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The Effects of Process Parameters on Tensile and Impact Strength in Dissimilar Welding Between AH36 Steel And 304 Stainless Steel

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Abstract

A Merger of different type of steel are one of the very important aspects in today's modern industrial era. One of merged steel applications that are often used are in cargo tanks used in tanker ships that carried corrosive chemical liquid. AH36 steel & stainless steel are one of the types that are used on chemical tanker construction. On dissimilar metal welding, a lot problem occurs because of not completed formed or not completed smelting of the filler metal. On this thesis, factors that may affects the final welding of these 2 different steels which is electrode type, welding current and welding voltage will be analyzed closely. Next step, specimens of welded steel were analyzed using tensile strength test, impact test & hardness checking on the optimum condition. Afterwards, optimization was conducted using Grey Relational Analysis (GRA) and Taguchi to find out types and level of factors that produce optimum results of impact & tensile strength. From the optimalization results, it can be concluded that factors which have a significant influence on the welding are electrode type and welding current. Levels that give optimum results are E7016L electrode, 85 A welding current and 110V welding voltage that gives tensile strength result of 97.781 kg.f and impact result of 75.679 j. The Results of Vickers hardness testing shows that the biggest value occurs on the root welding which is 415 HV and the smallest occurs on the AH36 base metal which is 145 HV.

Keywords: Template, IJMES, mechanical, experiment

1. Introduction

Today's technological advancements demand the production of many products with superior properties and durability. However, beyond this, the need for low-cost products that still meet existing standards is also pressing. Storage tanks, cargo tanks, and chemical processing tanks require superior properties and durability. Chemical storage requires materials that are corrosion-resistant and non-reactive when exposed to chemicals. Stainless steel is one such material. To increase strength and durability, cladding is often used. This is typically done to anticipate and accommodate differences in conditions between the two materials and to meet construction standards without incurring significant costs. Various methods for joining steel materials exist, such as adhesive bonding, mechanical fastening, and welding [1]. In this case, the joining is achieved using a welding joint.

This type of structure is often used in chemical tankers ship. In chemical tankers, carbon steel is used on the exterior (in the ballast tanks) and stainless steel is used on the interior, which is in direct contact with the chemical fluids. AH36 steel and 304 stainless steels are common materials used in the construction of chemical tankers. During the construction phase, a finished product, called cladding, is used, using a hot rolling process to join the sheets of both materials. Problems often occurs when partial (not complete) repairs or renewals are required. This happens because the joining process during the welding phase is quite complex, requiring two dissimilar materials. The reason for this problem quite varies, like different melting points, difference electrochemical potential, and undesirable formed compound, coefficients of thermal expansion [2].

This research will analyze several factors that can influence the welding results of these two materials. The goal is to ensure optimal welding results between AH36 steel and 304 stainless steels, even with limited equipment and conditions. The methods used to measure the strength will be using tensile strength testing and impact testing. Optimization will then be conducted to determine the types and levels of factors that produce optimal tensile and response test results. The Optimization methods used in this research is grey relational analysis (GRA) and Taguchi. The results of this research will show the factors that have significant effects, levels that gives optimum results and distribution of hardness based on the optimum sample result.

2. Experimental/theoretical method

Details of materials and methods used for testing and optimalization will be explained shortly.

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2.1. AH36 Steel

AH36 are a type of carbon steel that have a relatively high strength compare to other carbon steels [3]. This type of steel is often used in ship or offshore structure since its mechanical properties that are easy to be shaped and produced. AH36 steel has a relatively small amount of carbon which is 0.18%.

2.2. Stainless Steel 304

Stainless Steel 304 are types of steel that basically contain 18% chromium and 8% nickel from its overall weight and have a great resistance to corrosion. This type of stainless steel is the most widely used since it's easy to form and affordable to the market. Stainless Steel 304 is usually used in containers for food, pharmacy and chemical liquid.

2.3. Shielded Metal Arc Welding (SMAW)

Shielded Metal Arc Welding, are also known as stick welding, is a manual arc welding process that uses a consumable electrode covered with a flux to lay the weld [4]. The electrical energy will give heat that makes the base metal and the electrodes melt and then freeze back together. During the welding process, the flux will cover & protect the melting electrode and form a black layer afterwards. This type of welding is the most widely used method since it is easy and cheap to operate.

