NEW LIMITATION CHANGE

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AUTHORITY
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Metals Joining

A program at General Electric to develop joining techniques for TD Nickel-Chromium is now complete. (1) The program was directed toward the fabrication of jet-engine and aerospace components. Two processes, high-temperature brazing and yield-strength-limited diffusion bonding, were satisfactorily developed for the applications of interest. For high-temperature brazing, TD-6 (Ni-16Cr-4Si-17Mo-SW) was selected as the most satisfactory brazing alloy on the basis of load-carrying ability before and after long exposure (up to 500 hours) at 2000 and 2200 F. Tables 1 and 2 give tensile properties of TD Nickel-Chromium joints brazed with the TD-6 alloy.

Satisfactory spot diffusion bonds were made using three-phase resistance-welding equipment. Bonds that equaled or exceeded the load-carrying ability of the alloy were produced in 0.025- and 0.040-inch-thick material. However, the microstructure of these bonds was not ideal, exhibiting a layer of equiaxed recrystallized grains. Numerous welding-machine settings were investigated in an attempt to eliminate the problem without success.

TABLE 1. AVERAGE TENSILE PROPERTIES OF TD-6 BRAZED JOINTS(a) IN TD NICKEL-CHROMIUM(1)

<table>
<thead>
<tr>
<th>Test Load at Temperature, F</th>
<th>Indicated Shear Strength, psi</th>
<th>Base Metal Stress at Failure, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure, pounds</td>
<td>Failure Location, psi</td>
<td></td>
</tr>
<tr>
<td>Room</td>
<td>2,726</td>
<td>41,800</td>
</tr>
<tr>
<td>1000</td>
<td>2,598</td>
<td>37,700</td>
</tr>
<tr>
<td>1400</td>
<td>1,190</td>
<td>17,560</td>
</tr>
<tr>
<td>1800</td>
<td>398</td>
<td>5,830</td>
</tr>
<tr>
<td>2000</td>
<td>301</td>
<td>4,680</td>
</tr>
<tr>
<td>2200</td>
<td>204</td>
<td>3,178</td>
</tr>
</tbody>
</table>

(a) 0.060-inch-thick TD Nickel-Chromium sheet, 0.120-inch overlap, 0.005-inch gap.

TABLE 2. AVERAGE TENSILE PROPERTIES OF TD-6 BRAZED JOINTS(a) IN TD NICKEL-CHROMIUM AFTER HIGH-TEMPERATURE EXPOSURE(1)

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Test Temperature, F</th>
<th>Load at Failure, pounds</th>
<th>Indicated Shear Strength, psi</th>
<th>Failure Location</th>
<th>Base Metal Stress at Failure, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>As brazed</td>
<td>2000</td>
<td>301</td>
<td>4,680+</td>
<td>Base metal</td>
<td>10,020</td>
</tr>
<tr>
<td>100 hours at 2000 F</td>
<td>2000</td>
<td>275</td>
<td>4,130</td>
<td>Base</td>
<td>8,805</td>
</tr>
<tr>
<td>500 hours at 2000 F</td>
<td>2000</td>
<td>287</td>
<td>4,410</td>
<td>Base</td>
<td>9,200</td>
</tr>
<tr>
<td>100 hours at 2200 F</td>
<td>2000</td>
<td>286</td>
<td>4,290</td>
<td>Braze and base metal</td>
<td>9,330</td>
</tr>
<tr>
<td>500 hours at 2200 F</td>
<td>2000</td>
<td>277</td>
<td>4,350+</td>
<td>Base metal</td>
<td>9,140</td>
</tr>
<tr>
<td>100 hours at 2000 F</td>
<td>2000</td>
<td>251</td>
<td>3,460</td>
<td>Base</td>
<td>8,280</td>
</tr>
<tr>
<td>500 hours at 2000 F</td>
<td>2000</td>
<td>235</td>
<td>3,390</td>
<td>Base</td>
<td>7,690</td>
</tr>
<tr>
<td>100 hours at 2200 F</td>
<td>2000</td>
<td>246</td>
<td>3,660</td>
<td>Braze and base metal</td>
<td>7,790</td>
</tr>
<tr>
<td>500 hours at 2200 F</td>
<td>2000</td>
<td>239</td>
<td>3,400</td>
<td>Braze and base metal</td>
<td>7,770</td>
</tr>
</tbody>
</table>

(a) 0.060-inch-thick TD Nickel-Chromium sheet, 0.120-inch overlap, 0.005-inch gap.
In the final phase of the program, two jet-engine components were fabricated using the above processes and then tested. A TF59, second-stage turbine-nozzle vane performed satisfactorily when subjected to approximately 1100 engine test cycles. The center two "W" gutter rings of a GE-4 (B57) flameholder were fabricated using either butt or scarfed brazed joints, reinforced by a spot-diffusion-bonded and back-brazed internal doubler. These parts performed satisfactorily in full-scale component tests.

