International Journal of Technology (2015) 4: 604-612
ISSN 2086-9614

EFFECT OF PRESSURE AND LENGTH OF LAP JOINT ON SHEAR LOAD AND JOINT CLEARANCE DURING DISSIMILAR METAL JOINING USING TORCH BRAZING FOR THE SHIPPING INDUSTRY

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(Received: June 2015 / Revised: September 2015 / Accepted: October 2015)

ABSTRACT

Torch brazing is one method of brazing based on using a heat source for joining metals. This method is classified as a liquid-solid state thermochemical process and is generally used in joining pipes. This process heats the brazing filler metal until it reaches the melting point without exceeding the melting point of the base metals to be joined. After cooling, the filler metal grants a strong joining capacity to the base metal. Depending on the amount of pressure and the length of lap joint in the brazing process the quality of the joint will be affected. This research will investigate the effect of pressure and the length of the lap joint on the material strength properties of BJ DD2 steel and C12000 copper. An optimal configuration between pressure and the length of lap joint will be determined from the result of shear load and joint clearance, which are the factors that affect joint strength and the process of brazing. The greater the shear load and the smaller the joint clearance, the higher the joint strength will be. The result shows that the pressure has a larger effect than the length of the lap joint for dissimilar metal joining using torch brazing.

Keywords: Dissimilar metal joining; Joint clearance; Joint strength; Shear load; Torch brazing

1. INTRODUCTION

The development of the world shipping industry has affected the ship support systems industry. Bilge, ballast, fire fighting, freshwater, seawater, fuel oil, lubricant oil, refrigeration, and cooling are several systems located on the ship (Wibowo, 2014). The main engine cooling system, which is using a diesel engine in the ship consists of a freshwater cooling system (closed) and a seawater cooling system (open) (Taylor, 1996). Heat exchangers on board ship are mainly coolers, where a hot liquid is cooled by sea water. The heat exchange process is accomplished by having the two liquids pass on either side of a conducting surface. Marine heat exchangers tend to have the two liquids flowing in opposite directions, i.e. counter or contra flow (Taylor, 1996). Ship systems need to join systems to assemblies. In an assembly of heat exchanger components, the brazing process is used to join the materials.

Brazing is a metal joining process in which two or more metal items are joined together by a filler metal, which has a lower melting point and the process creates a metallurgical bond. Welding joins materials at high temperatures, whereas brazing uses lower temperatures. Brazing is a process of joining materials, where the filler is placed between the surface of two components or two materials at the joint until the filler itself reaches the melting temperature,

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Permalink/DOI: http://dx.doi.org/10.14716/ijtech.v6i4.1893

which is still below the melting temperature of the base metal. This process is known as thermochemical joining technology at the liquid-solid state of bonding. After cooling, the filler metal grants a strong joint to the base metal. During the brazing process, filler metals typically have a melting point above 450ºC, which is below the melting point of the filler metal (Kalpakjian & Schmid, 2009). Torch brazing is one method of brazing that is used generally in joining pipes. The brazing process has been selected because it has many distinct advantages, including an economical fabrication of complex and multi-component assemblies, a simple method to obtain extensive joint area or joint length, a joint temperature capability approaching that of base metal, excellent stress distribution and heat-transfer properties, an ability to join dissimilar metals, an ability to join metal thicknesses that vary widely in size, and no need for a high skill capability from the welder (ASM International, 1993). Provision of pressure in the brazing process can affect joint results with the onset of the fillet on the edge of the joint, which can improve the quality of the joint (Suzumura et al., 2003; Baskoro et al., 2014). In addition to the pressure, the area also can affect the joint results (Baskoro et al., 2014).

