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Effect of Current Strength and Flow Rate of Shielding Gas on the Impact and Tensile Strength of Gas Metal Arc Welding Result on Steel Plate Hot Rolled Coiled Materials

Radhi Nurvian Amrullah[1]* , Subagiyo[1]

1)Mechanical Engineering Department, State Polytechnic of Malang, Soekarno Hatta Street No. 09, Malang, Indonesia

Correponding email [1)] :
radhinurvian.rn@gmail.com

Abstract. Gas metal arc welding **(**GMAW) is one of the welding techniques that is easy to use, especially to weld low-carbon steel. Low-carbon steel In general, low-carbon steel is widely used in the process of making frame structures, an example is a car frame. Car frames are generally made using materials that are strong, ductile, lightweight, and able to withstand impact and tensile loads when the car is used, one example of the material is steel plate hot rolled coiled (SPHC). The problem is that GMAW results are affected by welding parameters. In this study, the parameter chosen was the strong variation of the welding current and the flow rate of protective gases CO_2. The purpose of this study is to determine the strong influence of the current and flow rate of protective gases as well as the interaction on the impact and tensile strength of GMAW results on SPHC materials. This research uses an experimental method with current strength parameters of 120 A, 130 A, and 140 A, as well as variations in the flow rate of protective gases, namely 15 L/min, 20 L/min, and 25 L/min. In general, the results of the research show that the impact strength of the weld metal is lower than the raw material and the tensile strength of the weld metal is higher than the raw material. From the study, it can be seen that the optimal current strength and flow rate of protective gas is a current strength of 140 A and a flow rate of protective gas worth 25 L /minute with an impact strength of 2.91 J/mm2 and a tensile strength of 431.72 MPa.

Keywords: GMAW SPHC Material, Impact Strength, Tensile Strength.

1. INTRODUCTION

Along with the development of technology, the field of welding also develops. There are also many types of welding, including gas metal arc welding (GMAW). GMAW is one of the easy-to-use detectors, especially to weld low-carbon steels. Low-carbon steel is generally widely used in the process of making frame structures, an example is a car frame. Car frames are generally made using materials that are hard, ductile, lightweight, and can withstand impact and tensile loads when the car is used, one example of the material is steel plate hot rolled coiled (SPHC).

SPHC material is steel plate produced through a hot rolled process with commercial quality. SPHC plates are often also called black plates because these plates are blackish. SPHC in Japanese industry standards is encoded with JIS G3131 (Steel. B, 2011). SPHC material is often used as a material for making industrial workpieces that require easy maintenance and affordable prices such as making car frames. the welding process itself can be done using a variety of types of welding, one of which is GMAW.

GMAW welding is the process of welding or joining metal materials that use a heat source from electrical energy which is converted into heat energy. In the welding process, GMAW uses welding wire rolled in a roll and uses gas as a protector of the welding metal that melts during the welding process, so that the welded metal can be permanently fused [1]. Some GMAW welding parameters such as current strength and torch distance to the workpiece, influence the mechanical properties of the material such as strong and ductile properties. Strong and ductile properties of the material are very important, especially in the car frame, to ensure the connection in the car frame remains strong when the car is used. Therefore, research is needed to analyze the nature of the material connection. From this description, the author took the initiative to make a research title entitled "The Strong Effect of Current and Flow Rate of Protective Gas on the Impact and Tensile Strength of GMAW Welding Results on SPHC Materials".

The purpose of this study is to determine the strong influence of current on the impact and tensile strength of GMAW welding results of SPHC material, the effect of protective gas flow rate on the impact and tensile strength of GMAW welding results of SPHC material, the effect of strong interaction of current and flow rate of protective gas on the impact and tensile strength of GMAW welding results of SPHC material.

2. METHODS

2.1 Research Concept Framework

This is a research concept framework, the independent variable is the current strength and flow rate of the protective gas, The controlled variable is gas the shield used is CO^2, the material is SPHC, the electrode is ER 70S-6 and the welding position is 1 G, the dependent variable is the result of the impact test and GMAW tensile allocation on the SPHC material.

