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ON THE SPOT BRAZING AND SPOT SOLDERING OF TANTALUM

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ABSTRACT

The main goal of this study is to investigate the possibility of joining pure tantalum to itself by resistance classical spot (RS), spot brazing (SB), and spot soldering (SS) welding methods. In order to evaluate the bonding strength and to understand its mechanism for these welding methods, foils of ASTM A63, AWS BCu-1, and AWS BVAg–O were employed as filler–metal alloys. The influence of welding time on the joint strength was studied. Hence, four different welding times (1, 2, 3, and 4 seconds) were chosen to determine the optimum welding time. Reflected optical microscopy tests of welded assemblies were performed to determine the mechanism of joint formation. Moreover, the joint strength was evaluated by a tensile shear strength test (TSST). Then, the total work done (i.e., joint toughness) was determined. Since the welding time is a key factor which controls the microstructure and hence the mechanical properties of the joint strength, it is therefore found that two seconds is the optimum welding time whatever the welding process. Spot brazing via AWS BCu-1 filler metal alloy leads to the best strength.

***Keywords*:** Spot brazing, Spot soldering, Welding time, Joint strength, Tantalum.

INTRODUCTION

In current applications of the refractory metals in several industries, welding joints should therefore be of appropriate dimensions to give the demanded properties of strength, ductility, corrosion resistance, etc (Schwartz, 1987).

High enough wettability of refractory metals by molten metal fillers is principal requirement for successful brazing. In fact, there are almost invariably limited degrees of inter solubility between fillers and parent metal surface. The diffused inter layer can laterally spread and penetrate underneath oxide films. The ability of the filler metal to wet the surface of the gap plays an important role on the bonding nature and its quality (Lankester, 1980).

According to Schwartz (1987) the strength and ductility of refractory metals are harmfully affected by the microstructural changes occurring when their recrystallization temperatures are exceeded. The maximum joint strength can be obtained when the brazing is conducted at temperatures below these at which recrystallization takes place. Note also that in the low-temperature service, copper and silver-based braze alloys can be employed in brazing refractory metals. Furthermore, the bonding mechanism is undoubtedly considered as an important topic regarding the joints strength. In soldering and brazing, similar bonding mechanism can almost be observed with parent metal forming consequently metallic bonds at the interface (Schwartz, 1987). The nature of the bond is obviously complex in both cases varying from true metallic bonding to Vander walls forces (Stuart & Gibson, 1997). The fact that the heating cycle plays an important role on the joint properties, hence it is recommended to decrease the brazing temperature with time since this has the advantages of decreased interfacial reactions (Schwartz, 1987; Schwartz, 1995; Chan et al., 2004).

The fusing dissolution of parent metal in the molten liquid brazing filler metal is inevitable, in particular at high temperatures. The major valuable aspect of the base metal dissolution is the enhancement of the alloying process of the brazed welds. This leads unambiguously to improve the mechanical properties of the brazed joints.

Technically, in resistance brazing or soldering, the electric current can be passed in different ways, which are classified into two types; carbon resistance method, and direct resistance one (Schwartz, 1987; ASM Handbook, 1997; Milner & Apps, 1968).

Spot brazing or soldering method is similar to direct resistance brazing or soldering method based on the same principles of the resistance spot welding, and the spot welding machines are used for both processes. Special techniques are necessary to satisfactorily braze or solder tantalum (Miyazawa et al., 2003).

Oxygen, carbon monoxide, ammonia, hydrogen, nitrogen, and carbon dioxide should be eliminated (ASM Handbook, 1997). Tantalum oxidizes in air at 343 ℃. It has high sol ubility for oxygen, nitrogen, and hydrogen at elevated temperatures. Small amounts of dissolved oxygen and nitrogen increase significantly the hardness of the metal, since the dissolved hydrogen provokes toughness reduction and increase notch sensitivity. Therefore, tantalum should be welded or brazed by shielding high purity inert gas or in a vacuum. This provides the brazing temperature which is high enough for the tantalum and rapid to dissolve its oxide film (lsserlis, 1962).

For spot brazing, Miyazawa et al. (2003)used this method to join CP–Ti to Ni as a base metal and employing clad type Ti–Cu–Ni foil, Ag–Cu alloy foil, Ni–based alloy foil, and Cu–P alloy foil as filler metal alloys. A satisfactory brazing joint has been obtained (Miyazawa et al., 2003), by spot brazing using clad BAg–8 brazing foil. Nowadays, spot brazing can be used in industrial situations without academic understanding (AWS, 1991).

