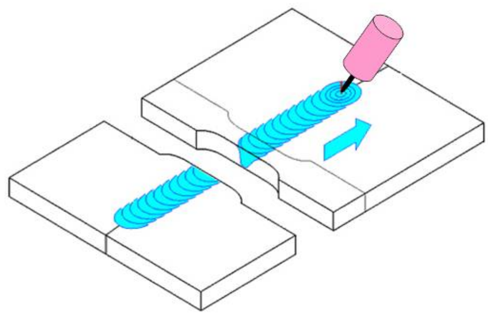

Figure 2 Characteristic of the cutting weld joint for mechanical properties test

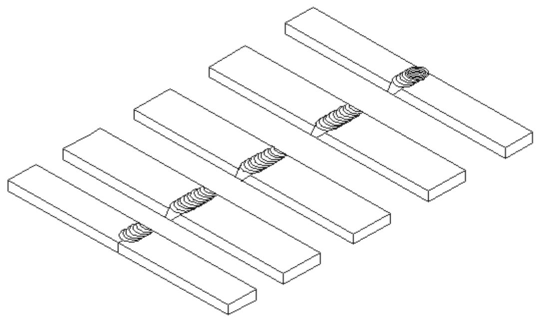

Figure 3 Slitting of preparing test piece for mechanical properties test

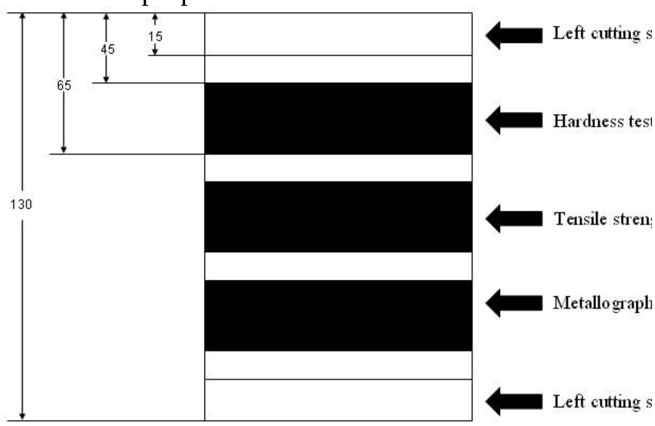

Figure 4 Dimension of preparing test piece for mechanical properties test

Table 1 Chemical composition of austenitic stainless steel grade 304

Cr	Ni	Mn	Si	P	C	S	Fe
18.82	8.36	1.38	0.35	0.042	0.012	0.005	balance

Table 2 Design of experiment condition chart

Welding Current (Amp)	Welding speed (mm/min)								
	300 mm/min			400 mm/min			500 mm/min		
	Shielding gas								
	$Ar+5\%O_2$	$Ar+5\%H_2$	$Ar+3\%N_2$	$Ar+5\%O_2$	$Ar+5\%H_2$	$Ar+3\%N_2$	$Ar+5\%O_2$	$Ar+5\%H_2$	$Ar+3\%N_2$
90	A1	A2	A3	D1	D2	D3	G1	G2	G3
	A4	A5	A6	D4	D5	D6	G4	G5	G6
100	B1	B2	B3	E1	E2	E2	H1	H2	H3
	B4	B5	B6	E3	E4	E5	H4	H5	H6
110	C1	C2	C3	F1	F2	F3	I1	I2	I3
	C4	C5	C6	F4	F5	F6	I4	I5	I6

Remark of parameter testing condition from table 2;

i) A1, A4, B1, B4, C1 and C4 were welding speed of 300mm/min, shielding gas of $Ar+5\%O_2$ and welding current of 90, 100 and 110 respectively.

ii) A2, A5, B2, B5, C2 and C5 were welding speed of 300mm/min, shielding gas of $Ar+5\%H_2$ and welding current of 90, 100 and 110 respectively.

iii) A3, A6, B3, B6, C3 and C6 were welding speed of 300mm/min, shielding gas of $Ar+5\%N_2$ and welding current of 90, 100 and 110 respectively.