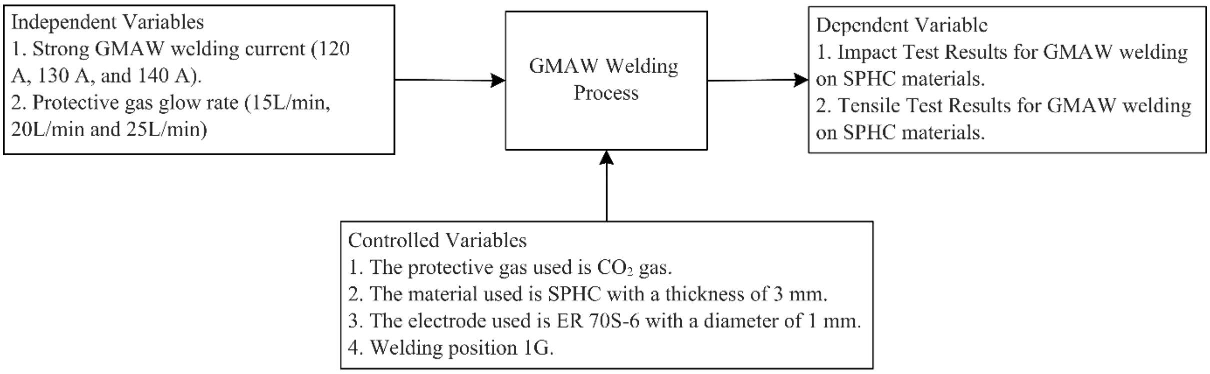

Figure 1. Research Concept Framework

2.2 Tools and Materials

Some of the tools and materials used in this research are the GMAW welding machine, CO_2 protective gas, material SPHC, hand grinding, drilling machine, and caliper.

2.3 Research Flowchart

The steps in conducting research follow the sequence of work as follows:

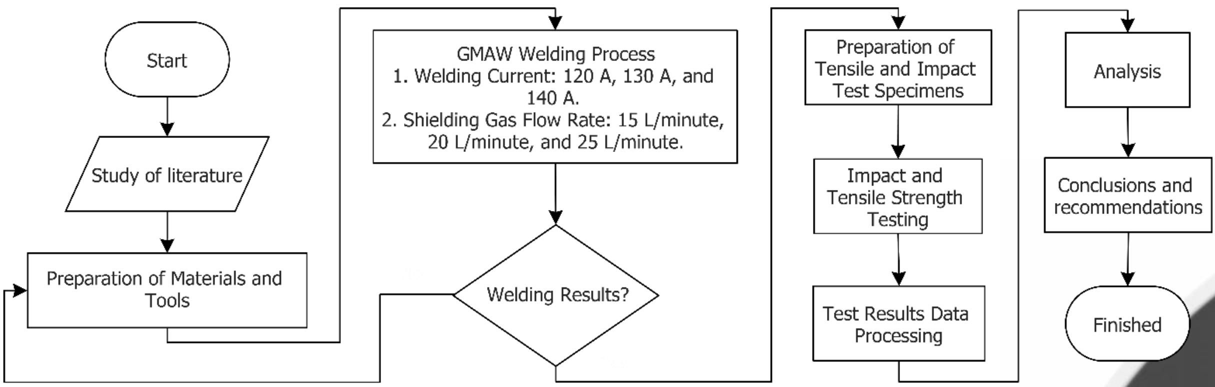

Figure 2. Research Flowchart

The welding process is carried out using strong variations of currents of 120 A, 130 A, and 140A, as well as the flow rate of protective gas used during welding of 15 L/min, 20 L/min, and 25 L/min. The manufacture of tensile test specimens is carried out using BS 709 (British *Standardtd*) standards, and charpy impact test specimens using ASTM E 23 – 02a standards. Tensile and impact strength tests are performed to determine the strength value resulting from GMAW welding using variations in the protective gas mixture and protective gas flow rate. Data processing of test results is carried out using the help of Excel and Minitab 2020 software with the DOE *Factorial* method. Then after obtaining the test data, data analysis will continue.

3. RESULTS AND DISCUSSION

3.1. Research Results

The results of the study were obtained from data collection from the GMAW welding process on SPHC material with a thickness of 3 mm with variations in current strength and protective gas flow rate, and each variable was replicated three times. The material tests used on these specimens are tensile and impact tests. The specification of SPHC material before welding is shown in Table 1.

