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THE EFFECT OF CURRENT AND LAYER IN BIMETALLIC WELDING USING J4-AH36 FILLER ON TENSILE STRENGTH

1,2,3) Mechanical Engineering Department, State Polytechnic of Malang, Jl. Soekarno-Hatta 9, Malang 65141, Indonesia
4) Mechanical Engineering Department, State Polytechnic of Jakarta, Jl. Prof. DR. G.A. Siwabessy, Kampus Universitas Indonesia, Depok 16425

Corresponding email [2)] :
syamsul.hadi@polinema.ac.id
syampol2003@yahoo.com

Andri Setiawan [1)], Syamsul Hadi [2)], Nila Alia [3)], Muslimin [4)]

Abstract. If filler metal AH36 steel is used in bimetallic welding, it has the disadvantage of oxidation in the weld area. Also, the weld crack is encountered if filler metal J4 stainless steel is used in bimetallic welding. In this research, welding methods include the preparation of two types of base metal and a twisted combined filler of AH34 steel and J4 stainless steel as a filler rod applied. The welding of 5 mm thick bimetallic material uses the GTAW (Gas Tungsten Arc Welding) or TIG (Tungsten Inert Gas) process with a current electric welding 60 A, 70 A, and 80 A, one layer and two layers, and angle position 90º to 75º. Preparation of tensile test specimens, provision of shallow notches in the weld where the cross-sectional area of the same as the two-parent metals that have been welded together, tensile testing, and analysis of research data are conducted. The welding results using a current of 60 A with one layer showed a tensile strength of 402 MPa. However, welding with two layers decreased to 200 MPa with a difference of 50 % that means there is a significant difference. In the current of 70 A with one layer, the tensile strength is 433 MPa and with two layers, the value decreases very little at 426 MPa with a difference of 2 %, which means there is a minimal difference and makes the best current selection. For current 80 A with one layer produces tensile strength of 412 MPa. Yet, with two layers, the value decreases slightly to 380 MPa with a difference of 8 %, which means there is a relatively small difference.

Keywords: TIG Welding, GTAW, Combined Filler, AH34 Steel, J4 Stainless Steel, Tensile Strength, Layer.

1. INTRODUCTION

The obstacle in bimetallic welding is the selection of filler rods that cause cracks or oxidation in the weld area. AH36 steel filler has the disadvantage of oxidation in the weld area for bimetallic steel and stainless steel welding. On the other hand, J4 stainless steel filler may become cracked, which should be avoided. The microstructure of carbon steel and stainless steel interface shows three types: a weakened ferritic layer, a ferritic layer, and austenitic steel dark layer [1]. The microstructure of the weld transforms gradually from ferritic to austenitic. Bimetallic welding defects are influenced by the type of electrode of the filler wire and the electrode coating material [2]. Wire and electrode coating significantly affect the results of bimetallic welding. The L415/316L mechanically coated bimetallic pipe is welded using an internal post-welding process to reduce costs and improve weld quality. The outer carbon layer is welded before the inner bimetallic stainless steel layer [3]. Welding of stainless steel bimetallic pipes is carried out after the outer part is coated with carbon as a composite pipe. Lighter materials are used with a combination of steel and aluminum by welding to achieve maximum benefits to reduce the car's weight [4]. Efforts to reduce vehicle weight are obtained by using lighter materials by welding to get fuel savings.

The joint behavior between AISI 304L stainless steel and copper plate by continuous-wave fiber laser welding at a maximum joint efficiency of 99% achieves a tensile strength of 224 MPa focused on the butt line [5]. The welding between AISI 304L and copper plate by continuous-wave fiber laser welding can achieve maximum joint efficiency. Butt welding on L415/316L bimetallic pipe is carried out by post-internal welding process with two sides of the most suitable groove is L415 V shape 60º, 1 mm blunt edge and 316L stripped 6 to 8 mm [6]. Particular weld joint grooves can provide the best weld results. Bimetallic welding between 2205 duplex stainless steel and X65 pipe sheet steel, multi-layer, and multi-pass is performed by GTAW [7]. Bimetallic welding has been performed well on 2205 duplex stainless steel and X65 sheet steel pipe, which shows the in-homogeneity of the properties of the welded joint.