iv) D1, D4, E1, E4, F1 and F4 were welding speed of 400mm/min, shielding gas of $Ar+5\%O_2$ and welding current of 90, 100 and 110 respectively.

v) D2, D5, E2, E5, F2 and F5 were welding speed of 400mm/min, shielding gas of $Ar+5\%H_2$ and welding current of 90, 100 and 110 respectively.

vi) D3, D6, E3, E6, F3 and F6 were welding speed of 400mm/min, shielding gas of $Ar+5\%N_2$ and welding current of 90, 100 and 110 respectively.

vii) G1, G4, H1, H4, I1 and I4 were welding speed of 500mm/min, shielding gas of $Ar+5\%O_2$ and welding current of 90, 100 and 110 respectively.

viii) G2, G5, H2, H5, I2 and I5 were welding speed of 500mm/min, shielding gas of $Ar+5\%H_2$ and welding current of 90, 100 and 110 respectively.

ix) G3, G6, H3, H6, I3 and I6 were welding speed of 500mm/min, shielding gas of $Ar+5\%N_2$.

2.2 Design of experiment

This paper is the experimental research for making the experimental is formed in standard regulation and in greater quality system under conditions control, parameters including the other connecting influences to observation or evaluation without partiality and repeatable results. This paper worked by design the experiment on 3 factors, the welding parameters on mechanical properties of weld zone and a change of microstructure on weld zone and heat affected zone are welding speed (A), shielding gas (B) and welding current (C). 3 factors consist of 3 levels and the operation is repeatedly for 2 times which have the parent plates as in table 2.

Figure 5 The specimen on higher Ultimate tensile strength by welding parameter on welding current of 90Amp 500, welding speed of mm/min shielding gas of $Ar+5\%O_2$.

3 Results and discussion

3.1 Result of analysis of welding parameter on Ultimate Tensile Strength

When considering of the relative between welding parameters and Ultimate Tensile Strength found that he main effect which has an influence on a change is welding speed. For the Interactions are 1) current * speed, 2) speed * shielding gas, 3) current * speed * shielding gas which concluded the results could be effected on a change of ultimate tensile strength with a statistical significant level at 0.05 ($F_{0.05,2,81}$ = 3.122 , $P < 0.05$) are listed in Table 2. From the relative between welding parameters and ultimate tensile strength can be calculated the means by following the proportion of welding current, welding speed and shielding gas at the confidence level of 95 %, it was also determined that the average of ultimate tensile strength resulted in a 683.16 MPa. Additionally, the higher value of ultimate tensile strength is the effect on welding process in term of welding current of 90Amp, welding speed of 500 mm/min and shielding gas of Ar+5%O_2 resulted in 940.68 MPa (Fig. 5), the lower value of ultimate tensile strength is the effect on welding process in term of welding current of 100Amp, welding speed of 300 mm/min and shielding gas of Ar+5%O_2 resulted in 617.53 MPa (Fig. 6-7)

Figure 6 The specimen on lower Ultimate tensile strength by welding parameter on welding current of 100Amp, welding speed of 300 mm/min shielding gas of Ar+5%H_2

3.2 Result of analysis of welding parameter on Yield Tensile Strength

When considering of the relative between welding parameters and Yield Point found that the mainly influence which has an influence on a change is welding speed. For the Interactions are 1) current * speed, 2) speed * shielding gas, 3) current * speed * shielding gas which concluded the results could be effected on a change of yield point with a statistical significant level at 0.05 ($F_{0.05,2,81}$ = 3.122 , $P < 0.05$) are listed in Table 3. From the relative between welding parameters and ultimate tensile strength can be calculated the means by following the proportion of welding current, welding speed and shielding gas at the confidence level of 95%, it was also determined that the means of yield point resulted in a 540.82 MPa. Additionally, the higher value of yield point is the effect on welding process in term of welding current of 90Amp, welding speed of 500 mm/min and shielding gas of Ar+3%N_2 resulted in 648.34 MPa, the lower value of yield point is the effect on welding process in term of welding current of 100Amp, welding speed of 300 mm/min and shielding gas of Ar+5%O_2 resulted in 424.67 MPa (Fig. 8).

