

# Spot Resistance Welding of a Titanium/Nickel Joint with Filler Metal

*The strength of titanium/nickel spot brazed joints produced with the use of a filler metal proved greater than those made without a filler*

BY H. ZUHAILAWATI, A. M. SAEED, A. B. ISMAIL, Z. SAMAD, AND T. ARIGA

## ABSTRACT

The shear strength and microstructural characteristics of the spot brazed titanium and nickel base metal was evaluated in this study with and without addition of 71Ag-28Cu-1Mg filler metal at the interfacial region of titanium and nickel. Welding current was varied in a range of 1.0 to 4.0 kA in order to understand the influence of welding current over the final properties of the joints. The strength of the joints was assessed using a shear test mode, and the microstructure was studied using an optical microscope, scanning electron microscope, and energy-dispersive spectroscopy. Results indicated that the strength of Ti/Ag alloy/Ni joints is higher than that of Ti/Ni joints when welding current in the range of 2.5 to 4.0 kA was applied. The absence of porosity in the joint and enlargement of the weld nugget significantly improves the bonding strength of the spot brazed joint. This observation is due to dissolution of the 71Ag-28Cu-1Mg filler, which results in diffusion of Ti and Ni into the molten filler, thus the molten filler can effectively wet the Ti and Ni substrate during spot brazing.

## Introduction

Titanium and titanium alloys are among the best metals for industrial applications due to their excellent corrosion resistance and high strength-to-weight ratio. Joining of titanium to other metals sometimes is needed due to service requirements. Welding of dissimilar metals is more challenging because of the differences in physical and chemical properties of the base metals, such as poor wettability and different thermal expansion (Ref. 1).

Brazing has been proposed for joining dissimilar metals wherein a filler metal is placed between the base metals and the joining operation is carried out in a furnace at a temperature between the liquidus of the filler metal and the solidus of the base metals (Ref. 2). However, in joining of thin metal sheets, such as in electronic and medical devices, spot welding is the most widely used, in which a small weld is formed between two metal workpieces through localized melting due to resistance heating caused by a passage of electric current (Refs. 3, 4). Because of the simplicity

of the process, it is easily automated, and once the welding parameters are set, repeatable welds are possible (Ref. 5).

Due to the established interesting features of brazing, which is its ability to join dissimilar metals, and spot welding techniques, which are its ability for automation and forming a spot weld, there is an effort to combine conventional spot welding and brazing principle methods whereby metal bonding is achieved using resistive heating of the filler metal (Ref. 6). Hiratsuka et al. (Ref. 7) have used the term of resistance brazing in their work to show the use of filler sandwiched between the metal workpieces. The implementation of this spot welding technique with a new approach, which refers to brazing using a spot welding machine, will require a better understanding of the issues associated with resistance spot welding of dissimilar metals with the use of a filler metal. This is because resistance weldability of sheet metals is determined by resistivity of the metal components between the copper electrodes, as well as other physical properties such as melting point, latent heat of fusion, and specific heat (Ref. 4).

However, to the authors' knowledge, literature on this technique such as factors affecting weld quality and the mechanisms involved, are limited. Miyazawa et al. (Ref. 6) have observed several reaction layers at the interface of titanium and nickel-base metals during spot brazing using different filler metals, including Ti-Cu-Ni, Ni-based, Ag-based, and Cu-P filler metals, which influenced the strength of the joints. However, explanation of the growth of weld nugget microstructure and strength in comparison to spot welding of titanium to nickel without filler metals was not discussed in their work. The correlation between spot brazing parameters, microstructure, and joining quality should be defined as well because as in the case of spot welding of BS 1050 aluminum, it was found that a combination of welding current, welding time, and electrode force is required to produce an acceptable weld (Ref. 8).

The joint strength of resistance spot-welded titanium sheets under different atmospheres also gave variation in tensile-shearing strength (Ref. 9). The objective of this investigation is focused on spot brazing of titanium to nickel sheet using 71Ag-28Cu-1Mg filler metal at various welding currents. Microstructure and tensile shear strength of the joined metals were examined and compared to the joints established by spot welding without filler.