This research will investigate the combined effect of pressure and the length of the lap joint on joint strength. The variables of exerting pressure on the joint and the length of the lap joint on the performance of the joint will affect the joint clearance, which is one of the most significant factors, which affect the joint strength in the brazing process. Joint strength will be investigated from the documentation of the tensile test results. Additionally, the research will also use metallography for purposes of observation to determine the quality of the joint. Brazing joint strength depends on joint clearance, joint area, and properties of the filler metal. Joint clearance usually ranges between 0.025–0.2 mm. Figure 1 shows the relationship between joint strength and joint clearance, where there is an optimum distance required in order to obtain maximum joint strength.

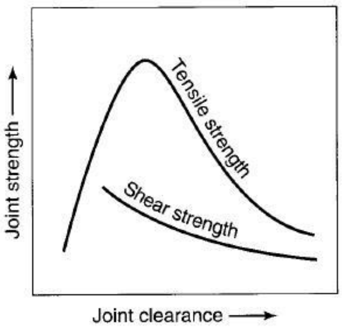

Figure 1 Effect of Joint Clearance for Joint Strength (Kalpakjian & Schmid, 2009)

2. EXPERIMENTAL PROCEDURES

2.1. Material and Torch Brazing Process

In this research, the specimens in Figure 2 were dissimilar metal (BJ DD2 steel and C12000 copper). The specimens used were flat plate with dimensions of 100×20×0.8 mm with a lap joint type.

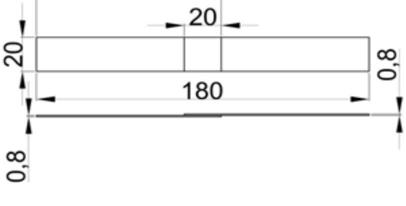

Figure 2 Specimen dimension

The chemical composition and mechanical properties of BJ DD2 steel and C12000 copper are shown in Table 1 and Table 2, respectively. The brazing process conducted in this research is classified as 'silver brazed,' since the type of filler metal used is silver alloy. BAg24 material (standard AWS A5.8) was used in this research and it is classified as a 'silver-brazed' type. The composition of this filler metal is listed in Table 3. BAg 24 was used for joining stainless steel (300 series), nickel alloy, and steel. The shape of the filler metal used in this research is a filler foil with a thickness of 0.035 mm. In this research, filler foil has been selected because the type of joint is a lap joint. Filler foil is a flexible material, without any flux, and it can be cut into desired shapes as needed for brazing welds.

Table 1 Chemical composition (%) and mechanical properties of BJ DD2 Steel

Symbol	**C (max)**	**Mn (max)**	**P (max)**	**S (max)**	**Thickness (mm)**	**Tensile Strength (N/mm^2)**	**Elongation (%)**
BJ DD2	0.08	0.40	0.03	0.02	$0.6 < t < 1$	270	40

Source: Badan Standardisasi Nasional (2014)

Table 2 Chemical composition (%) and mechanical properties of C12000 Copper

Symbol	**Cu**	**P**	**Section Size (mm)**	**Tensile Strength (MPa)**	**Yield Strength (MPa)**	**Shear Strength (MPa)**
C12000	99.9	0.008	0.8–1	248	193	172

Source: ASTM B152

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In this research, the brazing process used a STAY-SILV flux, which is designated as a (WHITE FLUX) SSWF60 60#PAIL type which meets a U.S. Federal Specification of 449 B type AWS A5.31 Class FB3 A AMS 3410. This flux can be used for all methods of brazing, work at low temperatures for silver filler. This type of flux is not recommended as a braze filler for aluminum, magnesium, and titanium. Working temperatures for flux range between 566ºC up until 871ºC (Harris Products Group, 2014).