Joining procedures for three nickel-base alloys were developed during a research program to design and fabricate lightweight heat exchangers at Garrett Corporation. The tube-and-shell-type heat exchangers were designed to withstand 100 hours of operation at 1540 to 2140 °F. Optimum bonding conditions for these service conditions were selected for Hastelloy X, L-605 (Haynes 25), and TD Nickel. Final recommendations are summarized in the following paragraph.

For 0.003-inch-wall tubes of Hastelloy X, brazing with Micro braz 30 alloy (Ni-19Cr-10Si-1Mo-4Fe) at 2175 °F in either a vacuum or dry-hydrogen atmosphere was satisfactory. The hydrogen atmosphere provides advantages in temperature-zone uniformity and in the speed of heating and cooling. Close control of the quantity of alloy and of the temperature were found to be critical to prevent erosion of the Hastelloy X by Microbrass 30. Tubes of the L-605 alloy having wall thicknesses of 0.006 to 0.010 inch were brazed with J8102 alloy (Ni-15Cr-35Si-5Mo) at 2200 °F. Again, both vacuum and dry-hydrogen atmospheres were satisfactory. Alloy L-605 was relatively insensitive to erosion by any of the brazing alloys considered. Several welding processes also proved satisfactory with L-605. It was easily welded by the inert-gas, tungsten-arc process, using either L-605 or Hastelloy W filler wire. Excellent quality spot welding was demonstrated, and two 0.006-inch-thick tubular inserts were successfully laser welded to an 0.008-inch-wall tube. TD Nickel in 0.006 to 0.008-inch-wall thickness was brazed in vacuum using TD-20 braze alloy (Ni-25Mo-16Cr-5W-4Si). However, excess quantities of the TD-20 alloy proved to be erosive to the TD Nickel. During high-temperature exposure, oxidation of the TD Nickel was accelerated at the base of the braze fillet, creating stress risers, limiting the service temperature of the uncoated structure to 1950 °F.

North American has reported some new information related to the elimination of weld-associated strain-age cracking in René 41. Resistance to strain-age cracking was found to be improved by a preweld solution anneal at 1975 °F with a 40 °F per minute cool to 1200 °F, and strain-age cracking was found to be eliminated by postweld stress-relieving anneals in high-purity argon or vacuum. Cracking in most heats of René 41 also can be eliminated by rapid heating, on the order of 50 °F per minute, through the age-hardening temperature range. During this study, low carbon content was shown to be extremely detrimental to strain-age cracking. The probable relation of oxygen to strain-age cracking was concluded to be one of lowering the resistance to crack propagation. In addition, the role of weld energy was minimized. Reduction in weld energy will reduce the severity of cracking, but it is the least important and least controllable variable.

A state-of-the-art report on the fundamentals of brazing technology for nickel alloys, prepared by Sidney Kaufman, has been received by EMIC. The report includes descriptions of brazing processes, designs, applications, and limitations.

**Aluminum**

The Feltman Research Laboratory recently completed a program to investigate the effects of relative humidity on the susceptibility and variability of 2024 aluminum alloy.

Relative humidity was concluded to noticeably affect these properties on chemically etched aluminum surfaces. With polyamide-epoxy adhesives, wetting was improved under conditions of high humidity. Also, adhesive joints prepared under high relative humidity conditions were stronger than those produced under dry conditions. With Epon 826/Versamid 140 (70/30 ratio by weight) the following bond strengths were obtained in lap shear specimens:

- 1845 psi ± 206 at 20 percent relative humidity
- 2700 psi ± 238 at 100 percent relative humidity.