EXPERIMENTAL PROGRAM

A tantalum pure sheet (manufactured by Plansee Metalwork Gmblt company) of 0.15 mm in thickness was used. Foils of 0.08 mm in thickness of different filler metals (solders and Brazing filler metals) were employed. Table 1 shows the chemical composition and sources of this types.

A manual resistance spot welding machine type Bergin Vliesena Werke GMBH was utilized. Before welding operation, tantalum surfaces were cleaned with acetone solution then dried by soft cloth. The filler metal used in spot brazing and soldering processes has a foil form of thickness of 0.08 mm $\pm$0.01. It was replaced between the two faying surfaces of lap joint as schematized in figure 1. Two types of joint assembles were made as shown in table 2. Determination of the joining time represents one of the main goals of this study. Therefore, forty eight samples of (Tantalum–Tantalum) were joined in different joining times and then characterized by mechanical tensile shear strength test (TSST). Dimensions of the tested specimens are summed up in table 3.

Table 1. Chemical compositions and sources of filler metal (foil)

Filter Metal	*Composition wt%*	*Melting pt range ℃*		*Sources*
ASTM A63	63Sn, 37Pb	183	183	Commercial
AWS – B Cu – 1	99.9 Cu	1083	1083	Commercial
AWS – BVA g – 0	99.95 Ag	961	961	Commercial

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Table 2. Sample dimensions with respect to test type

Type of Test	*Samples dimension mm*
Optical microscopy test (ROM)	30 x 10 x 0.15
Tensile shear test	50 x 5 x 0.15

Table 3. Details of optimization joining time (4 Samples for each joining time were used)

Joining Process	*Filler metal*	*Joining time (s)*	*Number of samples*
RSW	Non	1,2,3,4	16
Spot soldering	ASTM A63	1,2,3,4	16
Spot brazing	AWS BCu – 1	1,2,3,4	16

2.5 tons Instron universal testing machine was used to realize the TSST on the welded specimens under a constant cross head speed, namely 2 mm/min at room temperature. This employed speed gives evidently a quasi-static strain rate of 10^{-4}/s. Mechanical properties were evaluated through the recorded load-displacement curves. After each TSST test, the experimental total work done (i.e., toughness of the bond) was determined. Five samples were microscopically examined under several magnifications from X70 to X180 using universal optical microscope with digital camera. The specifications of these samples are shown in table 4. All samples were cut in perpendicular direction of bond surface. The cut surfaces were classically grinded by different abrasive papers and then polished using alumina powder.

Table 4. Specification of samples for (ROM) test (The 2-second joining time is applied)

Joint uss	*Joining process*	*Filler metal*
Tantalum - Tantalum	RSW	None
Tantalum - Tantalum	Spot soldering	ASTM – A63
Tantalum - Tantalum	Spot brazing	AWS – B Cu – 1
Tantalum - Tantalum	Spot brazing	AWS BVAg – 0
Tantalum - Tantalum	Spot brazing	BCu – 1 + BVAg – 0

RESULTS AND DISCUSSIONS

Optimum Joining Time Determination

In this study, each test was repeated four times under the same experimental conditions (welding time, applied cross head speed and temperature) in order to ensure acceptable results and its credibility with respect notably to its repeatability.

Assemblies Joined By Classical Spot Welding.

An examination of figure 2 shows that a successful bonding is obtained especially in the 2-second case where all the four results are relatively acceptable. Moreover, in this case, the corresponding load–displacement curves display the highest values for the recorded load as well as for the displacement. The 1-second welding time is not enough to heat and melt the joint surface to form an appropriate welded zone. In the case of 3- and 4-second welding time, the problem of contamination with atmosphere occurs. Hence, the probability of the weld dissolving the formed oxides and nitrides on the surface becomes higher due to these relatively long durations. As far as the determined total work done is concerned, it is considered as a crucial parameter in evaluating the optimum joint strength which corresponds a given joining time. Figure 3 points out a comparison of the total works vis-à-vis different joint assemble (Tantalum–Tantalum). As a result, it is concluded that the 2-second joining time gives the highest value of the bonding toughness. Therefore, it represents the optimum joining time.