Table 1 SPHC Material Specifications

Spec.	Chemical Composition (%)				Mechanical Properties		
	C	Mn	P	S	YS (MPa)	TS (MPa)	Elongation (%)
(*) SPHC	0,12 max	0,60 max	0,045 max	0,035 max	-	270 min	1,80≤T<3,20 : 29 min T<4,00 : 31 min

Table 2 Impact Strength Reference on Low-carbon Steel Material Raw

	Impact Strength (J/mm^2)
Raw Material 1	4,65
Raw Material 2	5,61
Raw Material 3	5,97
Average	5,41

3.2. Research Results of Tensile Testing Before Welding

Table 3 Tensile Strength Value in *Raw Material*

	Rated Tensile Strength (MPa)
Raw Material 1	433,38
Raw Material 2	406,98
Raw Material 3	415,94
Average	418,77

3.3. Results of Impact Testing Research Before Welding

Table 4 Value of Impact Strength in *Raw Material*

	Impact Strength (J/mm^2)
Raw Material 1	5,54
Raw Material 2	5,54
Raw Material 3	6,69
Average	5,92

3.4. Research Results of Tensile Testing After Welding

After the welding process and tensile testing of the specimen, the data used to determine the tensile strength is obtained using the calculation example formula as follows.

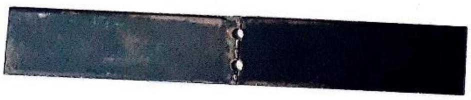

Figure 3 Welding specimen before the test

Of the twenty-seven specimens, tensile testing has been carried out, then calculations are carried out with formulas so that data is obtained and entered into the table as follows.

Table 5 Tensile Strength Value Data

Strong Current (A)	Protective Gas Flow Rate (L/min)	Rated Tensile Strength (MPa) I	II	III	Average
120	15	460,54	432,9	347,36	413,60
	20	329,3	408,87	366,1	368,09
	25	420,7	418,32	463,33	434,12
130	15	373,6	324,6	417,8	372,00
	20	421,65	572,48	409,23	467,79

	25	359,18	387,38	457,4	401,32
140	15	438,32	434,42	480,78	451,17
	20	553,29	398,93	412,28	454,83
	25	437,51	436,31	422,23	432,02

3.5. Results of Impact Testing Research After Welding

Figure 4 Welding specimen before impact test

Of the twenty-seven specimens, impact testing has been carried out, then calculations are carried out with formulas so that data is obtained and entered into the table as follows.

Table 6 Impact Value Data

Strong Current (A)	Protective Gas Flow Rate (L/min)	Impact Test Value (J/mm^2) I	II	III	Average
120	15	1,01	0,9	0,13	0,68
	20	1,33	1,09	1,91	1,44
	25	1,89	1,41	1,59	1,63
130	15	0,64	1,01	0,59	0,75
	20	0,14	0,34	0,59	0,36
	25	1,01	0,86	0,48	0,78
140	15	2,33	3,28	3,28	2,96
	20	1,15	1,19	1,36	1,23
	25	2,62	2,41	3,69	2,91

3.6. Tensile Test Data Processing

From the results of data collection, tensile test data processing was carried out *using* Minitab 2021 software using the DOE *Factorial method* to determine the influence of variables on specimens.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	30515	3814,4	1,28	0,312
Linear	4	9781	2445,3	0,82	0,528
KUAT ARUS	2	8320	4159,8	1,40	0,272
LAJU ALIRAN GAS PELINDUNG	2	1462	730,8	0,25	0,785
2-Way Interactions	4	20734	5183,5	1,74	0,184
KUAT ARUS*LAJU ALIRAN GAS PELINDUNG	4	20734	5183,5	1,74	0,184
Error	18	53504	2972,5		
Total	26	84020			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
54,5204	36,32%	8,02%	0,00%

Figure 5 *Analysis of Variance* and *Model Summary of* Tensile Strength

To find out whether the research hypothesis is accepted or not, namely by looking at the results *of the P-Value* in the *Analysis of Variance.* The alpha value used is, at 5% or 0.05, the alpha value is the maximum limit of the *P-Value* error for the alternative hypothesis to be accepted. Based on the data of this study, the current strong variable has a P-Value of 0.272, so it can be stated that the current strong variable, does not have a significant influence on the tensile strength variable, and because the P-Value of the current strong variable exceeds the alpha limit, the null hypothesis is accepted and the alternative hypothesis is rejected. The protective gas flow rate variable has a P-value of 0.785, so it can be stated that the protective gas flow rate variable, does not have a significant effect on the tensile strength variable, and because the P-value of the protective gas flow rate variable exceeds the alpha limit, the null hypothesis is accepted and the alternative hypothesis is rejected. The variable of strong current interaction and flow rate of protective gas has a P-Value of 0.184, so it can be stated that the variable of strong interaction of current and flow rate of protective gas, does not have a significant effect on the variable of tensile strength, and because the P-Value of the variable of strong current interaction and flow rate of protective gas exceeds the alpha limit, the null hypothesis is accepted and the alternative hypothesis is rejected.

