WELDING RESEARCH

SUPPLEMENT TO THE WELDING JOURNAL, OCTOBER, 1982

Sponsored by the American Welding Society and the Welding Research Council

Brazing of Inconel Alloy MA 754 for High Temperature Applications

Commercial alloys can be used to join the alloy for applications at 982°C (1800°F) and 1093°C (2000°F), and tuning fork specimens are recommended for stress-rupture testing

BY T. J. KELLY

Introduction

INCONEL alloy MA 754* is a Ni-Cr oxide dispersion strengthened (ODS) alloy which is being used in gas turbine engines and other applications involving service in extreme environments. This alloy is made by mechanical alloying (MA) wherein pre-alloyed and elemental powders are milled together in a ball mill to form a homogeneous alloy powder. Once each powder particle is homogeneous, the powder can be compacted into a fully dense alloy, which through proper hot working and heat treatment is processed into an alloy with a directional grain structure (Ref. 1). In its final form, the alloy has good high temperature strength and a high solidus temperature which enables it to be used at temperatures as high as 1093°C (2000°F). Nickel-based oxide dispersion strengthened alloys of this type cannot be fusion welded for structural applications because the oxide dispersion is rendered ineffective or lost through agglomeration or slagging of the oxide during welding; therefore, alloy MA 754 must be brazed.

Although alloy MA 754 is being used in the aerospace industry, there is very little published information on the joining of this alloy. It has been established that fusion welding of this ODS alloy is not feasible for structural application; however, it can be resistance spot welded for fixturing prior to brazing. Additionally it is known that, in several applications, it is brazed and is performing satisfactorily, but the users consider their joining procedures to be proprietary and, therefore, will not divulge their data or procedures.

In an attempt to provide the aerospace industry with some usable joining information on this alloy, a sampling of high temperature brazing alloys has been evaluated for application with alloy MA 754. These high temperature brazing alloys were selected from published government contract reports on the brazing of previous ODS alloys. The brazing procedure was developed at the Inco Alloy Products Company Research Center in Suffern, NY.

Materials

A commercial heat of INCONEL alloy MA 754 was supplied in bar form 27 mm (1 1/16 in.) × 85 mm (3 3/8 in.) × 914 mm (36 in.). The brazing alloys AM 788 and TD 6 were purchased commercial alloys – AM 788 from Alloy Metals, Inc., Troy Michigan, and TD 6 from Union Carbide. B93 was atomized at the Inco Alloy Products Company Research Center using the composition published in NASA CR 135269 (2).

Procedure

Coupons 28 × 57 × 3 mm (1 1/8 × 2 1/4 × 1/8 in.) were saw cut from the bar and

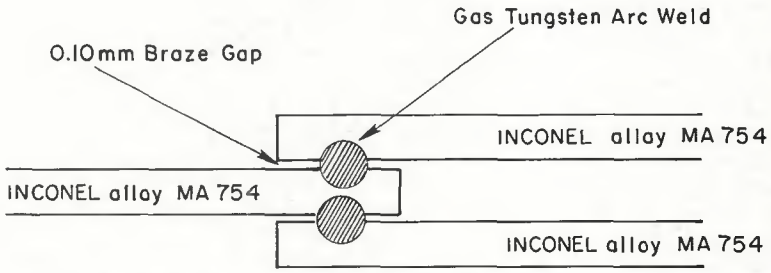

Fig. 1 – Schematic of braze specimen assembly used for evaluating stress rupture properties of brazed alloy MA 754

Table 1—Brazing Alloy Compositions and Brazing Temperatures Used with Alloy MA 754

Brazing alloy	Element, wt-%										Brazing temperature, °C (F°)	
	Ni	Cr	Co	Fe	Mo	W	Si	B	La	Al		
B93	bal	14	9.5	–	4	4	4.5	0.7	–	3	1260	(2300)
TD6	bal	16	–	5.0	17	5	4	–	–	1	1316	(2400)
AM 788	21	22	bal	–	–	14	2	2	0.03	–	1260	(2300)

*Trademark of the Inco family of companies.

Paper presented at the 13th International AWS-WRC Brazing and Soldering Conference held in Kansas City, Missouri, during April 27-29, 1982.

