RTNS-II Targets: Cooling Channel Collapse Under Simulated Bonding Conditions

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ABSTRACT

We experimentally determined the pressure limits that can be used to autoclave-bond RTNS-II targets without crushing the internal cooling channels. The maximum pressures are 40 to 55 MPa (6 to 8 ksi) in the 300-to-450°C temperature regime.

INTRODUCTION

Fabrication of RTNS-II Targets

The RTNS-II at LLNL produces an intense neutron flux that is used to study neutron damage in fusion-reactor materials. The target assembly for the RTNS-II (Fig. 1) includes a target coated with tritium-loaded titanium. When a deuteron beam is directed on the target, neutrons are produced by the reaction between deuterons and the tritium. Stopping the deuteron beam causes intense local heating of the target. This heat must be distributed and removed to keep the local temperature low so that tritium is not rapidly driven off. We distribute the heat by rotating the target at 5000 rpm, and remove the heat by circulating water through internal channels. We make targets of 23- and 50-cm (9- and 20-in.) diam. The larger targets are more highly stressed than the smaller at a fixed rotational velocity.

The targets are made as follows:

- Target blanks are cut to the proper size from sheets of copper alloy, and channels are chemically etched into one of the faying surfaces. Target alloys used to date include Glidcop (copper dispersion-hardened with alumina), Amzirc (copper precipitation-hardened with zirconium), and MZC (copper precipitation-hardened with magnesium, zirconium, and chromium).

- Areas not to be bonded are masked with Mylar tape.

- Faying surfaces of Glidcop targets are electrolytically coated with 13 μm (0.5 mil) of copper and 6.4 μm (0.25 mil) of gold; Amzirc and

MZC targets are coated with 2.5 μm (0.1 mil) of copper and 6.4 μm (0.25 mil) of gold.

- Three sets of targets are placed in a stainless steel bonding canister, each set separated by a stainless steel spacer that helps give uniform pressure transmission and prevents the targets from sticking to each other.

- The canisters are evacuated and sealed with an electron beam weld. They are hot isostatically pressed under a pressure of 21 to 35 MPa (3 to 5 ksi) for 1 h at 510°C (950°F) for Glidcop targets, or at 400°C (750°F) for Amzirc and MZC targets.

- The bonded targets are removed from the canisters and pressure-tested to 3.5 MPa (500 psi) for 23-cm-diam targets or to 17 MPa (2500 psi) for 50-cm-diam targets.

- Targets that pass the pressure test are cold-formed into the required dish shape and again pressure-tested. The forming process may damage a bond sufficiently that a target will fail the second pressure test after having passed the first.

- Surviving targets are coated with titanium by physical vapor deposition, and the titanium is loaded with tritium at 400°C.

Target Failures During Proof Testing

We report elsewhere¹ on the difficulties in making 50-cm-diam targets able to survive the 17-MPa (2500-psi) proof test. The location of failures was either at the gold-gold interface, or in

FIG. 1. Target assembly for the RTNS-II. A deuteron beam is directed on the target (which is coated with tritium-loaded titanium), and the reaction between deuterons and the tritium produces neutrons. Because stopping the deuteron beam causes intense local heating, the target is rotated at about 5000 rpm to distribute the heat. Cooling water is circulated through tiny internal channels in the target to remove the heat.

the copper adjacent to the gold coating. Failure at the interface was the result of inadvertently bonding at too low a temperature. Failure in the copper was through voids that resulted from unequal amounts of gold and copper interdiffusion (Kirkendall effect). Reverse bending during hydroforming further damaged already weak bonds.

The time-at-temperature window between poor adhesion and an unacceptable amount of void formation was small. For that reason we examined the bonding process to look for a remedy.

Fixing the Bonding Process

The bonding parameters that we control are temperature, pressure, time at temperature and

pressure, and interfacial barriers and bonding aids. The effects of these parameters on the bonding process are discussed in Ref. 1. We are in the process of determining the optimum parameters that will give good adhesion without an excessive amount of void formation.

The purpose of this experiment was to limit the size of our test matrix by determining the maximum external load a target can withstand at a given temperature without an unacceptable amount of channel closure. We did this by cutting coupons from previously bonded targets, and loading them at various pressure-temperature combinations. We measured the deflection during creep, and sectioned the coupons to estimate the amount of channel closure. From these data we estimated the upper limit of pressure that we can use for bonding.

TEST PROCEDURE

We used 16- μ m (5/8-in.) diam coupons cut from previously bonded Glidcop 50-cm-diam targets. We tested them in compression, doing stress-strain tests on Amzirc and Glidcop coupons at ambient temperature, and constant load creep tests on Amzirc coupons at elevated temperatures.

In these tests we measured the deflections under load with three extensometers spaced 120° apart. The reported deflections are the averages of these three measurements. We also cross-sectioned the creep specimens and estimated the amount of channel closure from photomicrographs.