Assemblies Joined By Spot Soldering.

Figure 4 illustrates load–displacement curves for the four welding times. In fact, several unreliable tests (UTs) are captured in the 1-, 3- and 4-second cases, i.e., their recorded force-displacement evolutions are far from acceptable results compared to other results obtained under the same experimental conditions. More uniform and relatively similar behavior of load–displacement curves are, in general, obtained in the case of 2-second joining time. The more important joining times (i.e., 3- and 4-second) give obviously non-uniform and dissimilar load- displacement evolutions. An excessive melting of the filler metal (solder) is therefore obtained. In addition, the problem of contamination causes faulty welds together with the expulsion of molten solder from the joint due to the extra-heating and the over-loading. On the other hand, the case of low melting point of filler metal presented by the 1-second as well as the 2-second lead to the optimum solution for these technical problems. The average maximum values of total work done for these different joining times of spot soldering method are compared as demonstrated in figure (5). It shows that the low joining times of 1- and 2-second give basically the best bonding toughness. Nonetheless, 1-second joining time provides a non-uniform and dissimilar behavior of load-displacement curves (figure 5). Accordingly, the 2-second joining time is considered as the optimum solution.

Assemblies Joint by Spot Brazing.

In the spot brazing process case, the load–displacement curves show relatively more uniform and repeatable behaviors in the case of 2- and 3-second joining times in comparison to 1- and 4-second (figure 6). This is due to the fact that the 2- as well as 3- second joining times provide lower contamination probability than that of 4-second case. Furthermore, they are considered as the more suitable times to offer sufficient diffusion than the 1-second case. The2-, 3- and 4-second have roughly similar maximum load values ranging from 137 to 144 joules. Figure 7 demonstrates also a comparison among the average obtained total works done. It is obvious that the high melting point of filler metal (1083 °C) ma kes it not very sensitive to a relatively long joining time condition (i.e., 4-second case). Besides, its ability to form bonding with Tantalum even with the contamination may occur. Nevertheless, the 2-second joining time is recognized as the best joining time. This is due to the most uniform and repeatable behavior of load–displacement curves compared to other joining times (figure 6).

Optical Microscopy Test Results

Assemblies Joined By Classical Spot Welding.

The effect of the electrode diameter on the joint formation and its mechanical features was investigated. Several microscope tests are conducted at jointed assembly zones. These tests confirm the significant influence of such a factor. Actually, the joining is naturally made in the region between the edges of electrode due to the heat effect generated by the electrical current flow together with the electrode pressure concentrated in this region (Figure 8). As a

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matter of fact, this bonding is usually formed by localized heating of the two faying surfaces of the base metal. In fact, it should be melted and then joined at the spot area (area of the applied force). Then, the bonding is consequently conducted, as clearly illustrated in figure 9.

Assemblies Joined By Spot Soldering Process.

In this case, it is shown that the Tantalum– Tantalum assembly is taken place in the region where the electrode force is applied and where solder is squeezed (figure 10). Such a solder has a low melting temperature; and a limited similarity between solder and Tantalum is clearly noticed, although there is bonding phase between Tantalum and solder. Forcing the two surfaces together with heat application in shorter time leads to molten solder. Afterward, Tantalum surface penetration and bonding take place as reported in figure 10.

Assemblies Joined By Spot Brazing Process.

Figure 11 points out the microstructure of (Tantalum–Tantalum) assembly brazed by the filler metal (AWS BCu-1) in which Cu penetration along the surface of Tantalum. Subsequently, bonding phase between Tantalum and Cu is achieved. In the case of (Tantalum–Tantalum) assembly using the foil filler AWS BVAg–0, the bonding phase between Ag and Tantalum occurs, Ag diffuses to Tantalum and gas porosity appears in the Tantalum structure due to the effect of filler metal as shown in Figure 12.

As far as the micrograph of welded assembly is concerned using sandwich of the foil filler metal (AWS BCu–1+BVAg–0), figure 13 reveals that the bonding phase between the filler metal and tantalum takes place. Besides, Ag causes certain porosity in the Tantalum structure due to the excessive heating of filler metal. In the spot soldering and brazing methods, bonding forms as a result of heating of the two faying surfaces of the parent metals and filler metal. They are melted in the spot area and the bond is made.