An explosive welding process fabricated a circular bimetallic pipe then reshaped it into a square tube by a shape-rolling process. It showed that the micro-crack propagation was accelerated during the shape-rolling process, and the number of micro-cracks was increased, which resulted in a decrease in shear strength [8]. The shear strength decreases due to the shape rolling process because the micro-crack propagation is accelerated, and the number of microcracks is increased. Carbon migration is formed in the soft zone near the interface of SA 516 grade 65 and the weld, and a hard zone forms near the interface of the weld and SUS 304L. The temperature should not be too high and can also be prevented by increasing the thickness of the carbon layer on carbon steel to stop carbon migration [9]. The interfacial zone temperature is not too high to prevent carbon migration.

Explosive welding is used in cladding aluminum plates on ship protective cover plates at different explosive ratios. The results show that the waves at the interface increase with increasing explosive ratio and parallel with their wavelength and amplitude [10]. Explosive welding of aluminum plate cladding on ship steel plates at different volatile ratios produces other waves at the interface. Galvanized steel (EX280) with a thickness of 2 mm was welded to aluminium 5754 with a thickness of 3 mm by MIG welding-brazing resulting in better tensile strength with $AlSi_3Mn$ filler wire of an average of 188 MPa than with $AlSi_5$, and $AlSi_{12}$ filler wire [11]. Different filler wires produce different tensile strengths in a bimetallic weld.

Laser hybrid welding with butt joints in stainless steel (304SS) and T2 copper achieves a tensile strength of 215 MPa or equivalent to 200-240 MPa of T2 copper [13]. Butt-joint laser hybrid welding of 304SS and T2 copper provides tensile strength comparable to that of T2 copper. Nd: YAG continuous-wave laser welding of H62 brass and 316L stainless steel with overlapping configuration improves performance [14]. Continuous-wave laser welding on H62 brass and 316L stainless steel shows better performance in the overlap configuration.

Stainless steel and copper laser welds exhibit some micro-cracks generated in the fusion zone due to thermal stress mismatch corrected by molten copper filling. The amount of fused copper must be limited during welding and excess smelting of copper leads to liquid separation and the formation of micro-cracks within the fusion zone [15]. Copper smelting should be limited to prevent micro-cracks within the fusion zone. The bonded CP-Ti/Q345 bimetallic sheet filled with Cu/V solid wire experienced severe cracking which could be reduced by the use of Cu-V flux core wire [16]. Flux wire suitable for bimetallic welded materials can reduce weld cracking.

2. METHODS

Bimetallic welding research uses the base metal material in AH36 steel, J4 stainless steel with a combined filler rod between ER304 electrode for J-4 stainless steel electrode and ER50-60 electrode for AH36 steel is twisted together as a joint welding wire.

The research procedure was carried out by:

1) Preparation of welding plate. The plates consist of AH36 steel and J4 stainless steel with a size of 100 mm x 100 mm x 5 mm to be later cut into 5 for tensile test specimens.
2) Welding wire of both types is the same material with the diameter of 0.8 mm was purchased directly from the trade.
3) Making V grooves for welding joints with a milling machine with an angle of 30^o for one side of the AH36 steel plate and 30^o for the stainless steel plate.
4) Preparation of welding by adjusting the distance between two-parent metals with different types of materials, a certain distance (2.5 mm) remains along the weld seam groove with locking.
5) Welding of 2 base metals using a combined filler rod of ER50-60 and ER304. Welding wire has been twisted into a filler rod at currents of 60A, 70A, and 80A for one layer and two layers, respectively.
6) Cleaning the welds to be cut into five pieces of tensile test specimens according to ASTM E8/E8M-90 standards.
7) Tensile test.
8) Analysis of tensile test results.

The chemical compositions of the AH 36 and J-4 stainless steel plates are shown in Table 1.

Table 1. The composition of AH36 steel and J4 stainless steel [17], [18]

Material	C (%)	Mn (%)	Si (%)	P (%)	S (%)	N (%)	Al (%)	Nb (%)	V (%)	Ti (%)	Cu (%)	Cr (%)	Ni (%)	Mo (%)
AH 36 Steel	0.18	0.9 to 1.6	0.1 to 0.5	0.035	0.035	-	0.15	0.02 to 0.05	0.5 to 0.1	0.02	0.35	0.2	0.4	0.08
J-4 Stainless steel	0.1 (max)	8.5 to10	0.75 (max)	0.08 (max)	0.015 (max)	0.1 to 0.2	-	-	-	-	1.5 to 2	15 to 17	1 to 1.5	

AH36 steel has a yield strength of 355 MPa and tensile strength of 490 to 620 MPa with a strain of 19% [17] and J4 stainless steel has a yield strength of 300 MPa and tensile strength of 650 MPa with a strain of 40% [18].