Welding processes have been investigated during a program at Battelle to produce high-quality electrical strip from ultrahigh-purity aluminum. The strip is intended for use at low temperatures in magnet applications. The aluminum strip used in these studies had a guaranteed resistivity ratio (resistance at room temperature/resistance at liquid-helium temperature) of 7000 or above. Inert-gas tungsten-arc welding was used to join 0.06-inch-thick strips. Welding was performed in a vacuum chamber purged to about 2 x 10⁻⁴ torr and backfilled with...
argon. Welds were made at 8.3 to 8.9 volts, 152 to 159 amperes, and 50 ipm, using 1/16-inch-diameter, 1 percent, thoriated tungsten electrodes. The resistivity ratios of welded strips were better than 80 percent of the ratios of unwelded base metal. Mechanical properties of the strip at liquid-helium temperatures after annealing were not affected by the presence of a weld. Thermal cycling between room temperature and liquid-helium temperature apparently did not affect the properties. Satisfactory electron-beam welds with resistivity ratios comparable to those of the arc welds were also made. However, the TIG process was considered more practical and controllable.

**REFRACTORY METALS**

Northrop has completed a study of solid-state diffusion-bonding technology for T-111 (Ta-8W-2Hf) honeycomb hot-structural and heat-shield panels for aerospace environments. Both flat and curved specimens were produced for each type panel. Diffusion bonding was done in a sealed envelope of 0.025-inch-thick Inconel 600 sheet using quartz-lamp radiant heating. Bonding parameters for 12-by-12-inch panels were:

- **Temperature** - 2250 F
- **Time** - 5.5 hours
- **Pressure** - 1000 psi
- **Intermediate** - 0.0015-inch Ti 55 (structural panels)
  0.0005-inch Ti 75 (heat-shield panels)

Following bonding, the structural panels were hermetically sealed by inert-gas tungsten-arc welding. There were no difficulties with flat panels, but a cracking problem was encountered on curved panels. This was corrected by repair welding. Weld and parent-metal cracking were more of a problem on heat-shield panels. Gas tungsten-arc, laser, and electron-beam welding were all tried without success in attempts to solve this problem. The majority of welding was finally done by the electron-beam process, which minimized the cracking.

The structural panels were tested at room and elevated temperatures. This consisted of edge-wise compression testing of curved panels and edge-wise shear testing of flat panels. The panels were coated with Al-Sn-No for oxidation protection during testing. The curved panels failed at stresses of 91,700 psi and 71,600 psi at room temperature and at 17,200 psi at 8000 F. The flat panels failed at 74,500 psi and 81,520 psi at room temperature, 35,420 psi at 2100 F, and 13,400 psi at 3650 F.

Unalloyed tantalum has been satisfactorily brazed to Type 316 stainless steel in a program at NASA-Lewis. Vacuum brazing was accomplished at 2150 F using J-8400 brazing alloy (Co-21Cr-21Ni-8Si-3.5W-0.4C-0.88). When flat sheet and tubular specimens were tested at 1350 F in a vacuum chamber (10^-7 to 10^-6 torr), all joints failed in the tantalum or stainless steel parent metal. There was no unfavorable diffusion observed between the braze alloy and the parent metals.

Solar has developed a brazing process for attaching internal fins of Ch-12r foil to Ch-12r heat-receiver tubes. In brazing tests on T-joint and lap-joint specimens of Ch-12r, 15 braze alloys (copper, gold, titanium/zirconium, and tin bases) were evaluated. The three alloys that performed most satisfactorily in both laboratory and the stage tensile shear strengths of brazed joints are:

- **Cu-2Ni** - 38,100 psi
- **Zr-25V-16Ti** - 38,500 psi
- **Zr-25V-16Ti-0.1Be** - 37,600 psi

Because of its braze fluidity and filleting characteristics, the Zr-25V-16Ti-0.1Be alloy was used to braze full-scale heat-receiver tubes. Brazing was performed satisfactorily at 2150 F for 5 minutes in an induction furnace at a vacuum pressure of 1 x 10^-5 torr. The specimens were enclosed in cylindrical tantalum susceptors to insure uniform and rapid heating.

The diffusion bonding of columbium and tantalum to themselves and to each other was investigated at RA-1 Research Corporation. Stricter atmosphere control and cleanliness procedures were suggested as means to improve joint strength and bond efficiency.

**NEW PROGRAMS**

**Materials Development**


**Electron-Beam Welding**


(6) Preliminary information from Columbus Laboratories, Battelle Memorial Institute, Columbus, O. on U. S. Air Force Contract AF 35(615)-8270.