An additional bonding, so-called out-of-spot area, is produced between the parent metal and the filler metal presented in Figure 14. This is due to the heat generated by the electrode and the effect of the pressure beyond the determined welded zone. Such an out-of-spot area is not captured in the classical spot welding because of the total absence of the filler metal. In spot soldering and brazing methods, precisely at the boundary of spot zone, more porosity can be observed (figure 15).

Mechanical Strength

Using 2-second joining time, figure 16 collects typical load-displacement curves of Tantalum-Tantalum assemblies joined by these five welding an examination of figure 16 reveals that the filler metal (AWS BCu–1) gives more uniform load–displacement curves and higher value of displacement than other brazing processes. The evolution of the work done versus the five different welding processes is presented in Figure 17.It is clear that an acceptable bonding is obtained with the BCu-1 compared to the other joining processes.

Indeed, it is obviously shown through the obtained values that the bonding toughness is remarkably sensitive to the joining configuration. The highest toughness of 144 joules is obtained in brazing using a filler metal of Bcu-1, whereas the lowest recorded one of 32 joules is observed with a filler metal of AWS BCu–1 + BVAg–0 type, i.e., the result of the brazing with Bcu-1 shows that the maximum gain of work done is about 450% with respect to the brazing with AWS BCu–1 + BVAg–0.

CONCLUSIONS

1. Based on the developed experimental observation, it can be concluded that the 2-second joining time is the best welding duration.
2. The best joint strength is obviously obtained by spot brazing method using AWS BCu-1.
3. It is found that bonding generated by classical spot welding occurs in spot zone only, whereas it exceeds the spot zone and forms out-of-spot zone (additional bonding) in the case of soldering and brazing spot joining.