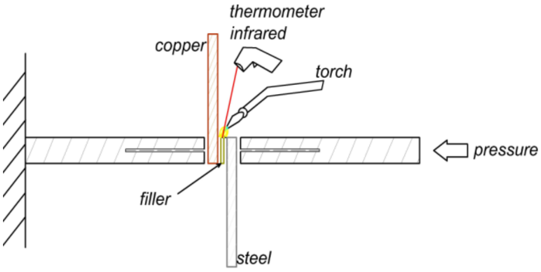

Figure 3 Schematic of Torch Brazing Procedures

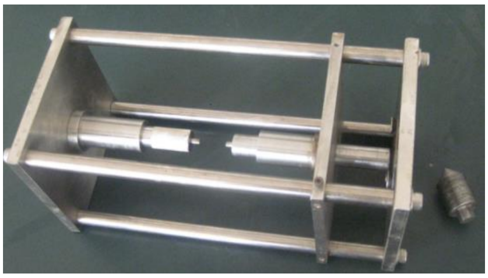

Figure 4 Torch Brazing Pressure Tool

Figure 3 shows a schematic of the torch brazing process conducted in this research. The heat source in this process was *oxy-acetylene gas*, and the heat given to the sample was between 630–660ºC. The pressure applied on the sample is derived from a tool that has been designed and used for previous research (Baskoro et al., 2014) and especially for this research as shown in Figure 4. Pressure applied on the joint increases from 0 MPa, 0.35 MPa, and 0.7 MPa, respectively with the length of lap joint varying from 10 mm, 15 mm, and 20 mm, respectively. Then, the samples that were successfully connected, as shown in Figure 5, will be tested by using a tensile test to obtain the shear load and metallography test results in order to determine joint clearance.

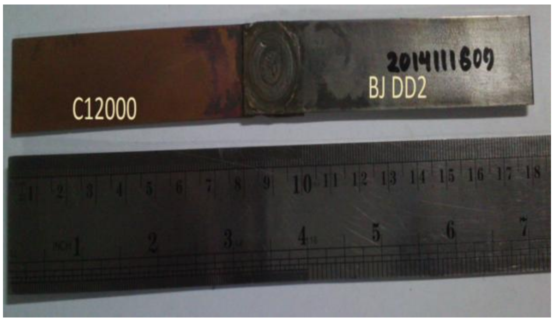

Figure 5 Joint specimen using Torch Brazing

Figure 6 Sample after tensile test

2.2. Tensile and Metallography Test

In this research, there were nine samples with each sample consisting of three specimens for tensile strength tests. In this experiment, there are 27 specimens. The tensile test used a tensile machine SHIMADZU. The tensile tests were conducted in the *Sentra Teknologi Polimer Badan Pengkajian dan Penerapan Teknologi (STP BPPT) Puspitek, Serpong.* Samples were composed in the form of a strip-shaped specimen. The specimens were conditioned at a temperature of 23ºC and a relative humidity of 50% for more than 40 hours, before conducting the tensile testing using a Universal Testing Machine (UTM) with a capacity of 50 kN, with a pulling speed of 5 mm/min at a temperature of 22.5ºC and a relative humidity of 53.5%. To obtain macrostructure and microstructure data, the samples must be prepared. Stages of sample preparation were sectioning, mounting, grinding, polishing and etching. The macrostructure and microstructure figures were taken with a magnification ranging from 50× to 200×, respectively. A measurement of the joint clearance was performed using the microscope in micron (µm) units. The measurement was performed three times on each sample.

3. RESULTS AND DISCUSSION

3.1. Tensile Test Results

Figure 6 shows the results of an investigation of the effects of pressure and the length of the lap joint on dissimilar metals joining using torch brazing. It shows that in almost all of the specimens in the tensile test fractures occurred in the Heat Affected Zone (HAZ) area of the copper. However, only several specimens broke at the joint. This is due to the tensile strength of copper being lower than steel and the result of dissimilar metals being joined using torch brazing in what would otherwise be a good joint.

Table 4 shows the parameters used in the process of torch brazing the joint and determining the shear load. Figure 7 shows that on the length of the lap joint at 10 mm, the shear load will be increased as a result of increasing the pressure. The highest shear load is obtained on the configuration pressure of 0.7 MPa and the length of lap joint is 15 mm. The pressure has the effect of being more dominant than the length of lap joint on the shear load during dissimilar metal joining using torch brazing.