## Experimental Procedures

Commercial pure titanium and nickel sheets with a thickness of 0.5 mm were selected as a base metal in this study. The metal sheets were cut into 5 × 40-mm pieces. The surfaces of the metal sheets were polished using silicon-carbide paper and cleaned with alcohol prior to welding. Alloy 71Ag-28Cu-1Mg foil with a thickness of 0.1 mm was selected as a filler metal and sandwiched between the overlapped area of the titanium and nickel sheets. A single lap joint of Ti/Ag-alloy/Ni sheets was made using spot welding machine Model SIW-608AD-D0B. A copper alloy electrode with a composition of 98.715 wt-% Cu, 1.175 wt-% Cr, and 0.11 wt-% Al and a 5-mm tip face diameter was

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## KEYWORDS

Resistance Weld  
Silver Braze Filler Metal  
Titanium  
Nickel

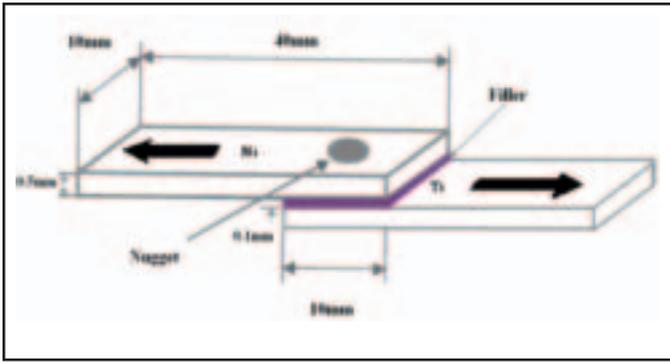


Fig. 1 — Schematic of the specimen and the setup for the tensile shear strength test.

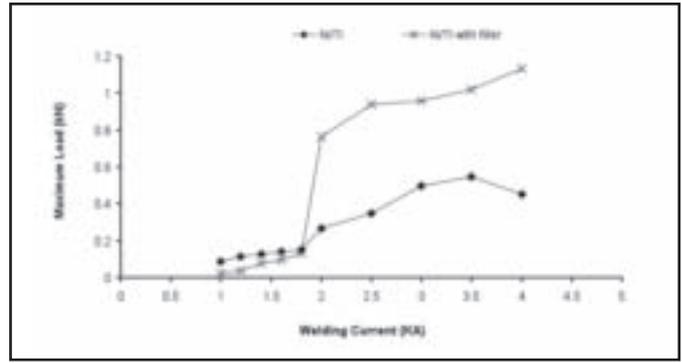


Fig. 2 — Maximum load vs. welding current for a Ti/Ni joint with and without 71Ag-28Cu-1Mg brazing filler metal.

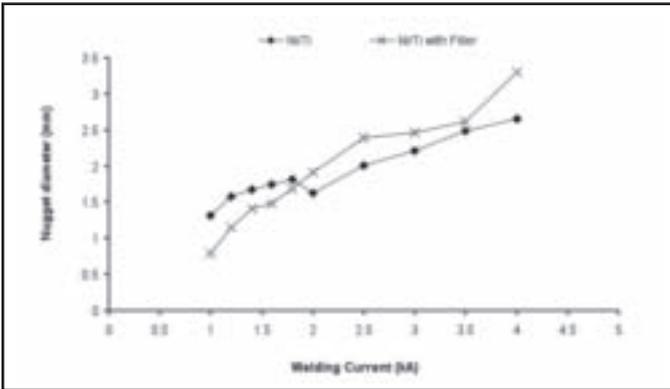


Fig. 3 — Nugget diameter vs. welding current for a Ti/Ni joint with and without 71Ag-28Cu-1Mg brazing filler metal.

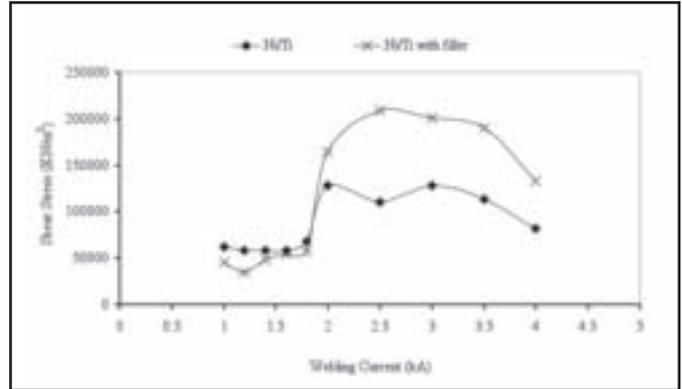


Fig. 4 — Shear stress vs. welding current for a Ti/Ni joint with and without 71Ag-28Cu-1Mg brazing filler metal.

used. The dimensions and configuration of the shear coupon specimen are shown in Fig. 1. The spot brazing was done with a current in a range of 1.0 to 4.0 kA with a current interval of 0.5 kA. Welding voltage was kept at 2 V, electrode force was kept at 3.0 kgf/cm<sup>2</sup>, and a welding time of 50 ms was used. As a comparison, spot welding was also performed on Ti/Ni sheets without addition of filler metal. Hereafter, Ti/Ni and Ti/Ni with filler joints are referred to as spot welded and spot brazed joints, respectively. Five pairs of joints were made for each condition to make the data meaningful.