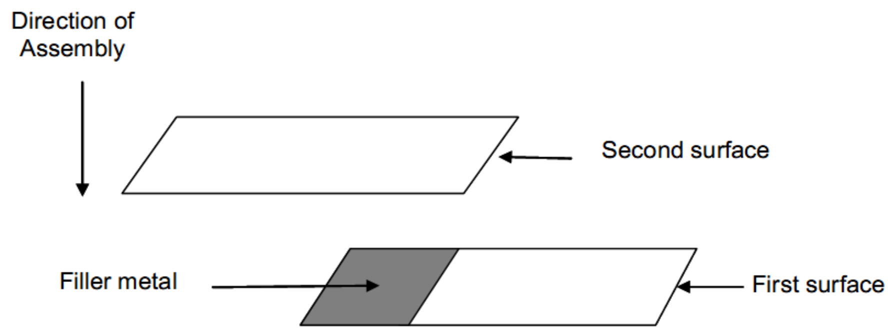

Figure 1. Application of filler metal

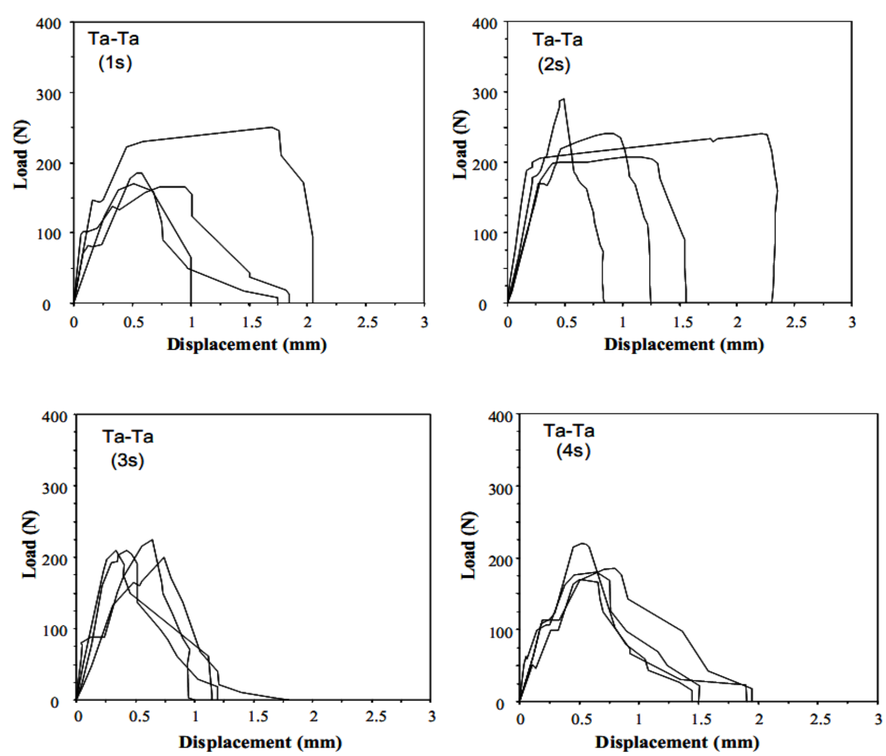

Figure 2. Load-displacement curves of Tantalum-Tantalum assemblies joined by RSW using different joining times

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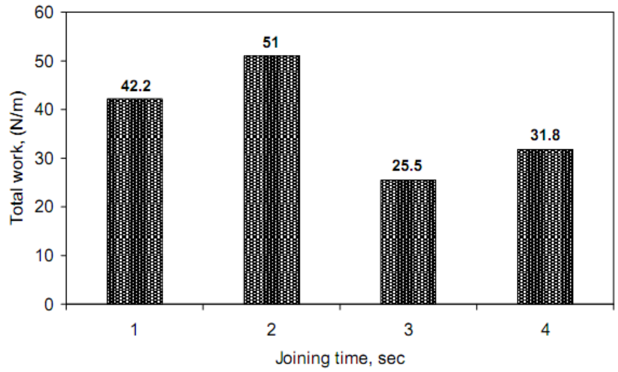

Figure 3. Comparison of the average values of total work done for different joining times of Tantalum-Tantalum assemblies joined by RSW

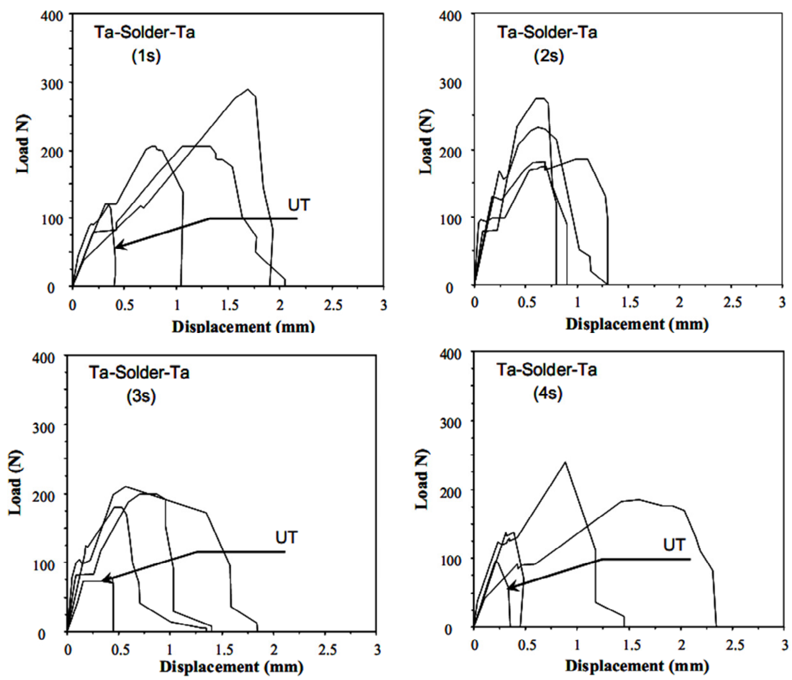

Figure 4. Load-displacement curves of Tantalum-Tantalum assemblies joined by spot soldering process at different joining times

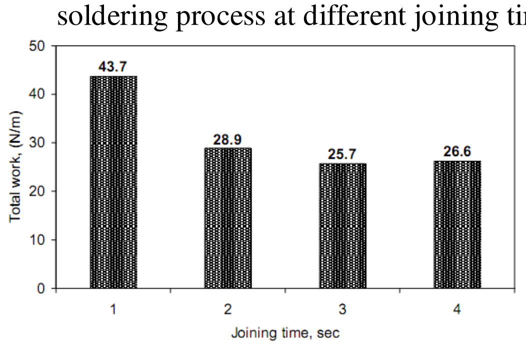

Figure 5. Comparison of total work done for different joining times of Tantalum-Tantalum assemblies joined by spot soldering