The composition of the filler rod was determined using a spectrometer to determine the chemical elements of the metal contained in it from 2 different types of electrode wires of ER50-60 and ER304 which are shown in Table 2.

Table 2. The composition of combined filler rod of AH36 steel and J4 stainless steel [19]

Material	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Mo (%)	Ni (%)	Cu (%)
Combine filler rod of AH36 steel and J4 stainless steel	0.064	0.591	5.797	0.129	0.063	7.189	0.03	1.094	0.0746
	Al (%)	Co (%)	Mg (%)	Nb (%)	Ti (%)	V (%)	W (%)	Fe (%)	
	<0.005	0.054	<0.005	0.0099	0.0044	0.052	0.152	84.02	

The independent variables consisted of welding current (60 A, 70 A, and 80 A) and layers (1 layer and two layers). In contrast, the dependent variable was tensile strength. The controlled variable was 60º seam grooves, the thickness of the main plate from the two different materials is 5 mm, constant welding speed and angle, and a filler rod J4-AH36 twist.

Tensile strength data is obtained directly from the test results using the Tarno Grocky Universal Testing Machine, equipped with an electronic circuit that can produce a plot of the stress versus strain curve. The plate shape and dimensions of the tensile test specimen according to ASTM E8/E8M-90 are shown in Figure 1.

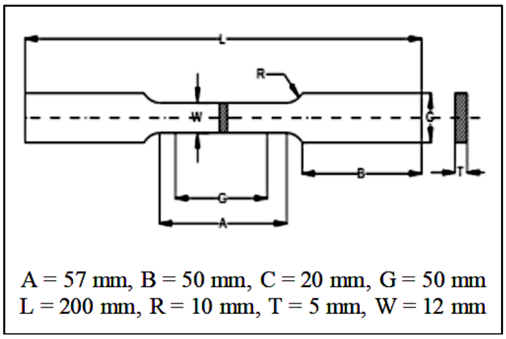

Figure 1. The plate shape and dimensions of the tensile test specimen [17]

Preparation of welded plate material consists of AH36 steel and J4 stainless steel. V-grooves of 30º angle of each specimen are made using a milling machine (a). Bonded with welds determines the distance between the bimetallic before welding (b). Welding using TIG Welding equipment is implemented (c). Cutting and shaping into a standard tensile test specimen size (d). Tensile testing is applied to obtain force and elongation data with a universal Testing Machine (e). Finally, the fracture surface of the broken specimen (f) is shown in Figure 2.

The calculations of the tensile strength, σ is used formula (1), cross-sectional area, A is used Formula (2), and strain, ε is used Formula (3).

$$\sigma = F/A \quad (1)$$
$$\varepsilon = (\Delta L/L_0) \times 100\% \quad (2)$$
$$A = w \times b \quad (3)$$

where: σ: tensile strength (MPa), F: force (N), A: cross-sectional area (mm^2), ε: strain (%), ΔL: elongation (mm), and L_0: gauge length (mm).