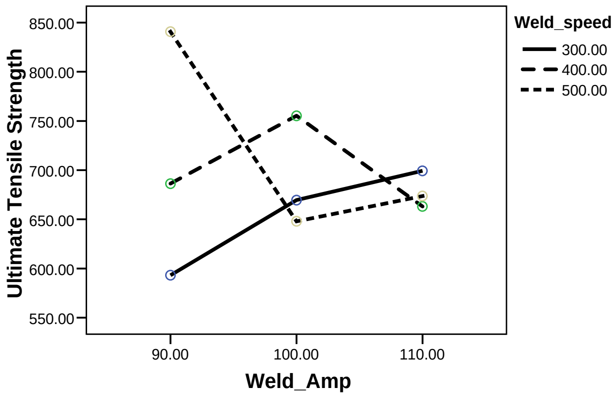

Figure 7 Interaction of parameters between welding speed and welding current (Weld_Amp) on ultimate tensile strength at Ar+5%O_2.

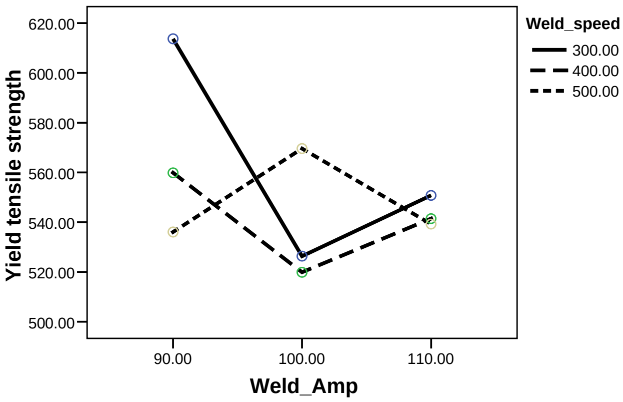

Figure 8 Interaction of parameters between welding speed and welding current (Weld_Amp) on yield tensile strength at Ar+3%N_2.

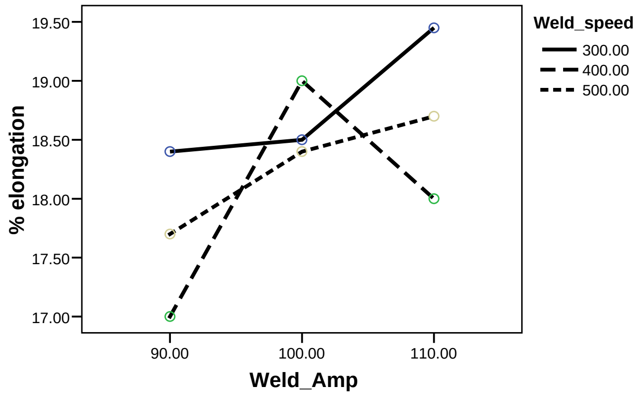

Figure 9 Interaction of parameters between welding speed and welding current (Weld_Amp) on elongation at Ar+5%H_2.

3.3 Result of analysis of welding parameter on Elongation

When considering of the relative between welding parameters and Elongation found that the mainly influence which has an influence on a change is welding speed. For the Interactions are 1) current * speed, 2) speed * shielding gas, 3) current * speed * shielding gas which concluded the results could be effected on a change of elongation with a statistical significant level at 0.05 ($F_{0.05,2,81} = 3.122$, $P < 0.05$) are listed in Table 4. From the relative between welding parameters and elongation can be calculated the means by following the proportion of welding

Table 2 Results of Analysis of ANOVA on Ultimate Tensile Strength

Source	Type III Sum of Squares	df	Mean Square	F	P-Value
Corrected Model	2244.447(a)	26	86.325	4.062	.000
Intercept	524027.103	1	524027.103	24656.960	.000
Current (Amp)	29.504	2	14.752	.694	.502
Speed (mm/min)	165.945	2	82.973	3.904	.024
Shielding gas (%)	85.200	2	42.600	2.004	.141
Current * Speed	361.008	4	90.252	4.247	.004**
Current * Shielding gas	33.659	4	8.415	.396	.811
Speed * Shielding gas	278.896	4	69.724	3.281	.015**
Current * Speed * Shielding gas	1290.234	8	161.279	7.589	.000**
Error	1721.469	81	21.253		
Total	527993.020	108			
Corrected Total	3965.916	107			