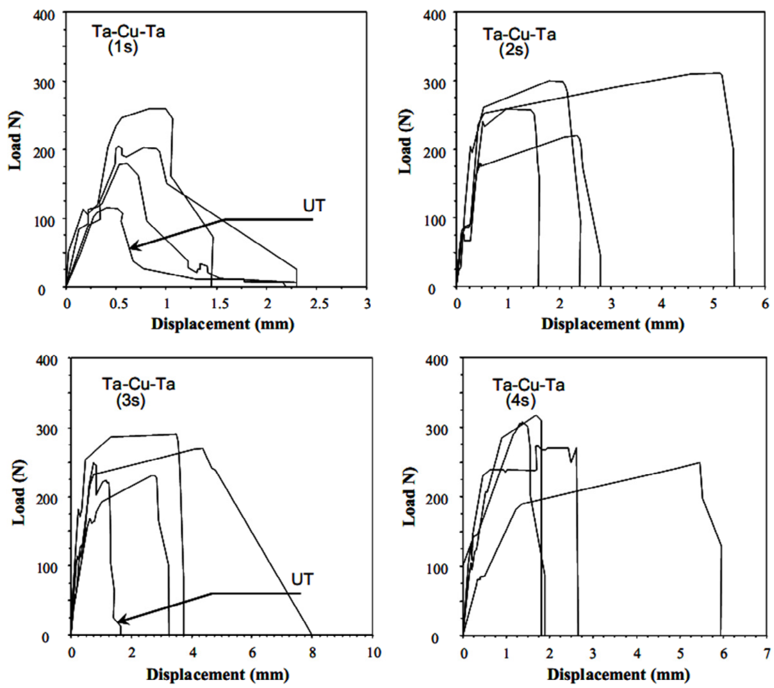

Figure 6. Load-displacement curves of Tantalum-Tantalum assemblies joined by spot brazing using different joining times

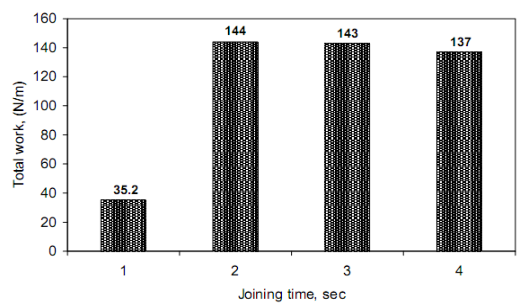

Figure 7. Comparison of total work done for different joining times of Tantalum-Tantalum assemblies joined by spot brazing

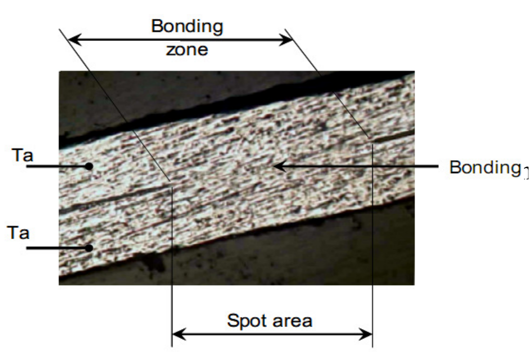

Figure 8. Bonding zone in Tantalum-Tantalum assemblies joined by RSW with

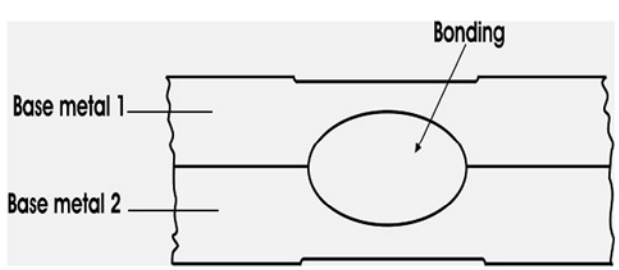

Figure 9. Bonding mechanisms during RSW

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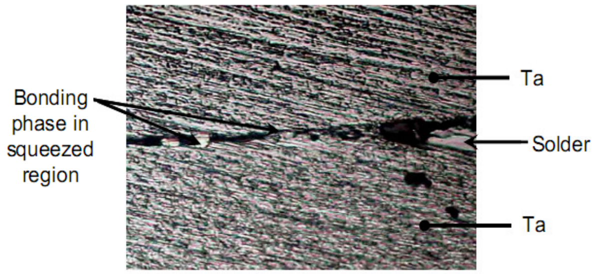