Figure 1. Overhead SMAW Welding Process

2.4. Charpy Impact Testing

Impact test is a test used to measure a material's notch toughness and energy absorption when it has a fracture after being hit by something [5]. This test will use a pendulum that is dropped from a certain height and struck a notched specimen of material. The standard procedure used in Charpy impact test is ASTM A370. It has a standard test piece dimension of 10 mm x 10 mm x 55 mm and the subsize specimen used in this research are 10 mm x 7.5 mm x 55 mm.

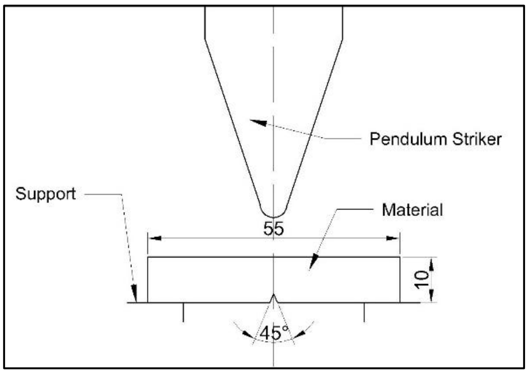

Figure 2. Charpy Impact Testing

2.5.Tensile Strength Testing

Tensile Strength Testing is a method used to calculate a force required to elongate a specimen to breaking point [6]. This test is carried out by pulling the specimen in two different angles until it breaks and then calculate the elongation and the force required. ASTM E8 is the most widely used standard in applying the tensile strength test. The test is carried out by cut the specimen to a specific shape where its length is 4x its width and the test is conducted on room temperature 10^{o} until 38^{o} Celsius.

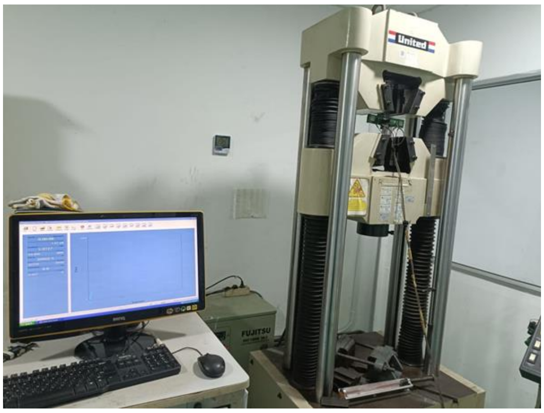

Figure 3. Tensile Strength Testing Machine

2.6. Grey Relational Analysis

Grey Relational Analysis (GRA) is a optimalization methods used to determine the optimum condition of various parameters to obtain the best quality [7]. The word "grey" refers to information of the research that is either incomplete or undetermined. GRA can be used to derive optimum condition for multi – objective problems by providing weightages to individual responses. There are 3 schemes used in determining GRA, which is "Higherthe-better", "Smaller-the-better" or "nominal the best". The final decision is determined through gaining the number of Grey Relational Grade (GRG). The steps required in GRA is:

- Data Pre – Processing
- Normalizing
- Deviation Sequence
- Grey Relational Coefficient
- Grey Relational Grade

2.7. Taguchi Analysis

Taguchi Method is a statistical approach to increase the quality of a product by reducing the variability that may cause an effect to the production process [8]. This method is widely used in manufactured good, marketing, advertising, and recently are used in engineering's. The method is carried out by selecting the controls and level's and then select the orthogonal array matrix. With this mathematical model, factors and levels that gives optimum results can be predicted. Taguchi can be specified into three situations, which is:

- Larger the better
- Smaller the better
- On-Target, minimum-variation

3. Results and Discussion

Both stainless steel 304 and AH36 steel are in form of 8 mm sheet plate and cut to 120 x 240 mm size and joint using a tag weld and a run off/on plate. Gap of 2 mm and bevels are shaped in the welding area to ensured good welding penetration.

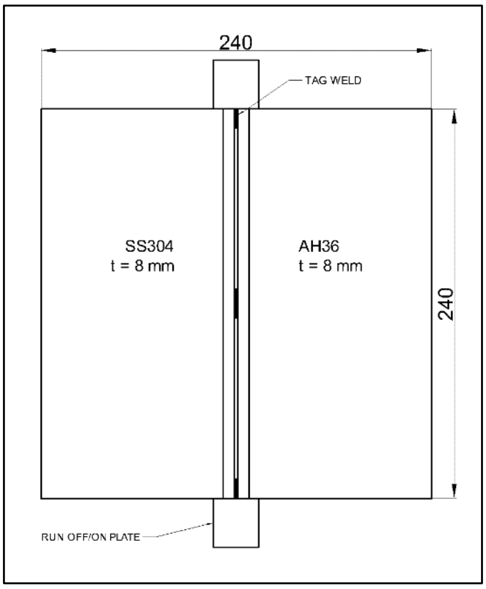

Figure 4. Test Piece Design

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The test piece welded using Shielded Metal Arc Welding Process with specific combination of parameters. The factors and levels used in this research are described as below:

Table 1. Factor & Design of Research

Electrode Type	Current (A)	Voltage (V)
E7016L	65	95
E309L	85	100
	100	110

Each of the samples were repeated once, so it makes the total samples of the research is 36 samples. After welding finished, the specimen is machined to specific shape and size for Tensile Strength and Impact Testing

3.1. Tensile Strength & Impact Testing

Both testing is carried out in laboratory after the machining process. The standard used in this research tensile strength testing is ASTM E8, while the impact testing use ASTM370. The tensile strength shows that the specimen break on the AH36 steel area. The Impact Test indicates the specimen didn't break entirely after being hit by the pendulum. This can be concluded that the specimen categorized as ductile. The Results shows as follow:

Figure 5. Impact Test Piece

JOURNAL OF INTELLECTUAL POWER
E-ISSN : 3048-3646

Figure 6. Tensile strength Piece from SS304 (Left) and AH36 Steel (Right)

Table 2. Results of Impact & Tensile Strength Testing

No. Samples	Electrode	Current (A)	Voltage (V)	A Sample		B Sample	
				Impact (J)	Tensile (N/mm^2)	Impact (J)	Tensile (N/mm^2)
1			95	67.12	92.184	69.16	90.345
2		65	100	69.165	94,216	68.52	93.65
3			110	70.567	93.621	69.324	92.426
4			95	70.22	94.771	72.54	93.112
5	E7016L	85	100	73.87	95.441	72.45	94.321
6			110	76.45	96.414	75.679	97.781
7			95	75.588	92.973	74.245	93.195
8		100	100	74.654	91.372	72.562	92.863
9			110	68.63	94.225	70.654	94.776
10			95	54.761	89.943	53.543	90.234
11		65	100	58.492	92.364	57.765	91.875
12			110	60.43	91.514	61.67	90.56
13			95	62.41	91.655	63.56	90.864
14	E308L	85	100	60.55	92.775	62.88	90.543
15			110	55.36	97.742	64.14	92.511
16			95	53.32	90.459	56.52	91.544
17		100	100	55.633	92.562	55.678	91.892
18			110	54.62	91.534	56.42	90.344

3.2 Grey Relational Analysis

Grey Relational Analysis is carried out using the results from the tensile strength and impact test. A total of 36 sample will be processed to gained the Grey Relational Grade. Afterwards, the Grey Relational Grade will be ranked to earn the optimum results. The results are shown below:

Table 3. Results of Grey Relational Grade

No. Samples	A Sample		B Sample	
	GRG	Rank	GRG	Rank
1	0.336	18	0.333	19
2	0.393	14	0.374	16
3	0.397	13	0.361	17
4	0.419	10	0.415	11
5	0.494	3	0.439	7
6	0.591	2	0.646	1
7	0.474	4	0.448	6
8	0.429	8	0.412	12
9	0.388	15	0.425	9
10	0.240	36	0.239	36
11	0.285	24	0.274	29
12	0.282	26	0.277	27
13	0.294	22	0.292	23
14	0.301	21	0.284	25
15	0.449	5	0.318	20
16	0.241	34	0.265	31
17	0.276	28	0.266	30
18	0.258	32	0.250	33

The results above shows that sample no. 6B have the largest GRG of 0.646. This shows that sample no. 6B has the most optimum results of both Tensile Strength and Impact Testing. Combination of E7016L electrode, welding current of 85A and welding voltage of 110V shows the most optimum results.

3.3. Taguchi Analysis

Analysis using Taguchi are conducted to each Impact and Tensile Strength results separately to shows which factor gives the significant effect to the research. The model used in this analysis is L36 since there were 36 samples and conducted 2 times.

A. Impact Testing

Taguchi of L36 of the impact results are modelled. The models consist of 3 factors with one factor of 2 levels and two factors. The models are analyzed using ANOVA to found the P – Value.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Kawat	1	1648.98	1648.98	207.26	0.000
Arus	2	118.13	59.07	7.42	0.002
Voltase	2	5.79	2.89	0.36	0.698
Error	30	238.69	7.96		
Lack-of-Fit	12	176.05	14.67	4.22	0.003
Pure Error	18	62.63	3.48		
Total	35	2011.59			

Figure 7. ANOVA results of Impact Testing

The coefficients of α used in this analysis is 0.05. The results shows that Electrode (*kawat*) and current (Arus) have P Value < 0.05. It can be concluded that Electrode and Current have a significant effect on the impact results.