In the R-sq coefficient, if the value is closer to 100%, it can be interpreted that the independent variable has a significant influence on the dependent variable. In the results of the data processing above, it can be seen that the R-sq coefficient has a value of 36.32%, so it can be interpreted that the independent variable has an influence of 36.32% on the tensile strength of the specimen.

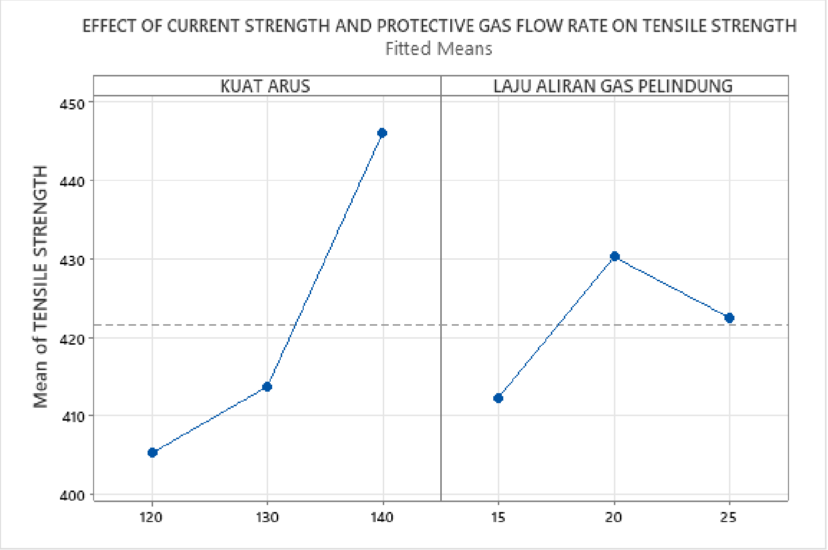

Figure 6 Effect of Current Strength Variation and Protective Gas Flow Rate on Tensile Strength

Figure 6 shows two lines, namely vertical and horizontal, the vertical line is a bound variable and the horizontal line is an independent variable. Based on the graph above, it can be seen that the current strength of 120 A and the flow rate of protective gas of 15 L/min produce the lowest tensile strength, and the current strength of 140 A and the flow rate of protective gas of 20 L/min produces the highest tensile strength.

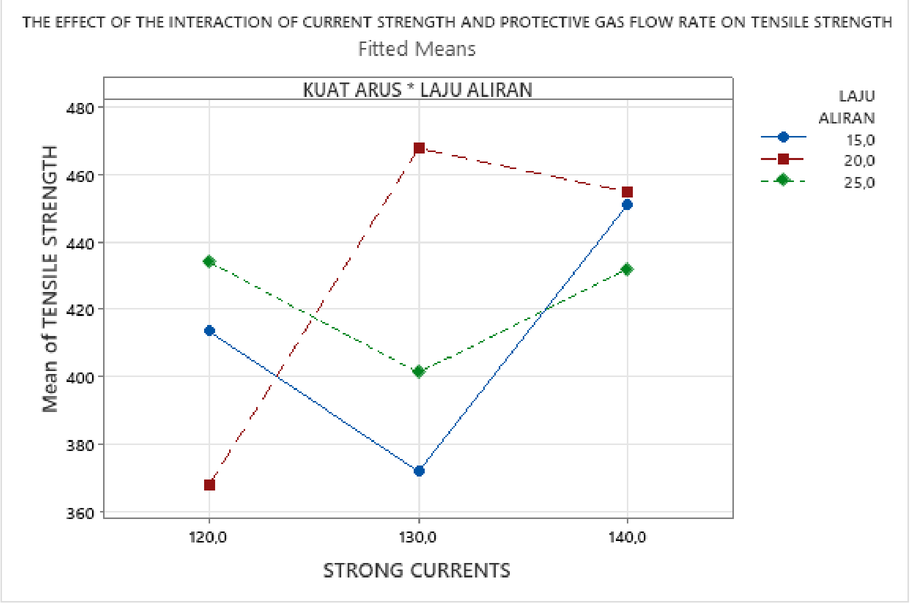

Figure 7 Effect of Interaction Current Strength and Flow Rate of Protective Gas on Tensile Strength