T. J. KELLY is Senior Metallurgist, Inco Alloy Products Company Research Center, Sterling Forest, Suffern, New York.

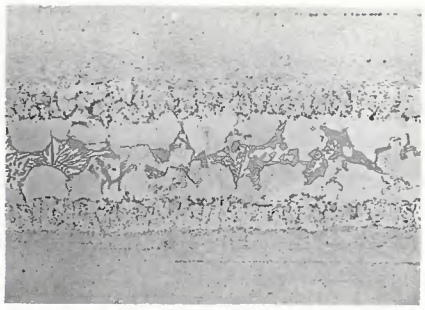

Fig. 2 — Brazement of alloy MA 754 made with B93; brazing cycle was ½ h at 1260°C (2300°F) in a 10^{-6} torr vacuum. X200 (reduced 50% on reproduction)

surface ground on the 28 × 57 mm (1⅛ × 2¼ in.) faces. The standard single lap specimen geometry given in AWS C 3.2-63 could not be used for stress-rupture testing due to complex bending stresses, which caused premature failure in stress-rupture testing. Specimens were then assembled, as shown in Fig. 1, with an effective 5 t overlap consisting of a 2.5 t overlap on both surfaces of the central piece and a 0.10 mm (0.004 in.) gap.

Gas tungsten-arc welds were used to hold the assembly together prior to and during the brazing cycle. Most of the brazes were made in a 10^{-6} torr vacuum at the temperatures indicated in Table 1. The brazing temperatures depended on the brazing alloy being used. The brazing alloys were selected from previous government contract reports on high temperature brazing, and published results as well as manufacturers' data were used to determine the brazing temperature used.

Once each braze was optically inspected, it was machined into a tensile test specimen and stress-rupture tested. Initial stress-rupture tests were done by step loading, i.e., a stress was applied for 24 hours (h) and then the stress was increased to a higher level and held for 24 h. The stress level was increased until the target stress level was achieved or the specimen failed. Since the aim of stress-rupture testing was to determine the 1000 h stress-rupture strength at 982°C (1800°F) and 1093°C (2000°F), the step-loading data was used to determine stress levels for 1000 h constant-load stress rupture tests.

The as-brazed microstructures were examined optically and microprobe analyses were carried out on the various phases present using an electron microprobe analyzer.

Results and Discussion

A braze was produced with each brazing alloy at the temperature shown in Table 1. The alloy MA 754 samples were surface ground and degreased with alcohol in preparation for brazing. All brazes appeared excellent upon visual evaluation; therefore, it was evident that a simple degreasing was the only surface preparation required for brazing alloy MA 754.

Table 2—Microprobe Analysis of Alloy MA 754 Brazements as Brazed with B93, AM 788 and TD6

Brazing alloy	Ni	Cr	Co	Mo	W	Si	B	Al	Ti	Fe
B93 matrix	Bal.	16	8	1.1	0	2.4	–	3	2.4	–
B93 2nd phase	Bal.	18	3.3	18	11.2	6.3	–	0.5	4.5	–
AM 788 matrix	Bal.	19.4	28	–	1.2	2	–	–	–	–
AM 788 2nd phase	3.5	51	6.3	–	25	0	8.5	–	–	–
TD6 matrix	Bal.	18	–	7.8	0	1.7	–	–	–	6
TD6 2nd phase	28	10	–	Bal.	7	5.4	–	–	–	0.8

Metallographic Examination

Brazing alloy B93, the composition of which is listed in Table 1, produced a pore-free braze, as shown in Fig. 2. The braze metal microstructure consists of two phases, as well as some dispersoid released from the alloy MA 754 during brazing. A microprobe analysis, Table 2, of the two major phases present determined the matrix to be gamma and an as yet unidentified second phase containing high concentrations of Mo and W. This second phase appears to contain too much Mo and W to be γ' or a Laves phase. An x-ray diffraction analysis of extracted second phase particles did not identify any standard crystal structure.

Brazing alloy AM 788, the composition of which is given in Table 1, produced the braze shown in Fig. 3. A minor amount of porosity is visible at X200, but this did not appear to affect the stress rupture properties of the brazement. Some dispersoid was released during brazing due to the apparent liquation of the alloy MA 754 in contact with the liquid brazing alloy. The matrix of the braze is gamma nickel with chromium boride as a well distributed second phase; a microprobe analysis of the two phases is shown in Table 2.

Brazing alloy TD 6 produced a good brazement with some porosity in both the braze and base metals; porosity shown in Fig. 4 was probably due to the high brazing temperature of 1316°C (2400°F) required for this material. Although this brazing temperature was the highest used with alloy MA 754, it produced a braze with a two-phase microstructure which contained no obvious dispersoid.