Joint strength was evaluated using a tensile shear test that was performed using

an Instron tensile test machine at a crosshead speed of 1 mm/min. Size of the weld nugget was estimated using a stereo zoom microscope. For microstructure observation, the bonded Ti/Ag-alloy/Ni and Ti/Ni joints were cut close to the cross section of the nugget area before being mounted and polished. Then, the cross-sectioned samples were etched in two solutions. The first solution was a mixture of 5 mL HF, 20 mL HNO<sub>3</sub>, and 75 mL glycerol, swabbed from 30 to 60 s on the titanium side, while the second solution was a mixture of 5 mL HCl, 35 mL HNO<sub>3</sub>, and 65 mL CH<sub>3</sub>COOH, swabbed from 5 to 30 s on the nickel side. The microstructure was observed under an optical microscope and a scanning electron microscope (SEM) equipped with an energy-dispersive spectrometer (EDS).

## Results and Discussion

### Evaluation of Joining Strength

Test structures for spot welds are usually designed in a way so that the joints are loaded in shear when the parts are exposed to tension or compression loading. Sometimes the welds may be loaded in tension, where the direction of loading is

normal to the joint of the plane (Ref. 5). In this work, samples were loaded in the tensile shear direction in order to evaluate the joint quality.

Figure 2 displays the average maximum load of spot welded Ti/Ni joints produced with and without 71Ag-28Cu-1Mg brazing filler metal with a welding current range of 1.0 to 4.0 kA. It can be seen that the maximum load of the joints display a significantly different trend within this current range. In the lower welding current range, i.e., from 1.0 to 1.8 kA, Ti/Ni joints gave higher strength than Ti/Ni joints produced with silver-based foil, which is in a range of 0.08 to 0.15 kN and 0.02 to 0.13 kN, respectively. However, in the higher welding current range, i.e., from 2.0 to 4.0 kA, the use of silver-based foil produced stronger Ti/Ni bonds (maximum load of 0.7 to 1.13 kN) compared to spot welding without silver-based foil (maximum load of 0.27 to 0.45 kN).

Welding current is an important variable affecting nugget formation and growth because the power generated for nugget formation is proportional to the square of the welding current. The total heat required to form a weld nugget in conventional spot welding without filler metal includes at least two components

Table 1 — EDX Composition Analysis Taken across Joint Shown in Fig. 7

	Composition (wt-%)		
	Ti	Ni	Ag
1	100	0	0
2	35.94	64.06	0
3	1.14	3.56	95.3
4	36.82	63.18	0
5	0	100	0

(Ref. 4). The first is to heat the weld metal to its melting point, and the second is to melt the weld metal to form a molten nugget. Miyazawa et al. (Ref. 6) clarified that during spot brazing, the base metal microstructure was coarsened and dissolution phenomenon of the base metal by the molten brazing filler metal took place, which was caused by overheating.

Therefore, the results of the present work suggest that the Ag alloy metal has reduced the contact resistance between the electrode and the metal workpiece, hence reducing the heat/temperature generated at the interface (Ref. 4). As a result, low joint strength was obtained in a lower current level. However, in a higher-current level, the heat generated from the contact resistance at the faying interfaces is sufficient to melt the Ag alloy filler when welding current of at least 2.0 kA was used. Once the Ag alloy filler melts, it penetrates by diffusion through the Ti and Ni base metal during welding. It was seen that for both spot brazed and spot welded workpieces, the weld nugget size increased with the increase in welding current — Fig. 3.