Table 4 Shear load data from tensile test

No	Pressure (MPa)	Length of Lap Joint (mm)	Shear Load (kg)	Standard Deviation (kg)
1	0.00	10	299.47	29.89
2	0.00	15	311.43	7.12
3	0.00	20	314.27	4.80
4	0.35	10	163.93	88.1
5	0.35	15	315.10	33.18
6	0.35	20	318.02	25.26
7	0.70	10	277.09	45.95
8	0.70	15	319.83	42.37
9	0.70	20	275.48	78.29

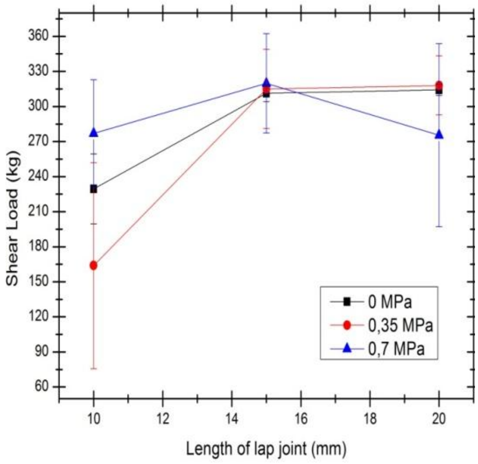

Figure 7 Effect of pressure and Length of Lap Joint on Shear Load

3.2. Metallography Observation Results

From Figure 8 it can be observed that the joint clearance and shape of the joint surface is influenced by the pressure and heating during the torch brazing process. The greater pressure will reduce the joint clearance, as was measured on the same level and at the distance between both of the base metals. It is also the same criteria as the length of lap joint that is inversely proportional to the joint clearance. The greater pressure and the length of lap joint will improve the quality of the joint for dissimilar metals being joined by torch brazing.

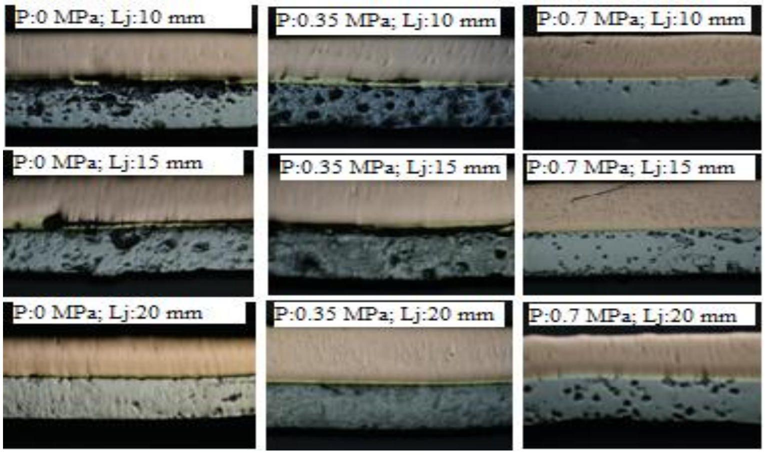

Figure 8 Macrostructures of Dissimilar Metal Joining on Torch Brazing at 50×

The optimum joint clearance is determined when the pressure parameter is 0.7 MPa and the length of the lap joint is 15 mm.