Figure 10. Microstructure Tantalum-Tantalum joined by spot brazing process using

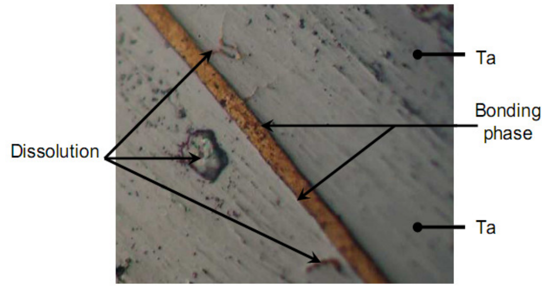

Figure 11. Micrograph Tantalum-Tantalum assembly AWS BCu-1 with X180 joined by spot soldering with X180

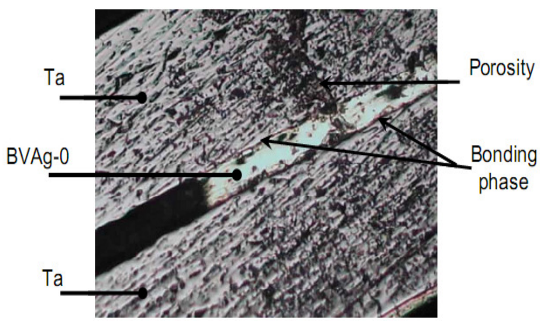

Figure 12. Microstructure of Tantalum-Tantalum assembly joined by spot brazing using BVAg-0 filler with X180

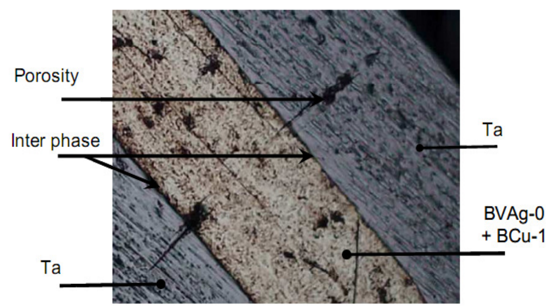

Figure 13. Microstructure of Tantalum-Tantalum assembly joined by spot brazing using(BVAg-0+BCu-1) filler with X180

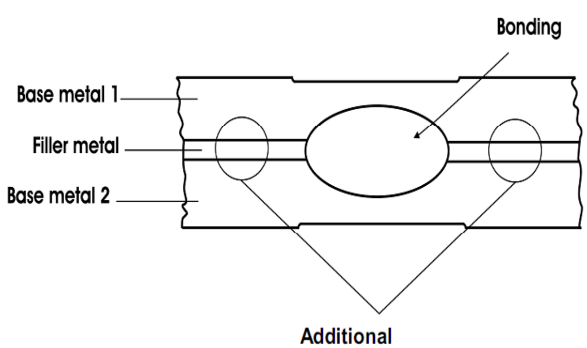

Figure 14. Bonding mechanisms during spot soldering and spot brazing processes

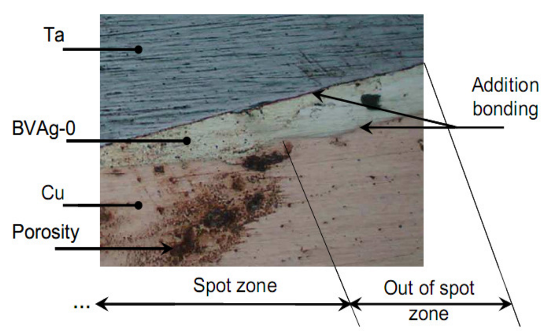

Figure 15. Spot zone and additional bonding in different joint assemblies with X180