a R Squared = .566 (Adjusted R Squared = .427), ** P>0.05

Table 3 Results of Analysis of ANOVA on Yield Tensile Strength

Source	Type III Sum of Squares	df	Mean Square	F	P-Value
Corrected Model	1181.279(a)	26	45.434	3.395	.000
Intercept	328266.072	1	328266.072	24531.987	.000
Current (Amp)	10.528	2	5.264	.393	.676
Speed (mm/min)	74.776	2	37.388	2.794	.067
Shielding gas (%)	61.363	2	30.682	2.293	.107
Current * Speed	111.112	4	27.778	2.076	.092
Current * Shielding gas	208.453	4	52.113	3.895	.006**
Speed * Shielding gas	181.428	4	45.357	3.390	.013**
Current * Speed * Shielding gas	533.620	8	66.702	4.985	.000**
Error	1083.873	81	13.381		
Total	330531.224	108			
Corrected Total	2265.152	107			

a R Squared = .522 (Adjusted R Squared = .368), ** P<0.05

-current, welding speed and shielding gas at the confidence level of 95%, it was also determined that the means of elongation resulted in a 18.33%. Additionally, the higher value of yield point is the effect on welding process in term of welding current of 100Amp, welding speed of 400 mm/min and shielding gas of Ar+5%H_2 resulted in 20%, the lower value of elongation is the effect on welding process in term of welding current of 90Amp, welding speed of 500 mm/min and shielding gas of Ar+5%N_2 resulted in 16.40% (Fig. 9).

3.4 Result of analysis of welding parameter on Hardness

When considering of the relative between welding parameters and hardness found that the mainly influence which has an influence on a change is welding speed. For the Interactions are 1) current * speed, 2) speed * shielding gas, 3) current * speed * shielding gas which concluded the results could be effected on a change of elongation with a statistical significant level at 0.05 ($F_{0.05,2,81}$ = 3.122 , P < 0.05) are listed in Table 5. From the relative between-

Table 4 Results of Analysis of ANOVA on Elongation

Source	Type III Sum of Squares	df	Mean Square	F	P-Value
Corrected Model	38.363(a)	26	1.475	4.825	.000
Intercept	36292.667	1	36292.667	118680.098	.000
Current (Amp)	10.583	2	5.291	17.304	.000**
Speed (mm/min)	3.736	2	1.868	6.109	.003**
Shielding gas (%)	2.154	2	1.077	3.522	.034**
Current * Speed	3.877	4	.969	3.170	.018**
Current * Shielding gas	3.193	4	.798	2.610	.041**
Speed * Shielding gas	3.119	4	.780	2.550	.045**
Current * Speed * Shielding gas	11.701	8	1.463	4.783	.000**
Error	24.770	81	.306		
Total	36355.800	108			
Corrected Total	63.133	107			

a R Squared = .608 (Adjusted R Squared = .482), ** P>0.05

Table 5 Results of Analysis of ANOVA on Hardness

source	Type III Sum of Squares	df	Mean Square	F	P-Value
Corrected Model	80321.781(a)	26	3089.299	8.208	.000
Intercept	4740750.379	1	4740750.379	12595.371	.000
Current (Amp)	166.993	2	83.496	.222	.802
Speed (mm/min)	3988.981	2	1994.491	5.299	.007**
Shielding gas (%)	23284.604	2	11642.302	30.932	.000**
Current * Speed	18650.822	4	4662.706	12.388	.000**
Current * Shielding gas	1330.443	4	332.611	.884	.478
Speed * Shielding gas	13429.982	4	3357.496	8.920	.000**
Current * Speed * Shielding gas	19469.954	8	2433.744	6.466	.000**
Error	30487.453	81	376.388		
Total	4851559.613	108			
Corrected Total	110809.234	107			

a R Squared = .725 (Adjusted R Squared = .637), ** P>0.05

-welding parameters and elongation can be calculated the means which following the grades of welding current, welding speed and shielding gas at the confidence level of 95%, it was also determined that the means of elongation resulted in a 209.51 HV. Additionally, the higher value of yield point is the effect on welding process in term of welding current of 90Amp, welding speed of 300 mm/min and shielding gas of Ar+5%H_2 resulted in 278.33 HV, the lower value of elongation is the effect on welding process in term of welding current of 90Amp, welding speed of 400 mm/min and shielding gas of Ar+5%N_2 resulted in 138.33 HV (Fig. 10).