Figure 7 shows the influence of interaction variations in current strength and flow rate of protective gases on tensile strength. At a current strength of 120 A with a protective gas flow rate of 15 L/min has an average tensile strength of 413.6 MPa, then at a current strength of 120 A with a protective gas flow rate of 20 L/min there is a decrease in tensile strength with an average of 368.1 MPa, then there is an increase in tensile strength at a current strength of 120 A with a protective gas flow rate of 25 L/min with an average of 434.12 MPa. At a current strength of 130 A with a protective gas flow rate of 15 L/min has an average tensile strength of 372.04 MPa, then at a current strength of 130 A with a protective gas flow rate of 20 L/min there is an increase in tensile strength with an average of 467.79 MPa, then there is a decrease in tensile strength at an average current strength of 130 A with a protective gas flow rate of 25 L/min of 401.32 MPa. At a current strength of 140 A with a protective gas flow rate of 15 L/min has an average tensile strength of 451.17 MPa, then at a current strength of 140 A with a protective gas flow rate of 20 L/min there is an increase in tensile strength with an average of 454.8 MPa, then there is a decrease in tensile strength at a current strength of 140 A with a protective gas flow rate of 25 L/min with an average of 432.01 MPa. From the graph above, it can also be seen that there is an interaction between the current strength and the flow rate of protective gas against the tensile strength, this can be seen from the lines on the graph that intersect each other.

3.7. Impact Test Data Processing

Dari hasil pengambilan data, selanjutnya dilakukan pengolahan data uji tarik menggunakan *software* minitab 2021 menggunakan metode DOE *Factorial* untuk mengatahui pengaruh variable terhadap spesimen.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	21,625	2,7031	17,02	0,000
Linear	4	16,618	4,1546	26,17	0,000
KUAT ARUS	2	13,974	6,9868	44,00	0,000
LAJU ALIRAN GAS PELINDUNG	2	2,645	1,3224	8,33	0,003
2-Way Interactions	4	5,007	1,2517	7,88	0,001
KUAT ARUS*LAJU ALIRAN GAS PELINDUNG	4	5,007	1,2517	7,88	0,001
Error	18	2,858	0,1588		
Total	26	24,483			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0,398474	88,33%	83,14%	73,73%

Figure 8 *Analysis of Variance* and *Model Summary* of Impact Test

To find out whether the research hypothesis is accepted or not, namely by looking at the results *of the P-Value* in the *Analysis of Variance.* The alpha value used is, at 5% or 0.05, the alpha value is the maximum limit of the *P-Value* error for the alternative hypothesis to be accepted. Based on the data of this study, the current strong variable has a P-Value of 0.000, so it can be stated that the current strong variable, has a significant influence on the impact strong variable, and because the P-Value of the current strong variable does not exceed the alpha limit, the null hypothesis is rejected and the alternative hypothesis is accepted. The protective gas flow rate variable has a P-value of 0.003, so it can be stated that the protective gas flow rate variable, has a significant influence on the impact strong variable, and because the P-value of the protective gas flow rate variable is less alpha limit, the null hypothesis is rejected and the alternative hypothesis is accepted. The variable of strong current interaction and flow rate of protective gas has a P-Value of 0.001, so it can be stated that the variable of strong interaction of current and flow rate of protective gas, has a significant influence on the strength of impact, and because the P-Value of the variable of strong interaction of current and flow rate of protective gas exceeds the alpha limit, the null hypothesis is rejected and the alternative hypothesis is accepted.

In the R-sq coefficient, if the value is closer to 100%, it can be interpreted that the independent variable has a significant influence on the dependent variable. In the results of the data processing above, it can be seen that the R-sq coefficient has a value of 88.33%, so it can be interpreted that the independent variable has an influence of 88.33% on the impact strength of the specimen.