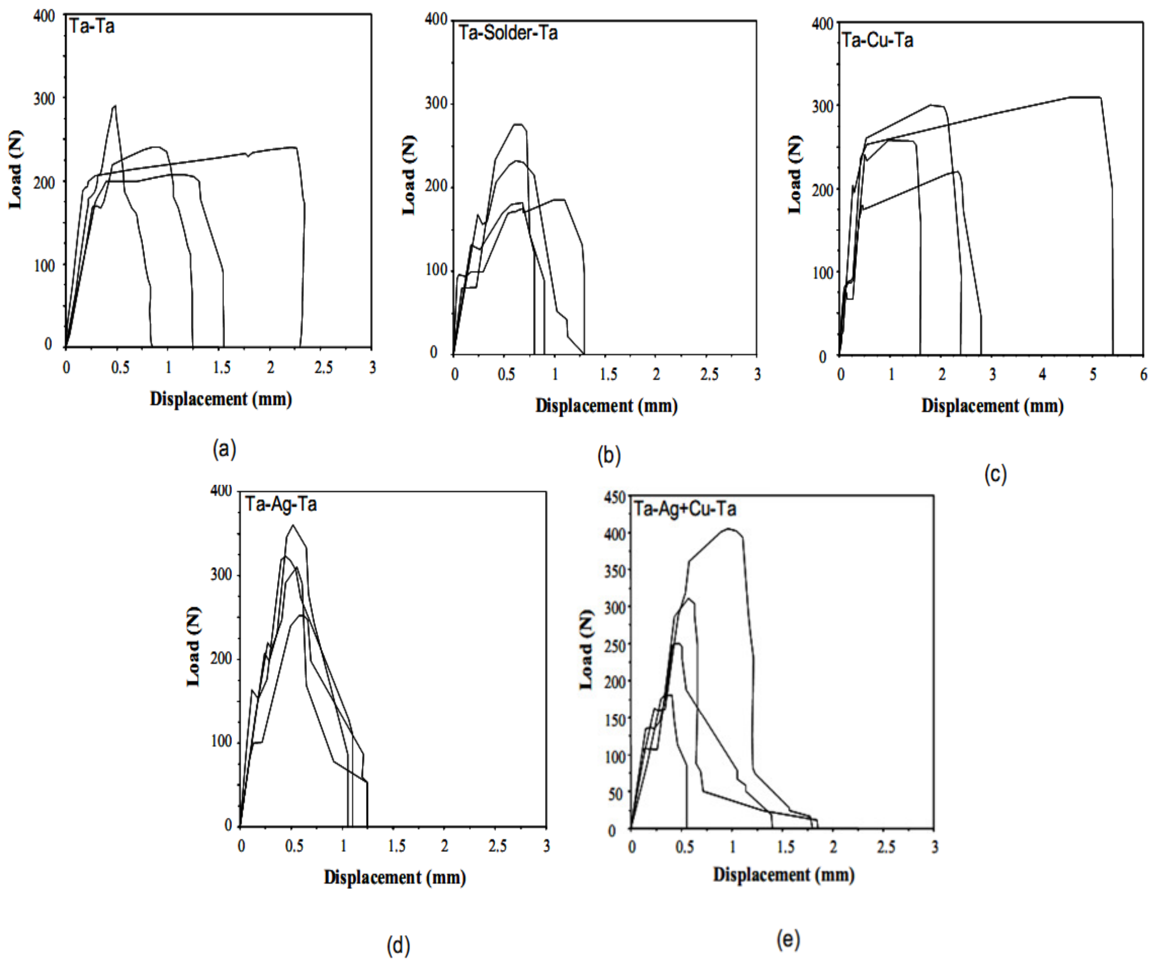

Figure 16. Load-displacement curves of Tantalum-Tantalum assemblies joined by: (a) RSW (b) spot soldering (c) spot brazing (AWS BCu-1) (d) spot brazing (AWS BVAg-0) (e) spot brazing (AWS BVAg-0+AWS BCu-1) using 2-second joining time

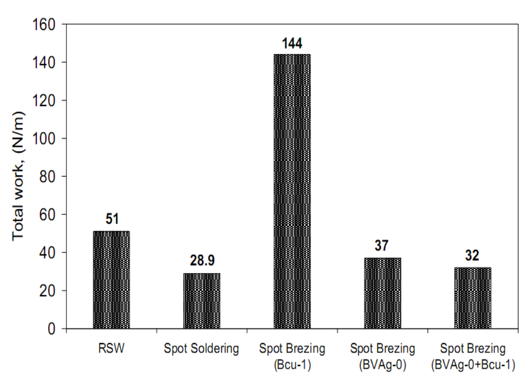

Figure 17. Comparison of total work done for different joining processes Tantalum-Tantalum assemblies

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