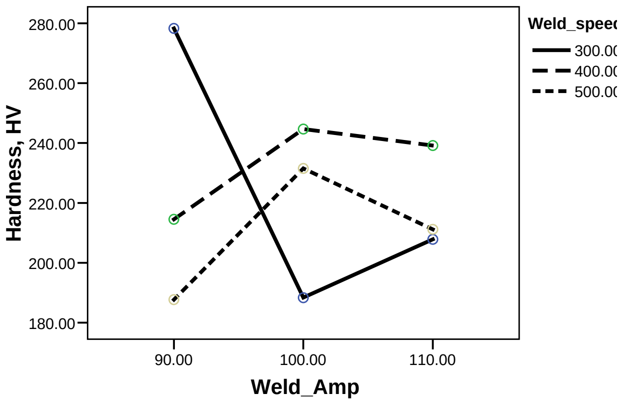

Figure 10 Interaction of parameters between welding speed and welding current (Weld_Amp) on hardness at Ar+5%H_2.

3.5 Result of microstructure analysis

3.5.1 Microstructure of specimen on higher Ultimate tensile strength

When considering of the microstructure of test pieces on higher ultimate tensile strength is welding current of 90Amp, welding speed of 500 mm/min and shielding gas of Ar+5%H_2 resulted in 95.85 Kg/mm^2. When checking the microstructure of base metal and Weld metal can be analyst as Fig. 11. When considering of the microstructure of test pieces on weld zone, found that the characteristic of Columnar Dendritic which has a very thin shape and grows in the direction orientated to the central part of weld melting pool in perpendicular direction to the wall of base metal. With the higher welding speed, and has short solidification time period when considering at Heat Affected Zone, found that chromium carbide grows occur along the grain boundaries according to the effect of the relationship between the temperatures and times. Through the test on microstructure will appear a region of the Heat Affected Zone where is next to the Fusion Line apparently with having a grains size that are more than a region where is not under the effect of heat and along the grain boundaries within a region of Heat Affected Zone, Chromium Carbide can also occur by including on the grain boundaries where are shown in darkness spot In the next region of the Heat Affected Zone running to the central part of weld, will appear Fusion Zone that occurs the solidification where appear the microstructure of Columnar Dendrite with having a smaller range in the direction to the central part of arc welding. According to the aforementioned phenomenon, can explain which is why the welding process in term of welding parameter gives more values of the tensile strength than every welding parameter.