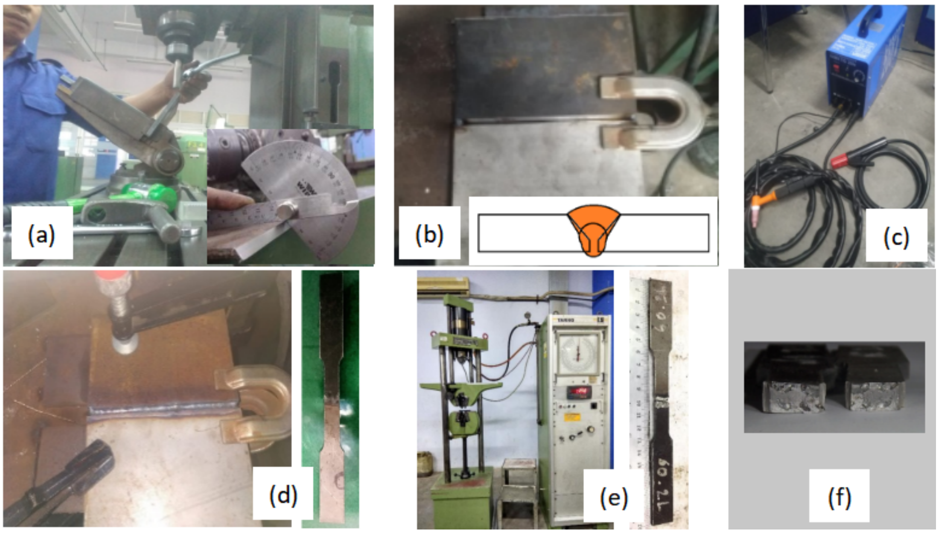

Figure 2. (a) Preparation of welded plate material by making side grooves at a 30º angle with a milling machine, (b) bonded with welds for setting the distance between the bimetallic, (c) welding with TIG Welding equipment, (d) cutting and shaping into a standard tensile test specimen size, (e) tensile testing with a Universal Testing Machine, and (f) the fracture surface of the broken specimen

3. RESULTS AND DISCUSSION

The tensile test results on the welded specimens of bimetallic AH36 steel and J4 stainless steel obtained force and elongation data. Force data is used to obtain tensile strength by dividing the force by the original cross-sectional area of the specimen in the gauge length area and for the strain obtained from elongation divided by the gauge length as the actual length of the sample multiplied by 100 % to obtain units in %. The serial data shows that tensile strength and strain can be plotted into stress versus strain curves. An example of stress- strain curve for a specimen welded with a current of 60A with one layer is shown in Figure 3.

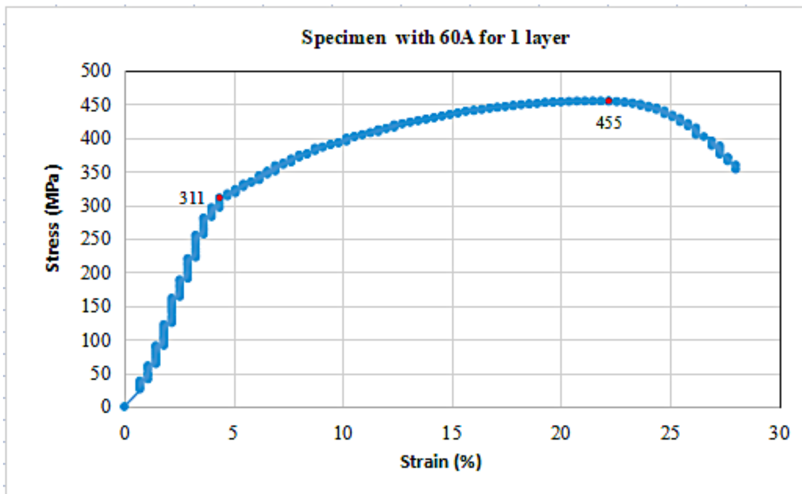

Figure 3. Stress versus strain curve for specimen welded with a current of 60 A with 1 layer

Each welding was repeated five times, which resulted in 5 tensile test data to determine the character of the data to ensure the results so that 30 serial tensile strength and strain data were obtained for three current welding treatments at 60 A, 70 A, and 80 A and the number of layers of 1 layer and two layers. Tensile test results data in the form of tensile strength and strain for current treatments at 60 A, 70 A, and 80 A and the number of layers of one layer and two layers are shown in Table 3.

Table 3. The tensile strength, σ and strain, ε results data for 60 A, 70 A, and 80 A and 1 layer and 2 layers

No.	I (A)	Layer	n-	F (kg)	W (mm)	T (mm)	F (N)	σ (MPa)	ΔL (mm)	L_0 (mm)	ε (%)
1	60	1	1	2783	12	5	27294	455	13	50	26
2			2	2487	12	5	24393	407	14	50	28
3			3	2800	12	5	27455	458	14	50	28
4			4	2735	12	5	26819	447	14	50	28
5			5	2699	12	5	26464	441	14	50	28
6		2	1	1133	12	5	11111	185	13	50	26
7			2	1145	12	5	11225	187	2	50	4
8			3	1176	12	5	11535	192	2	50	4
9			4	1157	12	5	11344	189	2	50	4
10			5	1208	12	5	11848	197	2	50	4
11	70	1	1	2762	12	5	27084	451	13	50	26
12			2	2794	12	5	27404	457	14	50	28
13			3	2645	12	5	25941	432	14	50	28
14			4	2720	12	5	26678	445	14	50	28
15			5	2695	12	5	26425	440	14	50	28
16		2	1	2582	12	5	25321	422	11	50	22
17			2	2463	12	5	24152	403	11	50	22
18			3	2593	12	5	25431	424	11	50	22
19			4	2579	12	5	25287	421	11	50	22
20			5	2594	12	5	25442	424	11	50	22
21	80	1	1	2667	12	5	26156	436	12	50	24
22			2	2522	12	5	24732	412	12	50	24
23			3	2574	12	5	25240	421	12	50	24
24			4	2597	12	5	25466	424	12	50	24
25			5	2612	12	5	25617	427	12	50	24
26		2	1	2265	12	5	22212	370	6	50	12
27			2	2251	12	5	22079	368	4	50	8
28			3	2328	12	5	22828	380	1	50	2
29			4	2263	12	5	22189	370	4	50	8
30			5	2254	12	5	22106	368	4	50	8

