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DEVELOPMENT OF MANUFACTURING METHODS FOR 50-CM DIAMETER NEUTRON SOURCE TARGETS FOR RTNS-II

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RTNS-II is an accelerator driven neutron source. We attempted to produce a larger version of our current accelerator target but experienced problems in diffusion bonding and thermal stability of the copper alloy used for target fabrication. We have identified the causes of these problems and demonstrated a new technique, diffusion firing, for fabricating targets.

1. INTRODUCTION

The rotating target for the RTNS-II (RTNS-II) is an accelerator-based neutron source and is fabricated from a variety of materials. The target is a 50-cm diameter target with concentric rings of tritium loaded in grooves. The target is used to produce fusion neutrons. The target is used in the RTNS-II as a primary source of neutrons. The target is used to increase the neutron flux in the RTNS-II, but are limited by the strength of the present 50-cm diameter target. To produce the additional beam power that will be required.

Neutrons are produced from the target and the neutrons yield to experimentally determined level not useful for experimental purposes. The degradation of the target is due to the integrated quantity of beam deposited on the target and the rate at which the beam is applied. We concluded the only feasible means of increasing neutron yield was to increase the diameter of the target, providing greater area over which to dissipate the beam. We adopted as a goal, to produce a target 50-cm in diameter.

The 50-cm targets currently used on RTNS-II have been routinely fabricated, for over three years, by chemically milling grooves into a copper alloy sheet and diffusion bonding* a cover sheet over the grooved surface to produce a target blank with internal cooling channels. The target blanks are then formed to shape, coated with titanium on one side and loaded with tritium. Figure 1 is a schematic representation of the finished target mounted on the RTNS-II accelerator.

We attempted to produce 50-cm targets using the

*Diffusion bonding joins metal components under heat and pressure to form a joint without melting. The process for 23-cm targets uses gold as a diffusion aid.

Figure 1. Target assembly for the RTNS-II. A deuterium 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 deuterium beam causes intense local heating, the target is rotated at about 5000 rpm to distribute the heat. Cooling water is circulated thru tiny internal channels in the target to remove the heat.

same fabrication techniques used to produce the 23-cm targets. The diffusion bonding joint failed when tested hydrostatically at the higher operating pressures which would be produced in the 50-cm target cooling channels. We concluded that an improved target design/fabrication process was required to produce 50-cm targets for RTNS-II.

STRUCTURAL REQUIREMENTS

The RTNS-II targets must withstand structural loads from the accelerator vacuum and 5000 rpm rotation. Neutrons are produced at the interior surface of the target and flux levels decrease rapidly with increased distance to the neutron source. To allow experimenters easy access to the highest neutron fluxes, the target must be as thin and stiff as possible.

Structural calculations [1] suggested two methods of reinforcing the target as shown in

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Fig. 2. Further calculations showed stresses, and deflections in the target during operation were relatively insensitive to target thickness. Targets as thin as 60 mils seemed possible if only they were stable to buckling.

Figure 2 Two methods of target reinforcement, shown as additions to the copper alloy substrate and the cover sheet. The first method involves replacement of a portion of the cover sheet with electrodeposited nickel and the addition of an inside lamination of electrodeposited nickel. The second method is the addition of a carbon fiber edge reinforcing ring at the outside of the cone. These reinforcements could be used singly or in conjunction.

Buckling tests were performed on a 60 mil unreinforced target under actual load conditions by rotating it at successively higher speeds. Failure by buckling occurred at 5800 rpm, reasonably over the 5000 rpm limit for RTNS-II. Adding reinforcing would increase the design margin for buckling failure. We decided that we would produce 60-mil thick targets. Table 1 summarizes the maximum stresses and deflections in the 50-cm target during operation.

Target Type	Maximum Stress	Maximum Deflection
a	42.8 ksi	0.060 in.
b	32.1 ksi	0.047 in.
c	33.2 ksi	0.046 in.
d	29.8 ksi	0.040 in.

TABLE 1. Maximum combined stress and axial deflection in an RTNS-II 50-cm, 0.080 inch thick, electroformed target during operation at 5000 rpm. a: unreinforced b) electrodeposited nickel reinforcing only (see Fig. 2) c) carbon fiber edge restraint only (see Fig. 2) d) both electrodeposited nickel and carbon fiber edge restraint (see Fig. 2).