This trend is in accordance with the results obtained by Hasanbasoglu and Kacar (Ref. 1) who investigated the resistance spot weldability of AISI 316L steel to DIN EN 10130-99 steel and concluded that the increase in energy input, which was due to the enhancement of welding current, had increased the weld nugget size. According to Sun et al. (Ref. 10), in the resistance welding, the welding current flowed through the faying surface of two metal sheets compressed by a pair of electrodes. Then the faying surface was locally melted to form the weld nugget by the heat, which resulted from contact electrical resistance. The higher current supplies greater heat and leads to the larger nugget. This is because the time to reach the melting temperature is shorter, and the time spent at or above the melting point is longer.

Result of failure load of the spot brazed joint shows a similar trend with nugget size as the welding current is increased. Increasing the nugget size indirectly widened the load-bearing area in the brazed joint, and thus increased the failure load of the joint (Ref. 11). It has been suggested that there is a direct correlation between joint tensile shear load and nugget diameter in the case of the spot welded magnesium alloy (Ref. 10). Therefore, a similar correlation is observed for spot brazed Ti/Ni joints in the present work. Figure 4 shows the variation of shear stress with welding current. According to Fig. 4, shear stress of the joining increased significantly with the use of brazing filler metal particularly for a high current range, which indirectly indicates an improvement in weldment properties after using brazing filler metal.

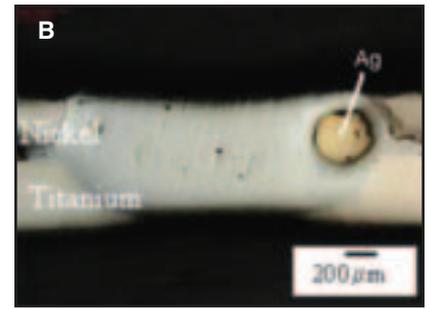
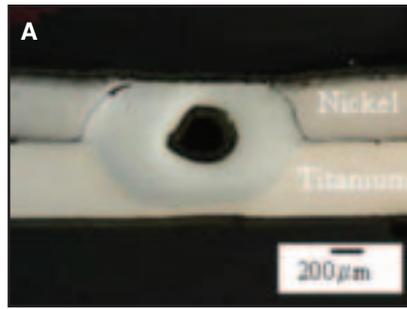


Fig. 5 — General views of the following under optical microscope using welding current 3.5 kA, welding time 50 ms: A — Ti/Ni joint; B — Ti/Ni joint with 71Ag-28Cu-1Mg brazing filler.

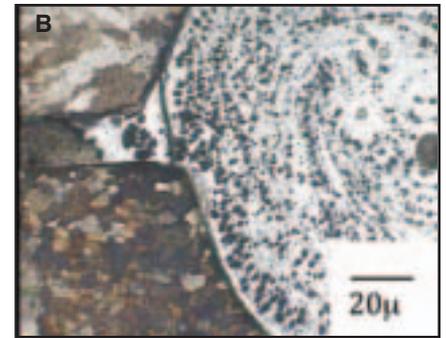
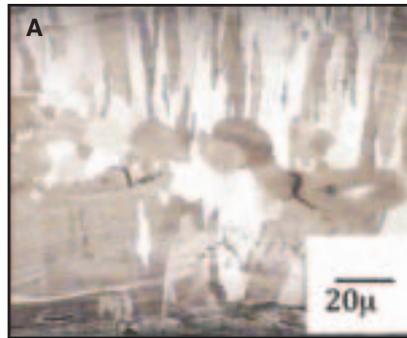


Fig. 6 — Optical microstructure of the following: A — Ti/Ni joint; B — Ti/Ni joint with 71Ag-28Cu-1Mg brazing filler using a welding current of 3.5 kA and a welding time of 50 ms at higher magnification.

#### Microstructure of Weld Nugget

Figure 5 displays a general view of the spot welded Ti/Ni joint and spot brazed Ti/Ag-alloy/Ni joints observed under an optical microscope.

The cross section of spot welded Ti/Ni joints revealed the presence of porosity within the weld nugget. This observation suggests that the decrease in maximum load of the spot welded Ti/Ni joint is mainly associated with the presence of porosity since the porosity reduces the available bearing area in the joint. This void could be attributed to the incomplete fusion of the Ti and Ni substrates at some points in the interfacial region since the heat generated was not enough to completely melt the metal substrates. Hasanbasoglu and Kacar (Ref. 1) explained that high welding shrinkage strains, which are caused by high thermal expansion, results in an internal discontinuity such as porosity or cavity.