The lack of dispersoid in the brazed microstructure is probably due to the lack of boron in the TD 6 brazing alloy. Boron is a melting point depressant for nickel-based alloys and can diffuse readily in the solid state at elevated temperature; therefore, the boron in AM 788 and B93 probably caused the liquation of a small amount of alloy MA 754 and the subsequent release of dispersoid into the brazement. The two phases present in the as-brazed microstructure of TD6 were gamma nickel and an as yet unidentified second phase. A microprobe analysis of both phases appears in Table 2.

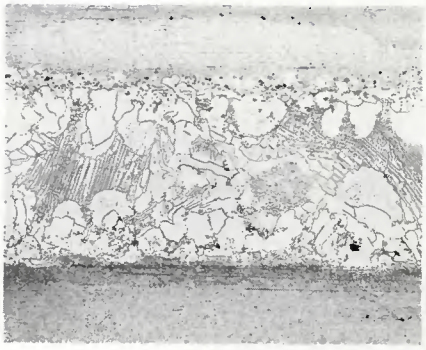

Fig. 3 — Brazement of alloy MA 754 made with AM 788; brazing cycle was ½ h at 1260°C (2300°F) in a 10^{-6} torr vacuum. X200 (reduced 50% on reproduction)

Stress-Rupture Testing

Previous vacuum brazing trials of alloy MA 754 at 10^{-6} torr with all three brazing alloys — TD6, B93 and AM 788 — had produced satisfactory brazements using the single lap joint specimen configuration designated in AWS C 3.2–63 (Ref. 3). Initially, it was believed that this type of specimen could be used for stress rupture testing; however, using this single lap joint design resulted in premature base metal failure when the brazement was stress-rupture tested at 1093°C (2000°F).

Figure 5A shows the failure of the base metal at well below its known stress-rupture strength for this temperature and time. This appears to be due to bending

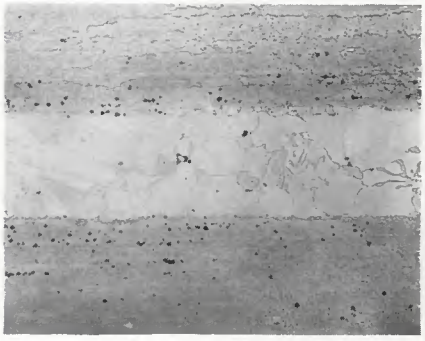

Fig. 4 — Brazement of alloy MA 754 made with TD-6; brazing cycle was ½ h at 1316°C (2400°F) in a 10^{-6} torr vacuum. X200 (reduced 50% on reproduction)

Fig. 5 — Comparison of AWS C3.2-63 specimen failure (A) to that of a "tuning fork" specimen (B) during stress rupture testing. The brazing filler metal was TD6; both specimens have the equivalent of a 5T overlap. A — failure through base metal after 15.7 h at 1093°C (2000°F) with a stress of 41.4 MPa (6 ksi); B — failure (shear) in brazement after 105.5 h at 1093°C (2000°F) with a stress of 55.2 MPa (8 ksi)

stresses developed in the tensile specimen made from the single lap joint brazements; these bending stresses do not appear to be a problem in room temperature testing; however, in stress rupture testing they can lead to premature failure of the base metal, as has also been noted by Yount (Ref. 4, 5). Therefore, a double lap or "tuning fork" specimen was made to eliminate the bending stresses that were causing premature failure; Figure 5B shows the result of testing a tuning fork braze of the same overlap and brazing alloy, TD6, as Fig. 5A. The failure, shown in Fig. 5B, was due to shearing of the braze alloy at a higher stress and longer time than the fracture of the base metal shown in Fig. 5A.

All of the stress-rupture results shown in Table 3 were obtained using the tuning fork specimen. The tuning fork specimen, as shown in Fig. 1, can be vacuum brazed in one brazing cycle with good fillets at all steps on the specimen.

Brazements using alloy B93 were stress-rupture tested at 982°C (1800°F). However, due to the low solidus temperature of 1110°C (2030°F) for B93, no stress-rupture tests were made at 1093°C (2000°F). It is possible that a boron diffusion treatment may have made B93 brazements useful at 1093°C (2000°F), but evaluating boron diffusion treatment schedules was not within the scope of this program. Using the equivalent of a 5T overlap and calculating the tensile stress using the cross-sectional area of the alloy MA 754, a 1000 h stress-rupture strength of 97 MPa (14 ksi) was achieved at 982°C (1800°F) without failure of the brazement.