MATERIAL REQUIREMENTS

Any material considered for RTNS-II targets must have high thermal diffusivity to dissipate D* beam power densities of up to 80 kw/cm².

*Trademark, Amax Metals Inc.

The production of targets includes two steps, diffusion bonding and tritium loading, which involve temperatures as high as 400°C. After these thermal cycles, the target material must still possess a room temperature yield strength of ~50 ksi to provide a reasonable margin over the operating stresses of Table 1. In addition, the material must be dimensionally stable through the production process.

We selected two precipitation-hardenable, high-conductivity copper alloys, Amzirc* and MZC,* for further study [2]. Sheets were procured of both materials in a size appropriate for 50-cm target fabrication. We cut tensile specimens parallel and transverse to the direction of rolling and exposed them to temperatures from 400°C to 650°C for times of 0.5, 1 and 10 hours. Figure 3 shows the effect of thermal treatment on the room temperature yield strength of these alloys. Our results for Amzirc compared well with data published by Amax. The MZC compared well as received, but showed much more rapidly than expected when exposed to thermal treatment.

Figure 3 Effect of thermal treatment on the room temperature yield strength of "Amzirc" and "MZC" copper alloy sheet

We examined metallographic samples of both materials in both optical and electron micro-

scopes [3]. In the as-received condition, both materials exhibit a typical cold-worked microstructure. Figure 4 shows the as-received Amzirc with a coarse, randomly distributed precipitate while Fig. 5 shows the as-received MZC with a fine, randomly distributed precipitate.

FIG. 4. Microstructure of Amzirc showing (a) longitudinal and (b) transverse structures. Material is in as-received condition. Note the presence of a coarse, randomly-dispersed, precipitate (arrows), 800 $\times$.

FIG. 5. Microstructure of MZC showing (a) longitudinal and (b) transverse structures. Material is in as-received condition. Note the presence of a finely-dispersed, general precipitate (500 $\times$).

Amzirc showed no significant recrystallization until exposure to 450°C, however, MZC began to recrystallize as low as 400°C. The MZC microstructure shown in Fig. 6 was produced by exposure to 650°C for one hour. Two distinct precipitates are visible. X-ray analysis of the SEM spectra indicates the chromium has segregated into one precipitate and the zirconium into the other, rather than into the normal single precipitate containing all of the alloying elements.

We were unable to put either of these precipitates back into solution by heating and quenching at temperatures as high as 1030°C. Attempts to chemically analyze MZC left an insoluble residue and showed no zirconium or chromium in the soluble portion. We suspect that the zirconium and chromium, the main pre-

FIG. 6. Microstructure of MZC after exposure to 650°C for 1 hr shows two different precipitates. Light areas are rich in zirconium and dark areas are rich in chromium. These precipitates could not be put back into solution even with a 30 min., 1030°C exposure followed by a water quench.

cipitation-strengthening phase, are present in the insoluble residue as stable compounds, possibly oxides. We are currently attempting to analyze the residue.

The MZC appears to have been improperly manufactured. The precipitation strengthening second phase appears not to have been taken into solution. The strength of the as-received MZC appears to be primarily due to cold work, which is removed by prolonged exposure to temperatures of 40 to 50% of the melting temperature or 270 to 405°C. The poor thermal stability of our as-received MZC makes it unsuitable as a potential target fabrication material.

The Amzirc can be exposed to temperatures as high as 450°C for one to two hours and still have sufficient room temperature mechanical properties to meet the structural requirements for an RTNS-1, 11-cm target. We have decided to fabricate such targets in the near future from Amzirc.

TARGET FABRICATION

The diffusion bond used to fabricate 23-cm targets is made by plating the faying surfaces of the copper sheets with 0.0005 in. of gold. The sheets are then packaged in an evacuated can and hot isostatically pressed at 3000 psi and 500°C for an hour to make the bond. The targets made in this manner reliably withstood the 750 psi hydrostatic test required for 23-cm targets. The 50-cm targets, because of their higher operating pressure require a 2500 psi hydrostatic test. The diffusion bonded joint in 50-cm targets failed in two different modes when hydrostatically tested.

