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SUBJECT: JOINING OF BERYLLIUM – A SURVEY OF THE UNCLASSIFIED LITERATURE

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ABSTRACT

The unclassified literature on the joining of beryllium was surveyed and is summarized ~~herein.~~ The fields covered are fusion welding, self-welding (diffusion- or pressure-welding), and brazing. The most successful attempts in each field are outlined and other work is referenced.

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JOINING OF BERYLLIUM - A SURVEY OF THE UNCLASSIFIED LITERATURE

Beryllium has been used for some time as a precipitation hardening agent in copper and aluminum alloys, but only with the coming of nuclear reactors has it become of importance as a pure metal. Beryllium has properties which make it an extremely desirable material for use in reactors, i.e., low atomic weight, high (thermal)-neutron-scattering cross section and low-absorption cross section. The use of beryllium also presents a number of problems, i.e., rapid oxidation at elevated temperatures, brittleness, high cost, and difficulties in the fabrication and joining. This paper deals with the latter problem, that of joining beryllium to itself. It presents a survey of the state of the art as presented in the currently available open literature and covers three sub-fields. These are (1) fusion welding, (2) self-welding (diffusion welding), and (3) brazing of beryllium. The bibliography also contains several references, not directly applying to the joining of Be, which are of interest (13, 14, 27, 28, 30, 31).

Fusion Welding of Beryllium

Attempts have been made at Battelle Memorial Institute[12,26] and at Massachusetts Institute of Technology[15-22], to develop a method of fusion welding for beryllium. Although some degree of success has been obtained in fusion welding of Be plate through 1/2-in. thickness, the difficulties involved (weld cracking, oxidation of base-metal and filler rod, if used, porosity in the weld metal, and flux inclusions in the weld area) indicate that other methods of joining may be more practical.

The work at MIT[15-22] included inert-arc welding using AC and DC current and helium and argon as shield gases. Welds were made without filler material, with beryllium filler rods, and with aluminum or copper as filler rod and/or spacer. Sound butt welds were obtained without filler material using straight polarity (DC), a tungsten electrode, and a helium shield with the under surface of the weld protected from oxidation by a locally applied argon atmosphere.[20] Other methods tested did not give as good results. These studies also revealed the following:

1. A helium shield gives less arc blow, a neater weld, and more available heat than an argon shield;[16]

2. Straight polarity DC gives greater penetration and a narrower zone of fusion than does AC;[18]

3. Although single passes were sound, all attempts to make multiple passes failed;[21] and

4. The use of copper filler rods and/or strips resulted in a brittle joint with cracking starting before the welds were completed.[22]

In early tests performed at Battelle Memorial Institute, a procedure was developed for the welding of beryllium - 3% aluminum alloys.[26] This process has been patented[29] and the patent states that the procedure is applicable to the pure metal as well. The patent claims that welds may be made using a noble gas shield which contains from 0.5 to 5% of a fluorochlorohydrocarbon, and with tungsten, aluminum or carbon electrodes. A filler rod of aluminum or beryllium base and AC and DC (straight or reverse polarity) may be used. The preferred conditions are:

Shield gas	-	Argon, 98 to 99.5% Freon-12, 0.5 to 2.0%
Electrode	-	Carbon
Filler rod	-	Same as base metal
Current	-	Straight polarity DC

The series of tests which led to this patent also developed the following facts:

1. The use of the atomic hydrogen and oxyacetylene processes caused excessive oxidation of base metal and that the oxyacetylene process caused excessive oxidation of the weld pool as well;

2. The metal-arc method, using a cast beryllium-aluminum alloy rod (bare or coated with Alcoa No. 27 flux), was not successful due to very poor metal transfer;

3. The use of a tungsten electrode with the Freon-12 flux gas was not practical due to corrosive attack by the Freon;

4. A braze type of bond could be made by using an Alcoa No. 27 welding electrode with standard aluminum arc-welding techniques.[26]

Later work at Battelle developed an inert-gas-shielded, consumable-electrode process using aluminum alloy filler wire for joining beryllium to itself and to aluminum. In these tests a Model 2 Aircomatic hand gun was used with Alcoa Alloy No. 718 filler wire, helium shield gas, and reverse polarity, direct current. Satisfactory welds were made in 1/4-in. and 1/2-in. plate. It was necessary to make a small pass on the back of the joints to eliminate points of incomplete penetration. Table I, p. 11 of reference 12 gives the detailed conditions for this procedure.