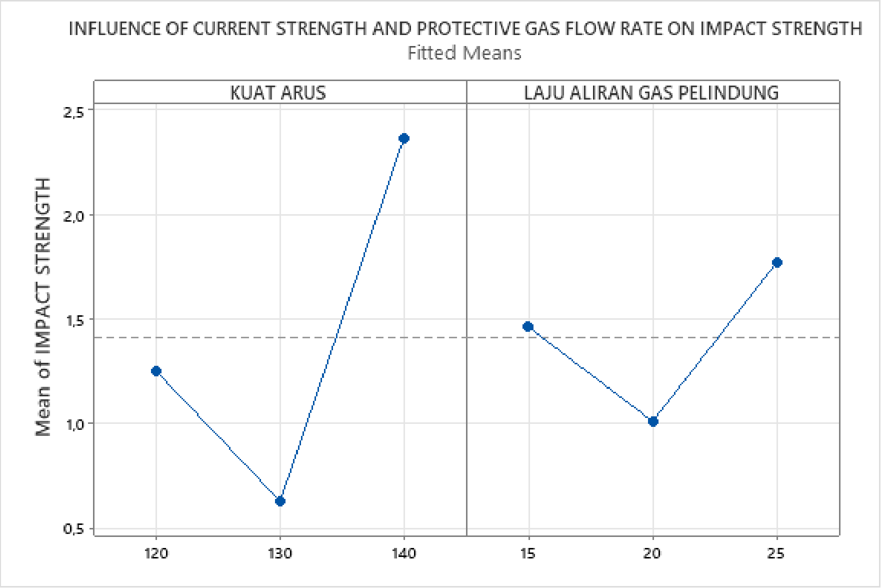

Figure 9 Effect of Current Strength Variation and Protective Gas Flow Rate on Impact Strength

The graph above has two lines, namely vertical and horizontal, the vertical line is a bound variable and the horizontal line is an independent variable. Based on the graph above, it can be seen that the current strength of 130 A and the protective gas flow rate of 20 L/minute produce the lowest impact strength, and the current strength of 140 A and the protective gas flow rate of 25 L/minute produces the highest impact strength.

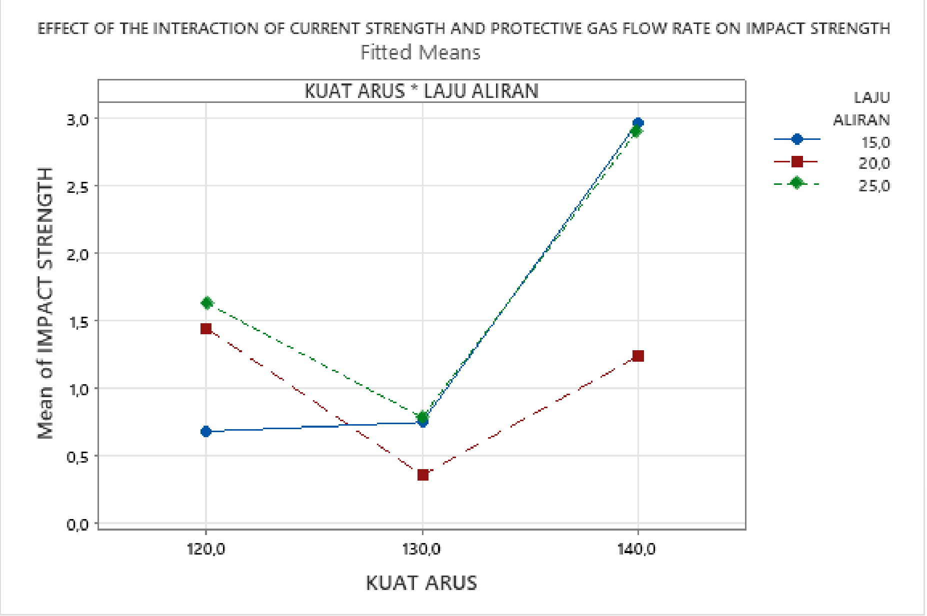

Figure 10 Effect of Current Strength Variation and Protective Gas Flow Rate on Impact Strength

The graph above shows the effect of interaction variations in current strength and flow rate of protective gases on impact strength. At a current strength of 120 A with a protective gas flow rate of 15 L/min has an average impact strength of 0.68 J/mm^2, then at a current strength of 120 A with a protective gas flow rate of 20 L/min an increase in impact strength with an average of 1.44 J/mm^2, there is an increase in impact strength at a current strength of 120 with a protective gas flow rate of 25 L/min with an average of 1.63 J / mm2. At a current strength of 130 A with a protective gas flow rate of 15 L/min has an average impact strength of 0.75 J/mm^2, then at a current strength of 130 A with a protective gas flow rate of 20 L/min an increase in impact strength with an average of 0.36 J/mm^2, there is a decrease in impact strength at a current strength of 130 A with a protective gas flow rate of 25 L/min with an average of 0.78 J/mm^2. At a current strength of 140 A with a protective gas flow rate of 15 L/min has an impact strength with an average of 2.96 J/mm^2, then at a current strength of 140 A with a protective gas flow rate of 20 L/min an increase in impact strength with an average of 1.23 J/mm^2, there is an increase in impact strength at a current strength of 140 A with a protective gas flow rate of 25 L/min with an average of 2.91 J / mm^2. From the graph above, it can also be seen that there is an interaction between the variation in current strength and the flow rate of protective gas against the impact strength, this can be seen from the lines on the graph that intersect each other.