Some 50-cm targets failed by separating along the Au-Au faying surface between the two sheets

as shown in Fig. 7. Other targets failed between the copper substrate and Au plating. When examined in an SEM, specimens that failed along the Au-Au interface appeared to have never been bonded while specimens that failed along the Au-Cu interface appeared to fail as a result of Kirkendall porosity* as shown in Fig. 8. We suspected the poor bonding at the Au-Au interface to be caused by too little time at temperature during the isostatic pressing and the Kirkendall voids to be caused by too much time at temperature.

We experimented with Au plated (.0005") Cu samples heated at 510°C for various times. We determined the degree of interdiffusion by examining an edge of the sample in an SEM and plotting the rate of decline of the Au x-ray as we scanned from the Au plating into the Cu substrate. The results are shown in Fig. 9 with typical diffusion slopes superimposed for targets which failed at the Au-Au and Au-Cu interfaces. It is apparent at 510°C there is only about a 20-minute time interval in which the targets could be diffusion bonded successfully. This is impractical for a production process in a large heavily loaded autoclave. In addition the 510°C exposure would degrade the yield strength of the Amzirc substrate to less than the 50 ksi required for the 50-cm target.

To improve the bonding process, we can vary either the autoclave conditions of time, temp-

FIG. 7. SEM photograph at 800X of (a) properly made diffusion bonded joint and (b) diffusion bonded joint in a 50 cm target which failed because of insufficient Au-Au diffusion.

*Copper diffuses into gold about an order of magnitude more rapidly than gold diffuses into copper. This results in the formation of voids in the copper immediately adjacent to the gold. These voids act as tiny perforations to form a weak plane.

erature and pressure or the condition of the faying surfaces. In general, higher temperatures and pressures give better bonding as they promote good interfacial contact, are conducive to the dissipation of interfacial contamination and speed the diffusion process. Excessive temperature and pressure may crush the channels. Excessive temperature degrades the substrate material as shown in Fig. 10 and promotes void formation.

We are currently studying a number of techniques with potential for improving the process for

FIG. 8. SEM photograph showing (a) Kirkendall voids at the Au-Cu interface of a diffusion bonded target (800X) (b) failure of a diffusion bonded joint along the plane of Kirkendall voids (150X).

Figure 9. Extent of interdiffusion as a function of annealing time at 510°C. Diffusion slope is the rate of decline of the Au x-ray signal in an SEM when scanning across the Au-Cu interface. The diffusion slope for two targets which failed by different mechanisms are also shown.

Figure 10 Limitations on temperature and pressure for diffusion bonding RTNS-II 50 cm targets made of "Amzirc" (Ref. 3 and 5).

fabricating 50-cm targets as follows:

- Nickel barrier. A diffusion barrier of Ni between the Au and Cu will reduce the total amount of interdiffusion and hence reduce the tendency for void formation.
- Reduced gold plating. The purpose of the Au is to provide a clean plastic surface. This might be accomplished with less Au, reducing the total amount of interdiffusion.
- Silver bonding aid. Ag can be used instead of Au as a bonding aid. Interdiffusion rates for the Ag-Cu system are more closely matched than those for the Au-Cu system, resulting in less void formation. Formation of Ag-Ag bonds appears possible at lower temperature and pressure as shown in Fig. 10.

The results of these studies will be reported in a future UCL report.

We have recently produced targets using a wax electroforming technique [4]. The channels are first filled with Higidax W Blue[®] wax and wet sanded to remove excess wax and expose the copper surface of the lands. The surface of the wax is made conductive using silver powder and the parts are then electropolished to remove the silver powder from the copper lands. A 20 mil cover of copper is plated over the surface to form the internal channels and the wax is removed by flushing hot perchloroethylene thru the channels. Only one electroformed target has failed during hydrostatic testing, even though tests have often been to the 3400 psi limit of our test apparatus.

SUMMARY

Causes of failure in the initial diffusion bonded 50-cm targets have been identified. Several potential improvements in the diffusion bonding fabrication method are currently being studied. A substrate material, Amzirc, has been selected for production of targets in the near future.

A second manufacturing method, electroforming, has been demonstrated for fabricating 50-cm targets. Electroformed targets appear much easier and cheaper to produce than diffusion bonded targets.

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