Brazements using alloy TD6 were stress-rupture tested at 1093°C (2000°F), but not at 982°C (1800°F). This was because there are many brazing alloys which are useful at 982°C (1800°F) and have a lower brazing temperature than 1316°C (2400°F). The very high brazing temperature of 1316°C (2400°F) for TD6 is at or above the limit of many commercial brazing furnaces. More importantly, after reviewing the microstructure of the as-brazed specimen in Fig. 4, it appeared that the high brazing temperature was causing a great deal of porosity in the base metal; therefore, TD6 would be unacceptable for use with alloy MA 754, particularly in view of the data generated with alloy AM 788.

Brazements using alloy AM 788 were stress rupture tested at 982°C (1800°F) and 1093°C (2000°F). Since this alloy was the last to be tested, much of the step-loading procedure was abandoned in favor of testing at levels already achieved by B93 and TD6. If alloy AM 788 could not equal the other brazing alloys, then it would be of less interest for further evaluation.

As shown in Table 3, the stress-rupture results of brazements made with AM 788 equaled the results of alloy B93 at 982°C (1800°F) and were comparable to the results of alloy TD6 at 1093°C (2000°F) without evidence of microstructural damage to the base metal during the brazing cycle. At 982°C (1800°F) the 1000 h stress-rupture strength is 97 MPa (14 ksi), and at 1093°C (2000°F) the 1000 h stress-rupture strength is 34.5 MPa (5 ksi). Both temperature regimes were evaluated using an equivalent 5T overlap.

Conclusion

Alloy MA 754 can be used at temperatures in excess of 1093°C (2000°F), and commercial brazing alloys can be used to join this alloy for applications at 982°C (1800°F) and 1093°C (2000°F). The results of the current study are as follows:

1. When evaluating the stress-rupture strength of ODS alloy brazements, the AWS C3.2-63 specimen should not be used because it promotes premature failure of the base metal due to bending stresses; rather, the tuning fork specimen should be used for this type of evaluation.
2. Amdry alloy AM 788 is the most versatile brazing alloy to use with alloy MA 754 due to its brazing temperature and its 1000 h stress-rupture strength at 982°C (1800°F) and 1093°C (2000°F).
3. Brazing alloy B93 is equivalent to AM 788 for use at 982°C (1800°F) and should be lower in cost than AM 788.
4. Brazing alloy TD6, though capable of being used at 1093°C (2000°F), appears to have too high a brazing temperature to provide pore-free brazes with alloy MA 754.

References

1. Benjamin, J. S. 1976 (May). Mechanical alloying. *Scientific America* 234(5).
2. Bailey, P. G. 1977 (Oct.). *Manufacture and engine test of advanced oxide dispersion strengthened alloy turbine vanes,* p. 100. NASA CR 135269.
3. Stainless Processing Division, Wall Colmonoy Corporation. *Nicrobraz engineering data sheet.* Detroit, Michigan, 19345 John R Street.
4. Yount, R. E.; Kutchera, D. L.; and Keller, D. L. 1967 (Oct.). *Development of joining techniques for TD nickel-chromium.* Technical report AFML-TR-67-224.
5. Yount, R. E. 1968 (Nov.). Joining techniques for thoria dispersion strengthened materials. *Advanced techniques for material investigation and fabrication.* SAMPLE.

Table 3—Stress Rupture Test Results for Alloy MA 754 Brazements Using a "Tuning Fork" Specimen

Brazing alloy	Stress, MPa	Stress, ksi	Temperature, °C	Temperature, °F	Life, h	Comments
B93	110	16	982	1800	392	Sheared braze
B93	13.8/27.6/41.4/56.2/69[a]	2/4/6/8/10	982	1800	24/24/24/24/1051	Did not break
B93	97	14	982	1800	1000+	Did not break
B93	83	12	982	1800	1000+	Did not break
AM 788	27.6/41.4/56.2	4/6/8	1093	2000	24/24/21	Sheared braze
AM 788	41.4	6	1093	2000	178.2	Sheared braze
AM 788	110	16	982	1800	168.4	Sheared braze and base metal
AM 788	97	14	982	1800	1000+	Did not break
AM 788	34.5	5	1093	2000	1000+	Did not break
TD6	27.6/41.4/56.2/69	4/6/8/10	1093	2000	24/24/24/6.4	Sheared braze
TD6	56.2	8	1093	2000	105.5	Sheared braze

[a]See text for explanation of step loading procedure.