3.8 Discussion

Based on research that has been done, generally, the tensile strength of the weld is higher than the tensile strength of the parent material, based on the catalog table above, the parent material SPHC has a minimum tensile strength of 270 MPa, the following is the discussion.

In the figure below is a graph showing the average tensile strength in the SPHC material from the process.

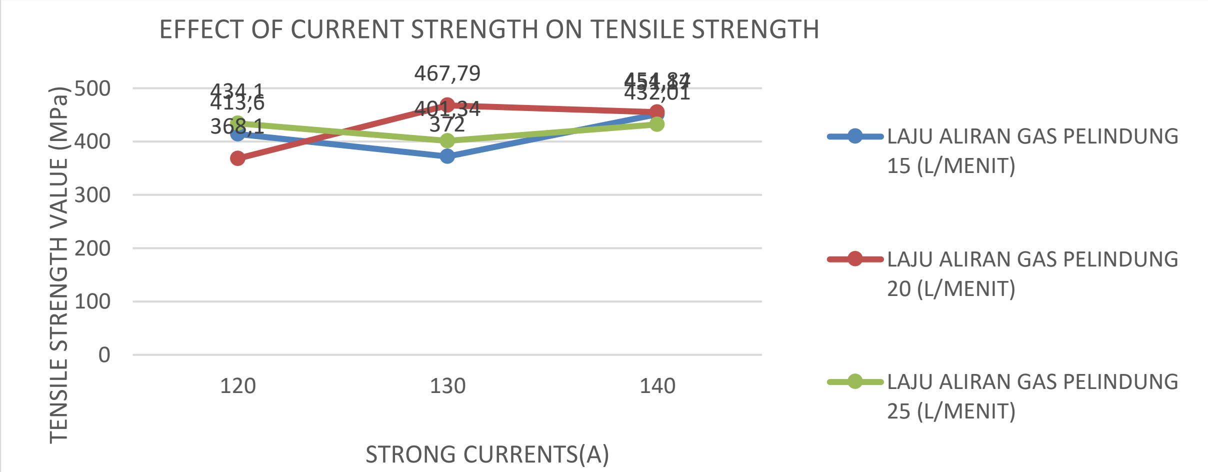

Figure 11 Effect of Current Strength Variation and Protective Gas Flow Rate on Tensile Strength

From the results of the graph above, it can be seen that the value of tensile strength after welding on average, has a higher value than the value of tensile strength before welding. The highest average tensile strength value of 467.79 MPa occurred at a current strength of 130 A and a protective gas flow rate of 20 L/mins, while the average value of a fixed tensile strength of 368.1 MPa occurred at a current strength of 120 A and a protective gas flow rate of 20 L/min. The increase in tensile strength is thought to be due to an increase in the strength of the current used to allow residual voltage not to occur. This decrease in tensile strength occurs allegedly because of the small strength of the current used it allows residual stress to occur in the weld area.

The figure below is a graph showing the average impact strength of SPHC material from the welding process with variations in current strength and a protective gas flow rate of 15 L/min.