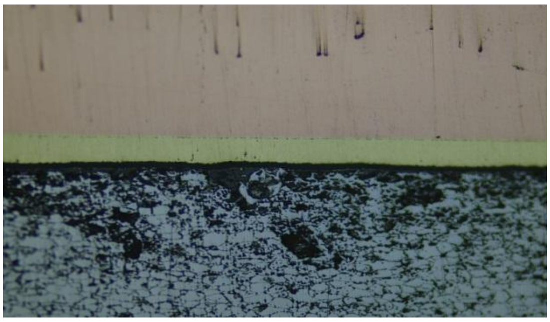

Figure 9 Microstructures of Dissimilar Metal Joining on Torch Brazing at 200×

Figure 9 shows the joint microstructures viewed by an Olympus microscope (with a magnification of 200×), with a pressure parameter of 0.35 MPa and a 20 mm length for the lap joint. In some of the pictures, intergranules can be seen that indicate fusion voids and a BJ DD2 steel cluster of shrinkage pores as well as less visible C12000 copper grain and gaseous porosity. Dissimilar metals occur in the eutectic melting phase. The boundary between steel, silver filler, and copper can be seen clearly. Loose joint clearances visibly show the poor quality of the joint.

3.3. Joint Clearance Measuring Results

Table 5 shows that measurements of joint clearance were performed three times for each specimen using microscope measurement. Using a microscope, Figure 10 shows the average measurement of the distance between the base metal and the joint. It can be seen that the highest and the lowest values of joint clearances are 0.35 MPa and 0.7 MPa, respectively.

According to Figure 10, the optimum joint clearance can increase the joint strength with an optimum joint clearance of 0.025–0.2 mm. The result obtained from the measurement data shows that the pressure on the joint has an effect greater than the length of the lap joint. The optimal joint clearance for the joining process for dissimilar metals such as BJ DD2 steel and C12000 copper using torch brazing is 0.2 mm with a pressure of 0.7 MPa and a 15 mm length for the lap joint.

Table 5 Joint clearance data from the microscope measurements

No	Pressure (MPa)	Length of Lap Joint (mm)	Joint Clearance (mm)	Standard Deviation (mm)
1	0.00	10	0.35	0.05
2	0.00	15	0.30	0.03
3	0.00	20	0.26	0.03
4	0.35	10	0.36	0.05
5	0.35	15	0.32	0.03
6	0.35	20	0.30	0.02
7	0.70	10	0.25	0.05
8	0.70	15	0.20	0.03
9	0.70	20	0.22	0.02

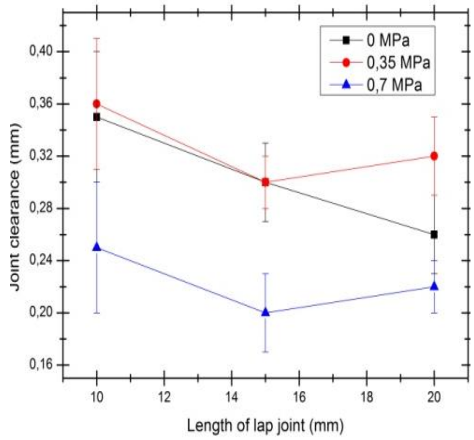

Figure 10 Effect of pressure and the Length of Lap Joint on Joint Clearance

4. ANALYSIS OF SHEAR LOAD AND JOINT CLEARANCE USING RESPONSE SURFACE METHODOLOGY (RSM)

To perform matrix calculations MATLAB software is used with (A) codes of pressure and (B) codes for the length of the lap joint. To lowest value of each parameter on the contour chart is written with the value (-1) and highest value is (1). From the calculation of the value of the coefficient β, the matrix obtained as follows.

The shear load regression models:

$$y_S = 300.62 + 2.87A + 39.55B + 22.25A^2 - 52.41B^2 - 21.60AB \tag{1}$$

The joint clearance regression models:

$$y_C = 0.31 - 0.04A - 0.03B - 0.06A^2 + 0.03B^2 + 0.02AB \tag{2}$$

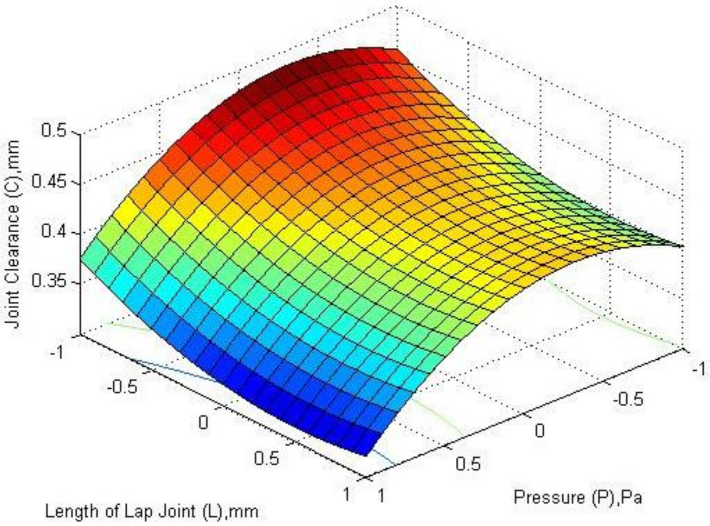

Figure 11 Effect of pressure and the Length of Lap Joint on Shear Load

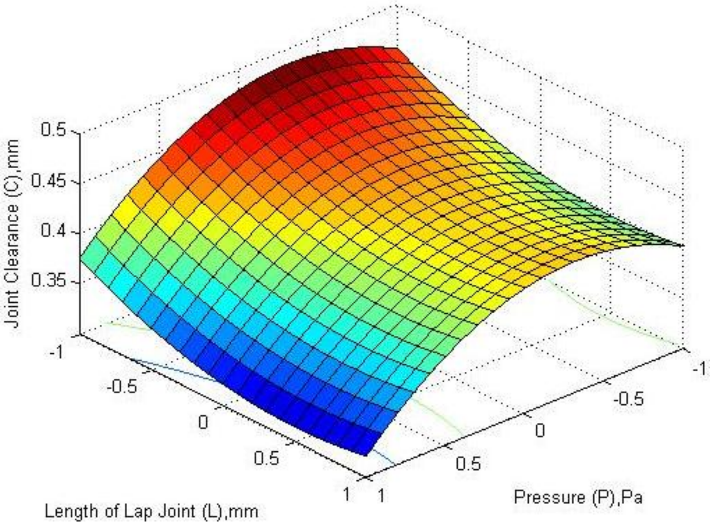

Figure 12 Effect of pressure and the Length of Lap Joint on Joint Clearance

In this research, the average value of the optimal shear load is 319.83 kg on the joint parameters for torch brazing with a pressure of 0.7 MPa and a 15 mm length for the lap joint. These results are obtained based on the pressure value that exerts a greater effect on the average value obtained for the shear load. The average value of the optimal joint clearance is 0.2 mm based on the joint parameters for torch brazing. These results are obtained since the length of lap joint that has greater effect on the average value obtained from the joint clearance. The form of the shear load can be shown in Figure 11, which represents a saddle-shaped curve. The highest value of shear load will be obtained at 0.7 MPa and medium length of lap joint is 15 mm. The lowest value of shear load occurs when the value of pressure at medium value of 0.35 MPa and medium length of lap joint of 15 mm. The results of joint clearance can be shown in Figure 12. The lowest value of the joint clearance occurs when the greatest pressure value, is 0.7 MPa and medium length of lap joint is 15 mm. The highest value of joint clearance occurs when the value of pressure at medium value of 0.35 MPa and lowest length of lap joint of 10 mm.

5. CONCLUSION

The effect of pressure and length of lap joint on shear load and joint clearance during dissimilar metal joints of BJ DD2 steel and C12000 copper by using torch brazing were investigated. The greater pressure increase results in a shear load on the length of lap joint of 15 mm. The configuration of the pressure of 0.7 MPa and the length of lap joint of 15 mm gives optimal results in the shear load of 319.83 kg with standard deviations of 42.37 kg and the joint clearance is 0.2 mm with standard deviations of 0.03 mm. The pressure gives greater effects than the length of lap joint during dissimilar metal joining using torch brazing.

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