RESULTS

Ambient Temperature Loading

We loaded Amzirc and Glidcop disks at a rate of 1.3 mm/min (0.050 in./min), and determined the stress at the proportional limit for each disk. The results for each specimen are presented in Tables 1

and 2. Here, flow stress refers to ratio of the applied load at the proportional limit to the total coupon area. The actual stress in the lands is, of course, higher than the flow stress. As is shown in Fig. 2, the etched channels in each target show three distinct areas from center to circumference as the

TABLE 1. Flow stresses of Amzirc coupons cut from a bonded 50-cm-diam target.

Position of coupon	Solid area (%)	Flow stress across coupon at proportional limit		Stress in lands at proportional limit	
		(MPa)	(ksi)	(MPa)	(ksi)
Center (no channels)	100	110	16	—	—
Outer channels	~29	97	14	330	48
Middle channels	~29	90	13	310	45
	~42	90	13	310	31
Inner channels	~28	130	19	470	68
	~21	130	19	620	90
Average		110	16		

TABLE 2. Flow stresses of Glidcop coupons cut from a bonded 50-cm-diam target.

Position of coupon	Solid area (%)	Flow stress across coupon at proportional limit		Stress in lands at proportional limit	
		(MPa)	(ksi)	(MPa)	(ksi)
Center (no channels)	100	220	32	—	—
Inner channels	~25	120	18	500	72
Middle channels	~29	93	13.5	320	47
	~42	86	12.5	210	30
Outer channels	~30	110	16	370	53

FIG. 2. RTNS-II 50-cm-diam target blank with cooling water channels etched into faying surface.

channels subdivide and become narrower. We measured the flow stress at the proportional limit for coupons from each of these areas, as well as for coupons cut from near the target center, which had no channels. The ratio of channel to land area depends on the actual position of the coupon in the target. We estimated the channel-to-land ratio for each coupon and used this ratio to calculate the compressive stress actually borne by the lands. Both the overall stresses and the stresses in the lands are given in Tables 1 and 2.

The flow stress for Amzirc was fairly independent of position and ranged from 80 to 130 MPa (12 to 19 ksi) for different areas of the target. As an average, we would expect that a stress of about 110 MPa (16 ksi) would be required to begin to crush the channels of an intact target at ambient temperature. The flow stress for Glidcop coupons taken from the inner and middle sections was 140

to 170 MPa (21 to 25 ksi), but only 80 MPa (12 ksi) for a coupon from the outer section. We do not understand why this outer section had a lower flow stress, but since we no longer use Glidcop for targets we did no further analysis.

Tables 1 and 2 also give the stress borne by the lands in each coupon at the proportional limit. No explanation for the difference in values between various target locations is obvious.

Elevated Temperature Creep

We measured the creep of Amzirc coupons at elevated temperatures. These tests were at constant load, and also nearly at constant stress, since the coupon area grew little during testing. Each test was for 1 h at the following pressures and temperatures: 70 MPa (10 ksi) at 350°C, 35, 70, and

FIG. 3. Creep of 5/8-in.-diam coupons cut from a bonded Amzirc target and subjected to compressive loading.

125 MPa (5, 10, and 18 ksi) at 400°C, and 35 MPa (5 ksi) at 500°C. The creep curves for these coupons are shown in Fig. 3. The measured deflections are a sum of three contributions: (1) flattening of the curved surfaces, since the coupons were cut from a target having spherical curvature (60- μ m max), (2) channel closure (15- μ m max), and (3) thinning of the bonded plates by creep in a radial direction.

We could not separate these different contributions to the deflection from the creep curves, so we sectioned each coupon, photographed the channel openings, and estimated the amount of closure from the photomicrographs. Figure 4 is a surface view of a typical etched channel area, and Fig. 5 shows the cross sections of channels from two autoclave-bonded targets. These channels exhibit little discernible crushing, but it is apparent

FIG. 4. Detail of etched channel pattern on bonded and delaminated RTNS-II target.

that the actual channel depth varies with the amount of etching, as well as its location in the target.

Figures 0 through 10 show the amount of channel closure for each tested coupon. Since heating was done in air, the dark layer that delineates the inside of the channels is copper oxide. This layer proved useful for determining the original width of each channel, inasmuch as the channels were of varying widths since they come from different parts of the bonded target. The amount of channel area remaining open was measured on each photomicrograph, and the original channel area was calculated from its original width. (For this calculation, we assumed that the original cross-sectional area was a semicircle.) The percentage of the channel area remaining open after pressing is given in Table 3 and Fig. 11. The amount of crushing depended much more strongly on pressure than on temperature. If we estimate that 20% closure is the greatest that could be tolerated, the safe pressure limit appears to be 40 MPa (6 ksi) for bonding at 450°C, and about 55 MPa (8 ksi) for bonding at 300°C. This limit may be conservative, as tests were made on coupons which had been previously bonded and hence had undergone some annealing. Unannealed Amzirc would probably deform somewhat less during bonding.