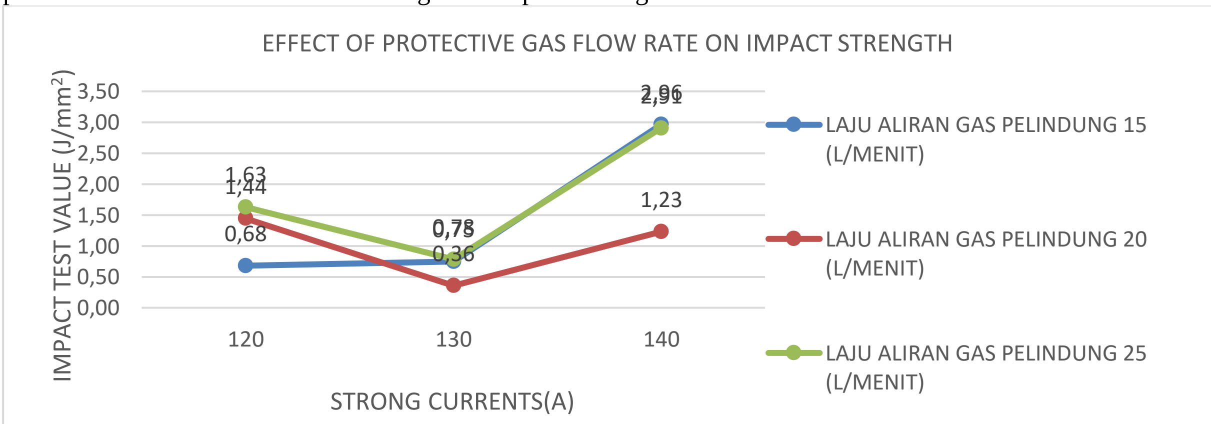

Figure 12 Effect of Current Strength Variation and Protective Gas Flow Rate on Impact Strength

From the results of the graph above, it can be seen that the value of impact strength after welding on average, has a lower value than the value of impact strength before welding. The highest average impact strength value of 2.96 J/mm^2 occurred at a current strength of 140 A and a protective gas flow rate of 15 L/min, while the lowest average impact strength value of 0.36 J/mm^2 occurred at a current strength of 130 A and a protective gas flow rate of 20 L/min. The increase in impact strength is thought to be due to the large amount of current used so that the residual voltage does not occur. This decrease in impact strength occurs allegedly because of the small strength of the current used so it allows residual voltage to occur in the weld area.

4. CONCLUSION

Based on the processing of analysis and discussion data, generally, the tensile strength of the weld metal has higher test results than the raw material, and the impact strength of the weld metal has lower test results compared to the raw material. Here are some conclusions from this study, namely:

4.1 The effect of strong current variations on tensile strength and impact results in the following conclusions:

a. Judging from the Analysis of Variance and the graph of the effect of strong current variations on tensile strength, statistically there is no effect but there is an insignificant increase. The highest average tensile strength of 446.01 MPa occurs at a current strength of 140A and the lowest average of 405.27 MPa occurs at a current strength of 120 A.

b. Judging from the *Analysis of Variance* and the graph of the effect of current strength variation on impact strength, statistically there is an influence on impact strength. The average high impact force of 2.3 J/mm2 occurred at a current strength of 140A and an average low of 0.63 J/mm^2 occurred at a current strength of 130 A.

4.2 The effect of protective gas flow rate variations on tensile strength and impact results in the following conclusions :

a. Judging from the *Analysis of Variance* and graphs of the effect of variations in protective gas flow rates on tensile strength, statistically there is no effect, but there is an insignificant increase. The average highest tensile strength of 430.24 MPa occurs at a protective gas flow rate of 20 L/min and the lowest average of 412.26 MPa occurs at a protective gas flow rate of 15 L/min.

b. Judging from the *Analysis of* Variance and the graph of the effect of current strength variation on impact strength, statistically there is an influence on impact strength. the highest average impact force of 1.78 J/mm^2 occurred at a protective gas flow rate of 25 L/min and an average low of 1.01 J/mm^2 occurred at a protective gas flow rate of 20 L/min.

4.3 The effect of the interaction of variations in current strength and flow rate of protective gases on tensile strength and impact results in the following conclusions:

a. Judging from the *Analysis of Variance* and the graph of the effect of the interaction of strong variations in current and flow rate of protective gases on tensile strength, statistics have no effect but there is an insignificant increase. From the influence of the interaction of variations in current strength and protective gas flow rate, the highest average tensile strength value of 467.79 MPa occurs at a current strength of 130 A and a protective gas flow rate of 20 L/min, while the average value of a fixed tensile strength of 368.1 MPa occurs at a current strength of 120 A and a protective gas flow rate of 20 L/min.

b. Judging from the *Analysis of Variance* and graphs, the effect of the interaction of variations in current strength and flow rate of protective gases on impact strength statistically there is an influence on impact strength. From the influence of the interaction of variations in current strength and protective gas flow rate on impact strength, the highest average impact strength value of 2.96 J/mm^2 occurred at a current strength of 140 A and a protective gas flow rate of 15 L/min, while the lowest average impact strength value of 0.36 J/mm^2 occurred at a current strength of 130 A and a protective gas flow rate of 20 L/min.

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