B. Tensile Strength Testing

Taguchi of L36 of the Tensile Strength results are modelled. The models consist of 3 factors with one factor of 2 levels and two factors. The models are analyzed using ANOVA to found the P – Value.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Kawat	1	50.82	50.8155	40.46	0.000
Arus	2	16.26	8.1308	6.47	0.005
Voltase	2	12.02	6.0117	4.79	0.016
Error	30	37.68	1.2560		
Lack-of-Fit	12	25.65	2.1377	3.20	0.013
Pure Error	18	12.03	0.6682		
Total	35	116.78			

Figure 8. ANOVA results of Tensile Testing

The coefficients of α used in this analysis is 0.05. The results shows that Electrode (*kawat*) and current (Arus) have P Value < 0.05. It can be concluded that Electrode and Current have a significant effect on the Tensile Strength results.

3.4. Factors Percentage

To predict the amount of contribution of each factor to the variation, the author calculates the contribution percentage using the grey relational grade (GRG) gained in the calculation before. The first step of analysis is by calculating the sum square total (SST) of the Grey Relational Grade (GRG) of each level.

$$SST = \sum_{t=1}^{n}(Y_1 - \bar{Y})^2 \text{ ......(1)}$$

Where:

Y_1 = Individual Observation of GRG

$\bar{Y}$ = Overall Mean

Therefore, we got the SST of each level are:

Tabel 4. SST Factor

SST Factor		
Electrode	**Current**	**Voltage**
0.432	0.316	0.333
0.283	0.412	0.352
	0.344	0.387

The Sum Square Total = 0.017

Afterwards we proceed with the percentage calculation which use the formula as below:

$$\%\ Contribution = \left(\frac{SS\ Factor}{SST}\right) \times 100 \text{ ....(2)}$$

Therefore, it calculated based on sum square per factor and shows results as below:

Table 5. Contribution Percentage

Factor	% Contribution
Electrode	63.68
Current	27.83
Voltage	8.49

3.5. Hardness Testing

After gaining the optimum levels of the research, the author aimed to validate the results by hardness testing using rockwell method. The sample used in the testing are no. 6B with the parameters of E7016L electrode, 85A welding current and 110V welding voltage. The hardness point taken consist of 1 row in Capping Area of 13 points 1.5 mm from top and 1 row in Root Area of 11 points 1.5 mm from bottom.