Table 3, compared to the current 60 A, 70 A, and 80 A used in TIG welding for one layer and two layers, shows the tensile strength and replication are shown in Figure 4 to Figure 6. The results of tensile strength and repeat for the current 60 A used in TIG welding for one layer and two layers are shown in Figure 4.

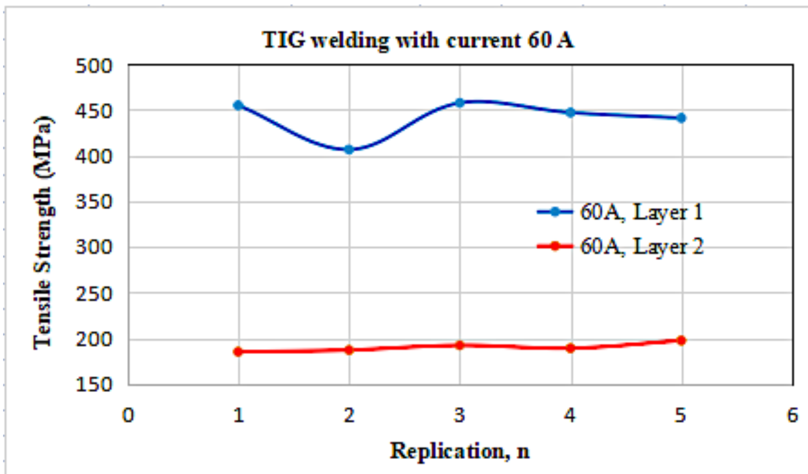

Figure 4. The tensile strength and replication for 60 A used in TIG welding for 1 layer and 2 layers

Figure 4 shows that the tensile strength is at a minimum value of 400 MPa and a maximum of 460 MPa, and the lowest is in the 2nd replication at a welding current of 60 A and one layer. Still, for two layers, it shows a typical tensile strength value of around 195 MPa. This is possible because the current used in TIG welding is too low for a plate thickness of 5 mm in welding bimetallic AH36 steel and J4 stainless steel.

The results of tensile strength and replication for the current 70A used in TIG welding for one layer and two layers are shown in Figure 5.

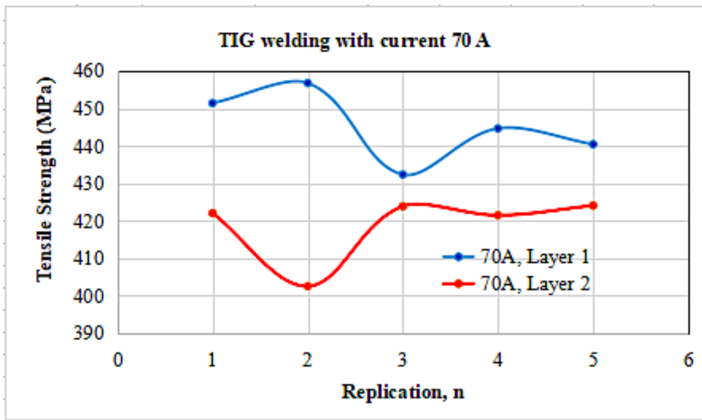

Figure 5. The tensile strength and replication for 70A used in TIG welding for 1 layer and 2 layers

Figure 5 shows that the tensile strength is at a minimum value of 432 MPa and a maximum of 458 MPa, and the lowest is in the 3rd replication at a welding current of 70 A and one layer. Still, for two layers, the tensile strength value is a minimum of 402 MPa and a maximum of 424 MPa. This shows that the results are close to the tensile strength results in one layer and two layers, which means that between 1 layer and two layers, the tensile strength results are good with a current of 70 in TIG welding bimetallic welding AH36 steel and J4 stainless steel.

