Brazing Titanium and Chromium Using Ion Bombardment Heating

A new method with both silver-based BAg-7 and aluminum-based BAlSi-4 filler metals is suitable for manufacturing small-size parts of electronic devices as well as relatively massive structures of other industrial applications

BY MICHAEL MARKOVICH, GEORGE FISCHER, AND ALEXANDER E. SHAPIRO

The application of gas and metal plasmas close to local thermodynamic equilibrium (LTE) for thin-film deposition and surface thermal treatment is well known and widely used in the industry.

The highly ionized, intense plasmas generated during physical vapor deposition (PVD) by arc evaporation are also suitable for intense heating of metallic parts. The common feature of these methods is bombardment with energetic particles. This, in turn, in addition to heating, also provides effective cleaning and activation of exposed surfaces.

To date, plasmas only occasionally have been utilized for joining applications. This is due to the lack of experience and insufficient knowledge of liquid-solid reactions between base and filler metals under plasma heating and ion bombardment, and the specifics of joining process control.

An example of applying an abnormal glow discharge plasma to the brazing of small ceramic parts is described in Ref. 1, demonstrating the suitability of process plasmas for joining purposes. Plasma brazing is well suited to joining parts with large open surface-to-volume ratios, with effective coupling of energy from the incident ion flux into the workpiece, making the process especially suitable for joining small parts, such as electronic components.

Also, good candidates for this approach are structures made of active metals, such as titanium, chromium, vanadium, or zirconium, that require rapid heating and careful prevention of oxidation or other forms of passivation of faying surfaces before brazing or welding.

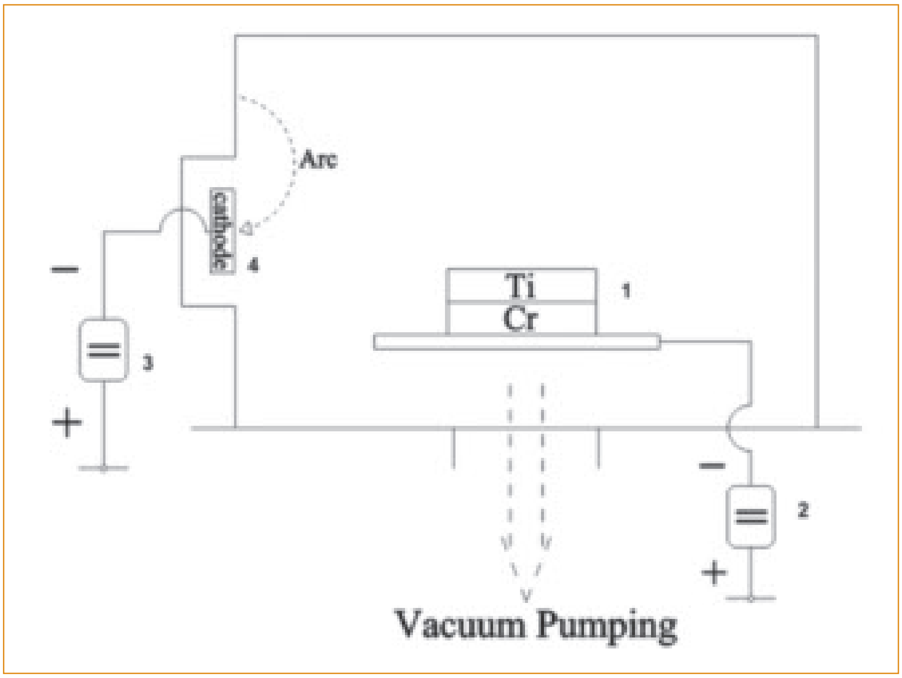

Fig. 1 — Plasma discharge chamber with brazing setup. 1 — Steel table with brazed parts; 2 — high voltage power supply; 3 — high-current arc supply; and 4 — titanium cathode.

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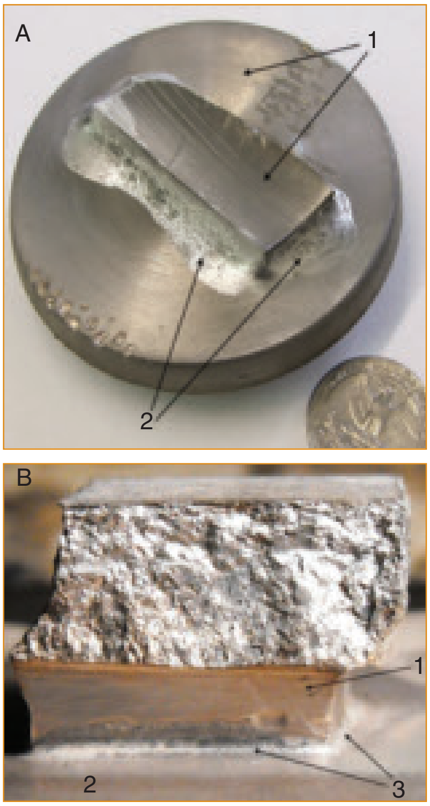