Self-Welding of Beryllium

Beryllium may be joined by self-welding (diffusion or pressure welding) according to the findings of both MIT and BMI. Self-welding, a process consisting of plastic flow, recrystallization, and grain coalescence, occurs when pieces of beryllium are held in intimate contact at elevated temperatures for suitable times. Temperatures of from 900° to 1250°C have been used to produce satisfactory self-welded joints.[1]

Tests at both MIT[23] and BMI[6] have shown the optimum temperature for self-welding to be about 1200°C. At 1200°C a successful weld may be made in one hour, while complete coalescence is obtained in 2-1/2 hr. (See Fig. 2, p. 286, ref. 1). At lower temperatures, the time and pressure required to obtain satisfactory bonding are increased. At 1100°C there is no grain coalescence and little dispersion of inclusions at the interface for times up to 24 hr while at 1150°C some coalescence and good dispersion of inclusions occur in 24 hr. At 900°C, a self-welded joint may be made, but it requires the use of considerable pressure.[1]

Self-welding seems to be best accomplished in vacuo, although successful welds have been made in argon atmosphere and in a Be chip-BeO bed. Results of typical tests are shown in Fig. 3, p. 287, ref. 1. Note that grain coalescence has occurred in all three cases, but that in the vacuum-welded sample that there is greater dispersion of inclusions. Welds made at 1150° and 1200°C have tensile strengths approaching that of blank specimens treated at 1200°C.[1]

The difficulties in the self-welding process are in the surface preparation and the jigging of the pieces to be welded. The surfaces to be welded must be flat and clean. The optimum preparation is accomplished by surface grinding to achieve flatness, scrubbing with acetone to remove grease and grinding wheel grit, dust, and other foreign particles, followed by a rinse with absolute ether. Vapor degreasing is not satisfactory since it does not remove the foreigh particles.[1] After cleaning, the surfaces to be joined must be held in intimate contact by suitable jigging. Graphite, molybdenum, tungsten and beryllium have been used for this purpose. The best results have been obtained using a beryllium jig (with the surface oxidized to prevent self-welding) with tungsten and/or molybdenum for wires, springs, rods, nuts and bolts.[2,4]

Brazing of Beryllium

Simple assemblies of beryllium may be joined by furnace brazing. Many brazing materials have been tested and reported to give satisfactory results. Among these are Al, Ag, Mg, Al-10 Ag, Al-96 Ag, Al-Cb, Al-2 Mg, Al-Si, Al-Ta, Al-Ti, Al-Zr, Mg-Cb, Mg-Ta, Mg-Ti, Mg-Zr, and Ag-28 Cu.[1,10,11,25] Of the materials listed, aluminum, silver, aluminum-silver (Al-10 Ag) and silver-copper (Ag-28 Cu) give the best results.[1]

The method of preparation of beryllium surfaces that is used for self-welding, i.e., surface grinding, acetone scrub, absolute ether rinse, should also be used for brazing preparation. Then the brazing material should be pre-placed in the joint to be made.[1] The brazing material is usually a foil of about 0.005 in. thickness[10] and this also should be thoroughly cleaned and degreased. The assembled joint should be supported with suitable jigs or clamps.

In using aluminum brazing-foil, the assembly should be held at 815°C for 24 hr for optimum results.[12] Successful joints have been obtained at 870°C for a like period.(1, p. 290) The brazing should be done in a vacuum but may be accomplished in an atmosphere of hydrogen or an inert gas.[1] The effect of holding time (at 870°C) on joint strength is shown in Table III, p. 291, ref. 1. This table indicates an increase in strength with increased time at temperature; however, the joint will fail from formation of voids due to aluminum migration into the beryllium if the temperature is maintained too long (170 to 200 hr at 870°C, 500 hr at 815°C).

With silver or silver-copper eutectic alloy brazing material the same methods of preparation should be followed but the actual brazing procedure is different. With these materials it is necessary only to bring the assembly to temperature long enough for the brazing material to melt and flow.[1,12] Since the heating and cooling should be done as rapidly as possible to prevent diffusion of beryllium into the braze, induction heating is suggested for use where possible.[12]

Silver and silver-copper alloy brazing may be used for joining beryllium to itself and to Monel, nickel, copper and stainless steel. The brazing may be carried out in vacuum or in an atmosphere of hydrogen, helium or argon with the exception of beryllium to stainless, which must be done in a dry hydrogen (dew point -40°F or lower) atmosphere.[1,12] Results of tests on silver and silver-copper alloy brazing materials are given in Tables 6 and 7, p. 36, 37, and 38, ref. 12.

Although lap joints are the easiest type to make, they are undesirable due to the inherent notch effect in them. Step-, scarf-, or butt-joints should be used where possible.[1]

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