The effects of tensile strength and replication for the current 80A used in TIG welding for one layer and two layers is shown in Figure 6.

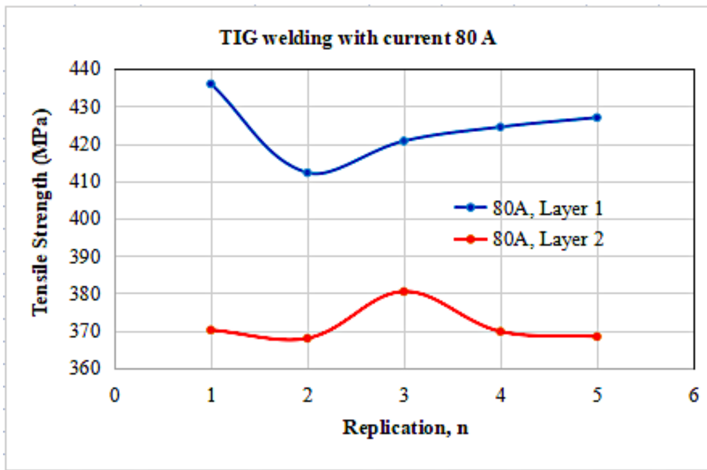

Figure 6. The tensile strength and replication for 80A used in TIG welding for 1 layer and 2 layers

Figure 6 shows that the tensile strength is at a minimum value of 412 MPa and a maximum of 437 MPa, and the lowest is in the 2nd replication at a welding current of 80 A and one layer. Still, the minimum tensile strength value for two layers is 369 MPa and a maximum of 380 MPa. This shows that the results are pretty different and lower between the tensile strength results in one layer and two layers, which means that between 1 layer and two layers, the tensile strength results are pretty good with current 80 A in TIG welding bimetallic welding of AH36 steel and J4 stainless steel.

The tensile strength of the parent metal of AH36 steel with a value of 490 MPa is lower than the tensile strength of J4 stainless steel with a weight of 650 MPa. Therefore the tensile strength of the weld with a bimetallic filler rod is compared with a lower value, namely the tensile strength of AH36 steel. Tensile strength is good in one layer and two layers, which results close together. Both of which reach a reasonably high value, namely in welding current 70 A, the highest is 458 MPa, and the lowest is 402 MPa, when compared to the tensile strength of AH36 steel, which is worth 490 MPa, meaning that it has reached tensile strength is about 82%. In contrast, at the current 60 A, it only reaches the lowest of 40 % at the current of 80 A. It resembles a relatively high of 75%.

The welding results using a current of 60 A with one layer showed a tensile strength of 402 MPa. In two layers, the value decreased to 200 MPa with a difference of 50 %. It means there is a significant enough difference. For a current of 70 A with one layer, the tensile strength is 433 MPa, but with two layers, the value decreases very little at 426 MPa with a difference of 2%, which means there is a minimal difference, and for current 80 A with one layer produces tensile strength of 412 MPa. Still, with two layers, the value decreases slightly to 380 MPa with a difference of 8 %, which means there is a relatively small difference. Selection of the best current of the three TIG welding is at 70 A with a difference in tensile strength for one layer 433 MPa close to two layers 426 MPa or about 2%.

4. CONCLUSION

The conclusions that can be drawn from the study of dissimilar welding of materials from AH36 steel and J4 stainless steel using a combined filler rod of ER304 electrode for J4 stainless steel electrode and ER50-60 electrode for AH36 steel include as follow:

1) Welding using a current of 60 A with one layer showed a tensile strength of 402 MPa. Still, with two layers, the value decreased to 200 MPa with a difference of 50 %, which means that there is a significant enough difference.
2) Welding using a current of 70 A with one layer, the tensile strength is 433 MPa, but with two layers, the value decreases very little at 426 MPa with a difference of 2 %, which means there is a tiny difference.
3) Welding using a current 80 A with one layer produces tensile strength of 412 MPa, but with two layers, the value decreases slightly to 380 MPa with a difference of 8 %, which means a relatively small difference.
4) The best current of the three TIG welding is at 70 A with a difference in tensile strength for one layer 433 MPa close to two layers 426 MPa or about 2%.

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