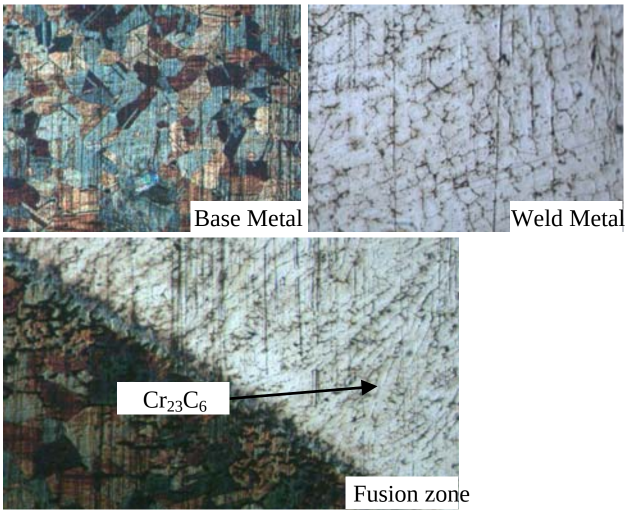

Figure 11 Microstructure of on higher ultimate tensile strength

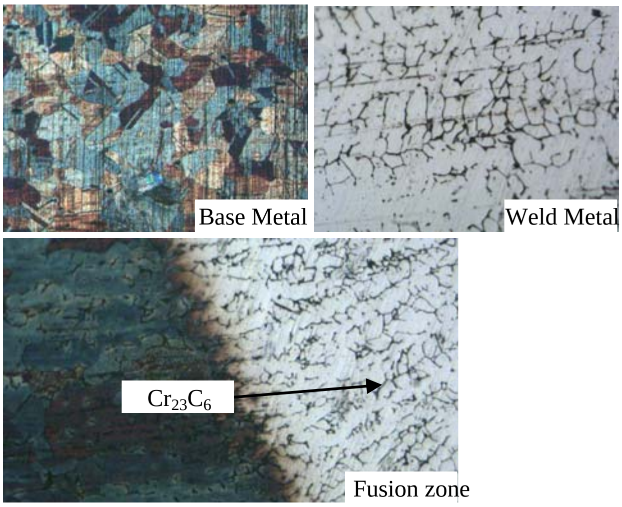

Figure 12 Microstructure of specimen on lower ultimate tensile strength

Because of the specimen is done in lower welding current, the specimen takes low heat input and also leading to the heat treatment on the Heat Affected Zone small quantities on the microstructure of the Heat Affected Zone also having fewer changes. This process can causes the increasing and reducing in changing of interpass temperature for a short period including the higher welding speeds which make the quenching and also has the effect on solid state transformation very fast to the microstructure Columnar Dendrite which offers the microstructure of filler metal into the fine microstructures. When considering on the Heat Affected Zone, it is caused temperatures can pass through the serious risk cracking at faster rate which reduce the Chromium Carbide ($Cr_{23}C_6$) precipitation which give the Ultimate Tensile Strength [11] and the shielding gas of Ar+5%O_2 also the reaction with the welding process, especially both on the active head and active tail of the weld bead revealed that the shielding gas of Ar+5%O_2 will gives the smoother atmosphere during unless the risk cracking as covering with another shielding gas. Likewise, this phenomenon liquid metal occurs the fusion during the arc will make the weld pool has the riser feeding consistently and also leading to the size of weld pool and the rate of completely root penetration, the typically defect such as porosity, cavitations etc. thus leading to good corrosion resistance. [12]

3.5.2 Microstructure of specimen on lower Ultimate tensile strength

When considering of the microstructure of test pieces on lower ultimate tensile strength, in term of welding current of 90Amp, welding speed of 400 mm/min and shielding gas of Ar+5%H_2 resulted in 62.95 Kg/mm^2. When checking the microstructure of base metal and Weld metal can be analyzed as in Fig. 12. And when considering of the microstructure of the specimen equal magnitude, in part of weld metal is shown the microstructure on Columnar Dendritic with the larger size than the specimen on the lower Ultimate Tensile Strength with the welding direction to the central part of the weld melting pool in vertical position on the surface of base metal. When considering at the Heat Affected Zone, found that chromium carbide grows occur along the grain boundaries including the changes of size in the growth of grains, as a result of the relative between the temperatures and times. Through the test on microstructure will appear a region of the Heat Affected Zone where is next to the Fusion Line apparently with having a grains size that are more than a region where is not under the effect of heat and along the grain boundaries within a region of Heat Affected Zone, Chromium Carbide can also occur by including on the grain boundaries where are shown in darkness spot In the next region of the Heat Affected Zone running to the central part of weld, will appear Fusion Zone that the solidification occur with the microstructure of Columnar Dendrite with having a larger area than Columnar Dendrite of the specimen on higher Ultimate Tensile Strength. Likewise, as welding speed is under the lower value, the weld metal is also under the lower solidification time and the columnar dendrite is grown in the direction running to the central part of the arc.

3.5.3 Elongation

According to the test revealed that the higher welding parameters are in term of welding current of 100Amp, welding speed of 400 mm/min and shielding gas of Ar+5%H_2 resulted in 20 % due to the purposes of the combination of Hydrogen is an increase the higher heat source in welding, controlling the shape of weld metal shape, given good metal fluid flow in weld melting pool and constant weld metal. According to the aforementioned properties, are in term of welding current and welding speed in the medium level but have high amount of heating because of the influence of Hydrogen will take the great resulting in welding by present in the addition of the efficient Cohesion.