We used this information to calculate "safe" bonding parameters, i.e., those regimes of pressure and temperature in which bonding will occur with less than 20% channel closure. From Fig. 11 we estimated four pressure-temperature pairs, each of which should result in about 20% channel closure.

FIG. 5. Cross section of autoclave-bonded RTNS-II target showing cooling channel as bonded (100X).

From these four pairs, we constructed the 20% channel closure curve shown in Fig. 12, using constant second differences to smooth the curve. Combinations of pressure and temperature above this line should result in more than 20% channel closure and those below this line in less than 20% closure.

We used data of Knowles² to construct the silver-to-silver bonding curve also shown in Fig. 12. Pressure-temperature pairs above this curve should give bond strengths greater than 70 MPa (10 ksi). Knowles' data are for bonding very clean silver surfaces at temperatures below 200°C. Since our electroplated silver surfaces will get much handling and thus not be as clean, we extrapolated his

FIG. 6. Cross section of autoclave-bonded RTNS-II target showing a cooling channel. Pressed for 1 h at 35 MPa (5 ksi) and 400°C after bonding. No detectable channel closure (75X).

FIG. 7. Cross sections [(a) and (b)] of autoclave-bonded RTNS-II target showing a cooling channel. Pressed for 1 h at 70 MPa (10 ksi) and 350°C after bonding. Channel cross section 29 to 30% of original area (100X).

FIG. 8. Cross sections [(a) and (b)] of autoclave-bonded RTNS-II target showing a cooling channel. Pressed for 1 h at 70 MPa (10 ksi) and 400°C after bonding. Channel cross section 10 to 21% of original area (100X).

FIG. 9. Cross sections [(a) and (b)] of autoclave-bonded RTNS-II target showing a cooling channel. Pressed for 1 h at 70 MPa (10 ksi) and 500°C after bonding. Channel cross section 5 to 20% of original area (75X).

FIG. 10. Cross sections of autoclave-bonded RTNS-II target showing a cooling channel. Pressed for 1 h at 125 MPa (18 ksi) and 400°C after bonding. Channel cross section 0 to 2% of original area (75 $\times$).

FIG. 11. The effect of pressure and temperature on channel closure in coupons cut from a bonded Amzirc target.

TABLE 3. Channel area remaining open after pressing for 1 h, expressed as a percentage at the original cross-sectional area.

Temperature (°C)	35 MPa (5 ksi)	Pressure 70 MPa (10 ksi)	125 MPa (18 ksi)
350		29 to 37%	
400	~100%	10 to 21%	0 to 2%
500		5 to 20%

FIG. 12. Prediction of "safe" bonding parameters. Safe areas lie between the 20% channel closure line and either the Ag-Ag bonding line or the Au-Au bonding line.

data to above 300°C, the decomposition temperature of Ag_2O . Above this temperature, silver dissolves its oxide and also scavenges many surface contaminants. The area for "safe" bonding of silver-plated targets is marked on Fig. 12.

Gold is much more difficult to bond than silver.^{3,4} While it does not form an oxide, neither

does it dissolve surface contamination. Thus gold-to-gold bonding parameters are higher than silver-to-silver bonding parameters. We used a correlation by Bryant⁵ to estimate bonding parameters for gold using mechanical and elastic properties of the metal. The area for "safe" bonding of gold-plated targets is also shown on Fig. 12.

CONCLUSIONS

The upper limits of pressure for autoclave-bonding Amzirc target disks without crushing the cooling channels is 40 to 55 MPa (6 to 8 ksi). These limits are relatively insensitive to temperature in the probable bonding temperature range of 300 to

450°C. We expect that silver will bond at temperatures above 300°C and gold will bond at temperatures above about 425°C when subjected to pressures near the channel crushing limit.

REFERENCES

1. W. D. Ludemann, G. A. Harter, and B. J. Schumacher, *Analysis of Bond-Failures in RTNS-II Targets*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53184 (1981).
2. J. L. Knowles, *High-Strength, Low-Temperature Bonding of Beryllium and Other Metals*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50766 (1970).
3. R. F. Tylecote, "Investigations on Pressure Welding," in *Brit. Welding J.* 1, 117-135 (1959).
4. J. L. Tellison, "Effect of Surface Contamination on the Thermocompression Bondability of Gold," in *IEEE Trans. on Parts, Hybrids, and Packaging*, PHP-11(3) (Sept. 1975).
5. W. A. Byrant, "A Method of Specifying Hot Isostatic Pressure Welding Parameters," in *Welding Research Supplement* 54, 433-435 (1975).