Fig. 2 — A — Titanium sample used for the setup brazing thermal cycle upon melting and spreading the BAlSi-4 filler metal. 1 — Titanium samples; and 2 — melted and solidified brazing filler metal; B — chromium sample used for the setup brazing thermal cycle upon melting and spreading the BAg-7 filler metal. 1 — Sample of sintered chromium (the top section is an as-fractured surface, while the bottom is machined); 2 — titanium base metal; and 3 — melted and solidified brazing filler metal.

Production vacuum brazing of titanium parts for aerospace, automotive, and other applications is an expensive, energy-intensive process (Refs. 2, 3). While brazing titanium is well developed in the industry, brazing chromium is done seldom due to its high reactivity and the formation of stable surface oxides, which starts at 538°C even in vacuum of 10^{-4} Torr (Ref. 4). Therefore, chromium brazing requires higher vacuum and short processing time at the lowest possible process temperature.

This article describes brazing titanium to titanium and titanium to chromium in a titanium vapor cathodic arc discharge. Control of the thermal cycle and microstructure of the resulting joints are also discussed.

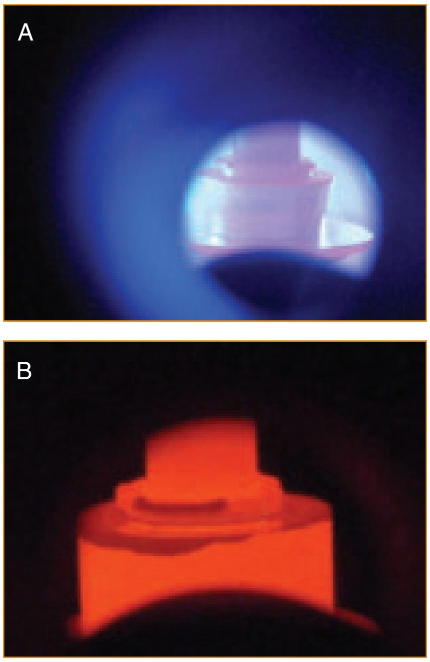

Fig. 3 — A — Brazed parts heated by the titanium ion bombardment. The view is through a quartz window in the plasma chamber; B — hot structure immediately after completion of the brazing process. The dark area is a brazing alloy after spreading along the surface of a titanium part.

Materials Required to Carry Out the Research

For the experiments, 2–4 in. (50–100 mm) diameter, 1–2 in. (25–50 mm) thick Grade 2 titanium and hot isostatic pressed (HIP-ed) chromium (100% theoretical density from powder with purity >99% and maximum grain size of 0.315 mm) discs were used.

The faying surfaces were polished, cleaned with acetone in an ultrasonic bath for 10 min or wiped with a lint-free cloth, and dried in air immediately before assembling with filler metal preforms. The chromium surface was polished to a "mirror" finish.

AWS BAg-7 filler metal in the form of $\frac{1}{16}$-in. (1.6-mm) wire was used for joining titanium to chromium, as well as for joining titanium to titanium, and AWS BAlSi-4 (Al-12Si) foil 0.015 in. (0.4 mm) thick was used for brazing titanium to titanium. Brazing was performed in a plasma discharge chamber — Fig. 1.

The parts were loaded with a dead weight of 1.5 kg and biased negatively by the high voltage power supply (2) to –700 V. The chamber was pumped down to

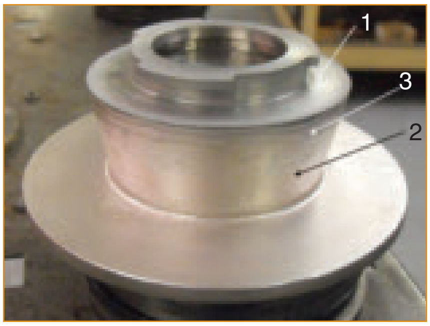

Fig. 4 — Brazed structure. 1 — Titanium part; 2 — chromium part; and 3 — brazed joint made with the AWS BAg-7 filler metal.

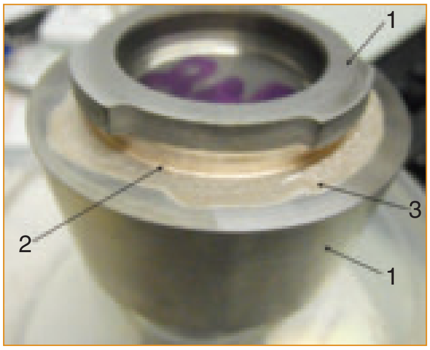

Fig. 5 — Brazed parts. 1 — Titanium parts; 2 — brazed joint; and 3 — area covered with filler metal BAg-7 spread along outside surfaces.