3.5.4 Hardness

According to the test revealed that the higher welding parameter are in term of welding current of 90Amp, welding speed of 300 mm/min and shielding gas of Ar+5%H_2 resulted in 278.33 HV due to when using the shielding gas which compound with Hydrogen and also given more opportunity in cracking easily, this welding can undergo a more Hardness in weld metal, because Hydrogen is an inert gas which hard to take away from the weld melting pool as same as Hydrogen is also added.

4 Conclusion

4.1 Analysis of welding parameter on Ultimate Tensile Strength

Through the test on welding parameters of GMAW by fully understanding revealed that the changes on the microstructure of weld metal and heat-affected zone welding current, welding speed and shielding gas. The following conclusions can be drawn.

1). Current parameters, welding speed, gas shield effected to the Ultimate tensile strength, Yield Strength and hardness by using welding current of 90Amp, welding speed of 500 mm/min and shielding gas of Ar+5%O_2 will give the results of the Ultimate tensile strength in 95.85 Kg/mm^2, in term of welding current of 90Amp, welding speed of 300 mm/min and shielding gas of Ar+3%N_2 resulted in 20 % and in term of welding current of 90Amp, welding speed of 300 mm/min and shielding gas of Ar+5%H_2 resulted in 278.33 HV.

2). According to the results of the microstructure of the higher and lower on Ultimate tensile strength revealed that the characteristic of the structure of Columnar Dendrite and having more differences in the growth of grains in the Heat-Affected Zone which can explain that the shape of Columnar Dendrite is smaller than the specimen which has the higher on the Ultimate tensile strength and the size of the growth of grains in the Heat-Affected Zone is also smaller and chromium carbide ($Cr_{23}C_6$) can occur on all conditions.

References:

[1] H.H. Uhlig. *Corrosion and corrosion control* Wiley, New York, NY (1985).

[2] E. Zumelzu and C. Cabezas, Observations on the influence of cleaners in the food industry. *Mater. Charact.* 37 (1996), pp. 187–194.

[3] S.A. David and J. Vitek, Correlation between solidification parameters and weld microstructures. *Int. Mater. Rev.* 34 (1989), pp. 213–245.

[4] S. Kou and Y. Le, Welding parameter and the grain structure of weld metals—A thermaldynamic consideration. *Metall. Trans.* 19A (1985), p. 1075.

[5] J.J. Smith and R.A. Farrar, Influence of microstructure and composition on mechanical properties of some AISI 300 series weld metals. *Int. Mater. Rev.* 38 (1993), pp. 25–51.

[6] S. Polgary, Mechanical properties of stainless steel weld metal at elevated temperature with special regard to the influence of ferrite, *ESAB Tech. Report No. 59A* 83001, 1982..

[7] G.P. Halada et al., Electrochemical and surface analytical studies of the interaction of nitrogen with key alloying elements in stainless steel, *Corrosion'95, NACE, Orlando, FL, Paper 95531*.

[8] E. Zumelzu, Repairing tungsten filaments through microwelding, *Weld. J., AWS, 70* (1991) 65–67.

[9] J.A. Brooks et. al., On the origin of ferrite morphologies of primary ferrite solidified stainless steel welds, Trends in Weld. Res., *ASM International*, 1993..

[10] E. Zumelzu, O. Ojeda, Study on the mechanical performance and intergranular corrosion of AISI 304 stainless steel welded joints, Proc. III Nat. *Congress of Mech. Eng., Universidad de Concepción, Vol. 2,* 1988, pp. 1–5.

[11] Heiple, CR. and Burgardt, P., 1993, Fluid Flow Phenomena during Welding. *ASM Hanbook, Vol 6*, ASM International Materials Park, Ohio USA., pp. 19-22.

[12] F.C. Hull, Effect of delta ferrite on the hot cracking of stainless steel, *Weld. J. 46 (1967) (9)*, pp. 339s–409s.