On the other hand, the Ti/Ag-alloy/Ni joint showed no evidence of porosity. A good titanium and nickel wetting behavior of the Ag-Cu-Mg alloy was observed as this filler metal spread over both sides of the titanium- and nickel-based metals. This observation is due to good wettability of the molten 71Ag-28Cu-1Mg alloy on the titanium and base metals (Ref. 12). Minor addition of active ingredient, in this case Mg, improved the wettability of Ag-Cu alloy molten on Ti- and Ni-based metals (Ref. 13). As a result, the use of Ag-

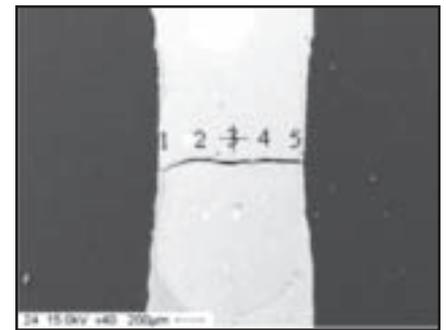


Fig. 7 — SEM microstructure of the weld nugget for Ti/Ni joint with 71Ag-28Cu-1Mg brazing filler metal.

alloy brazing filler at the interface of Ti and Ni results in good wetting and a homogenous diffusion of base metal and hence produced a joint free from porosity. In the case of the Ti/Ni joint, porosity is observed in the weld microstructure. In the case of the Ti/Ni joint with filler, porosity is not evident, instead a silver-rich particle is observed as indicated in the micrograph. Figure 5A shows the porosity inside the welding region of the Ti/Ni joint while no porosity is evident in Fig. 5B. A round shape in Fig. 5B is silver-rich filler metal that does not melt.

The macroscopic sectional view at higher magnification shows in the case of the Ti/Ni joint, grain growth has occurred in the base metal of the nickel side closest to the weld interface — Fig. 6. This re-

gion corresponds to the boundary between the melted and unmelted metal, which experiences the highest temperature. This equiaxed structure changed to a columnar structure in the Ti side, and the direction of growth was observed to be normal to the fusion boundary, which has been reported in several Ti alloys (Ref. 14). This is because the direction of growth of the columnar grain is always along the direction of the steepest temperature gradients in the weld. On the other hand, the sectional view of the Ti/Ag-alloy/Ni joint shows a different solidification pattern and structure. It is seen that the microstructure of Ti- and Ni- base metals does not change significantly and a brazing alloy pool is evident in the weld nugget area.

An EDX analysis was taken across the spot brazed Ti/Ag-alloy/Ni joint at several points as shown in Fig. 7. The brazed joint is mainly comprised of the Ag-rich phase, as marked by point 3, with some evidence of Ti and Ni (Table 1). It means that the dissolution of Ti- and Ni-base metals results in Ti and Ni transport into the molten filler, so the Ag-rich braze alloyed with Ti and Ni can readily wet both Ti and Ni substrates during welding. This result is in agreement with Wu et al. (Ref. 2) who clarified that in the case of vacuum brazing, once the brazing temperature is reached, the filler metal melts. Due to capillary action, the liquid fills the joint clearance and eliminates potential porosity at the interface between two metal sheets. Then, some dissolution of the base metal does occur due to interdiffusion between the filler metal and base metals. The work deals with a nontraditional method of brazing titanium, which is flux-free brazing in air using a resistance welding machine as a heat source. The brazing filler metal used is a new alloy that is unusual, with a composition of silver-copper eutectic alloy modified with 1% of magnesium, while the standard brazing alloys of this system are alloyed only with titanium or zirconium. The present results showed that the presence of magnesium improves wetting of the braze in air.

## Conclusion

The joining strength of spot brazed titanium to nickel base metal using 71Ag-28Cu-1Mg filler material was evaluated by considering its shear strength and microstructure characteristics. As a comparison, the spot welding of a titanium and nickel joint without filler material was also conducted. The results showed it is possible to spot weld titanium to nickel by using a spot brazing method using 71Ag-28Cu-1Mg as filler material. However, the strength of the applied welding current should be carefully selected to achieve

good joint performance of the spot-brazed Ti/Ag alloy/Ni. The recommended range of the electrical current for spot welding of Ti/Ni using 71Ag-28Cu-1Mg brazing filler material foil is 2.0–4.0 kA. Dissolution of 71Ag-28Cu-1Mg filler material results in diffusion of Ti and Ni base metals during the spot brazing process, which eliminates porosity in the welded joint as well as enlarges the weld nugget. As a result, the strength of the spot brazed joint has been improved significantly.

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