$4 \bullet 10^{-5}$ Torr, and an arc was ignited and maintained on the titanium cathode (4) by a high-current power supply (3) — Fig. 1. The filler metal was squeezed out upon melting under compression.

Step-by-Step Details of the Testing Process

The process was carried out in the following steps:

1. Preheating to 500°C.
2. "Soaking" to minimize the temperature gradient between the surface and the interior of the brazed structures. Equilibration could be ascertained by observing the cooling rate of the surface while the ion bombardment is disrupted.
3. Continue the bombardment to heat the parts to the brazing temperature as evidenced by the appearance of molten filler metal in the gap between the parts. The heat-up rate was carefully limited to ensure low volatile impurity desorption rates, so that the chamber pressure remained below $5 \bullet 10^{-5}$ Torr for the duration of the process.

Fig. 6 — Brazed structure. 1 — Titanium parts; and 2 — brazed joint.

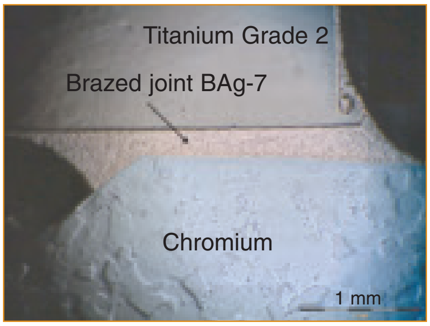

Fig. 7 — Macrostructure of titanium-chromium brazed joint, ×38.

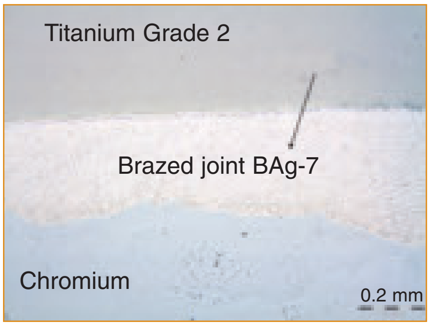

Fig. 8 — Microstructure of titanium-chromium brazed joint, ×100.

4. The ion bombardment was stopped 30 s after melting and spreading of the filler metal. The brazing temperature for Ti-Ti parts with BAlSi-4 was in the range of 620°–650°C, while it was in the range of 750°–780°C for Ti-Cr parts with BAg-7.

5. The brazed parts were cooled in the chamber under vacuum to 200°C before opening the chamber.

Brazing filler metals BAlSi-4 (Fig. 2A) and BAg-7 (Fig. 2B) can be seen after melting and spreading, and an operation mode is set up after one or two tests of the thermal cycle. Melting and spreading of the filler metal was ascertained visually through a quartz window. Heating could be monitored by an infrared thermometer — Fig. 3.

Brazed titanium-to-chromium parts are shown in Fig. 4, and brazed titanium-to-titanium parts are shown in Figs. 5 and 6. Possibly due to zinc evaporation, upon melting of the BAg-7 filler metal, the plasma color turned reddish. At the moment of melting, a pressure transient could be observed where the desorption integral (the area under the pressure vs. time curve) was a measure of the release of volatile impurities from the melt.

Macro and microstructure of titanium-to-chromium brazed joints made with AWS BAg-7 filler metal and heating by ion bombardment are shown in Figs. 7 and 8. As can be seen from these figures, the joint metal contains no porosity: It is fully dense, and there is good wetting and fillet formation on both base metals. No intermetallic phase formation is seen at the joint metal/chromium interface, while there are a thin intermetallic layer (likely $TiCu_2$) and a diffusion zone at the titanium side of the joint. The joint metal has a fine, even, completely eutectic structure, which is common for this class of brazing filler metals. It is likely that the filler alloy possesses sufficient plasticity due to the fine-grained microstructure of the Ag-Cu-Zn eutectic and uniform distribution of dendrites, even in fillet zones.

Conclusions

1. Metal ion bombardment is applicable to brazing such active base metals as titanium and chromium in a wide range of brazing temperatures from 600° to 800°C using silver-based or aluminum-based filler metals.

2. In comparison with traditional vacuum furnaces, brazing by ion bombardment has the following advantages:

- Possibility of using Zn-containing filler metals that enable brazing at lower temperatures;
- Rapid cooling due to processing in a cold chamber, resulting in the formation of a uniform, fine grained microstructure of joint metal;
- Absence or insignificant formation of brittle intermetallics at the interface with titanium; and
- Visual observation of the brazing process, allowing accurate control of the heating and temperature regimes, thus avoiding both under or overheating, and enabling the manufacture of high-quality joints of reactive base metals.♦

References

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