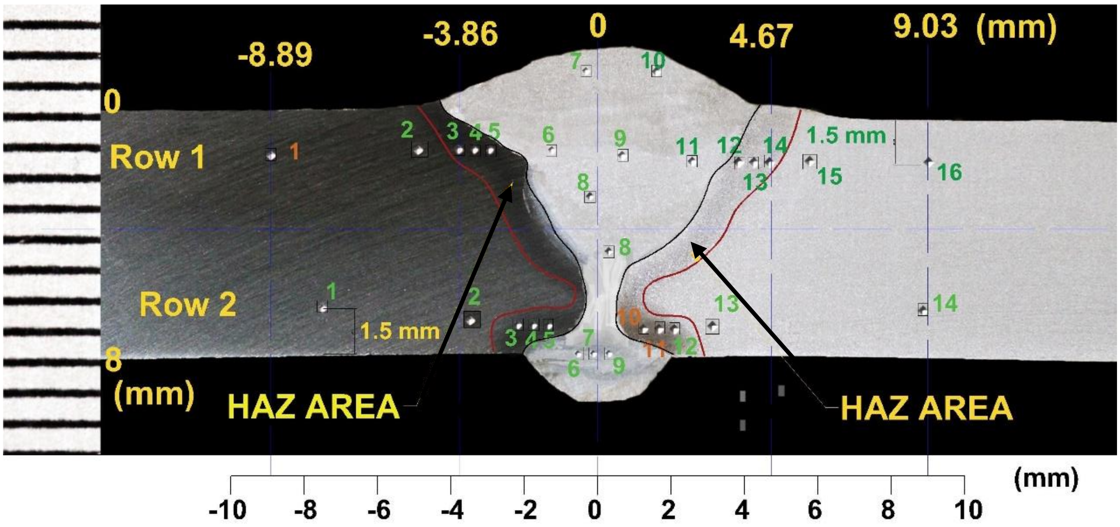

Figure 9. Hardness Point

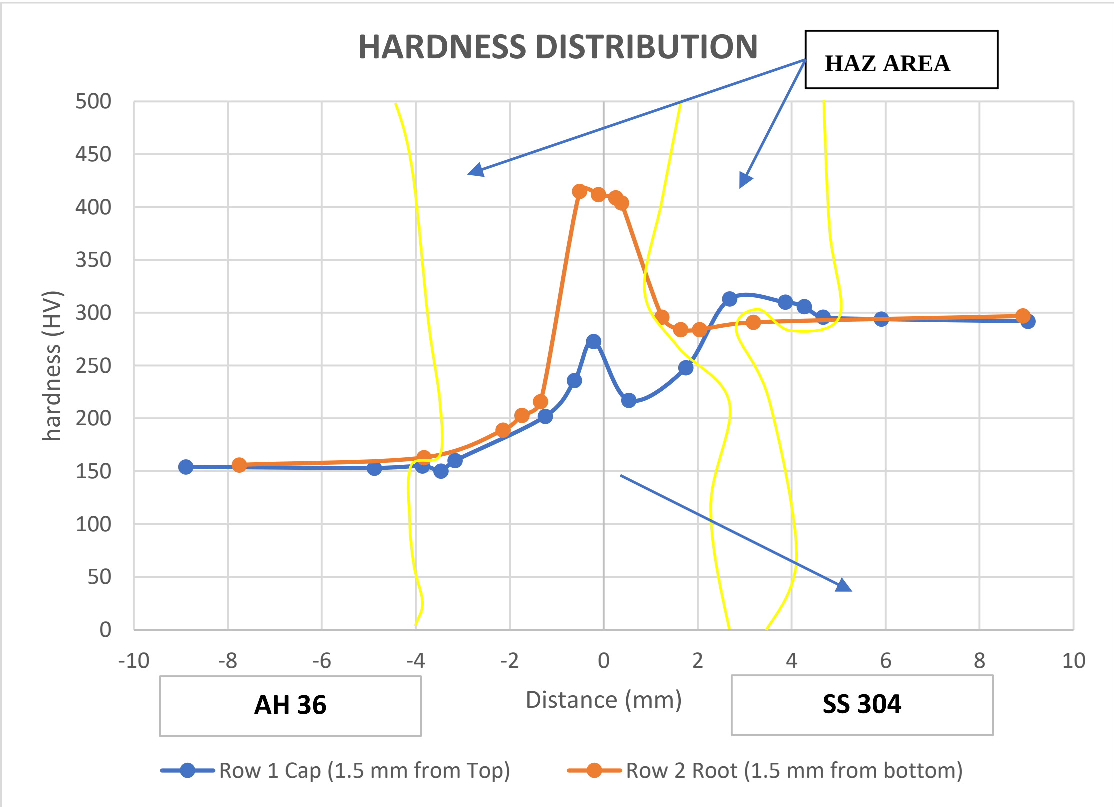

Figure 10. Hardness Distribution Graph

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Table 6. Hardness Result

Row 1		Row 2	
Jarak (mm)	Hardness (HV)	Jarak (mm)	Hardness (HV)
-8.89	154	-7.75	156
-3.86	155	-2.14	189
-3.46	150	-1.74	203
-3.16	160	-1.34	216
-1.24	202	-0.51	415
-0.62	236	-0.11	412
0.54	217	0.38	404
1.75	248	1.24	296
2.68	313	1.64	284
3.87	310	2.04	284
4.27	306	8.92	297
4.67	296		
9.03	292		

From the hardness testing, the maximum results occur on row no. 2 in the root welding area with 415 HV. The smallest results occur on row no. 1 in the base metal area with 150 HV. This match the conclusion on the tensile strength testing that the specimen was break in the AH36 steel area. This might happen because of the strength of the welding & stainless-steel area are larger than the AH36 steel area.

4. Conclusions

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This research demonstrates a successful method of finding parameters for a welding sequence. For this research case, for welding stainless steel 304 and AH36 steel materials of 8 mm sheet plate using shielded metal arc welding (SMAW), factor of electrode type and welding current found to have significant effect on the process. Parameters of E7016L welding electrode, 85A welding current and 110V welding voltage are found to give optimum results in impact testing & tensile strength testing. Hardness Test indicates that the strongest position is on the welding area, while the weakest position are on the AH36 steel area. Author strongly suggests to carry out research on other form of steels like pipes or round bar.

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