STUDY OF HIGH-STRENGTH COPPERS FOR RFQ1'S NEW VANES*

T. Tran-Ngoc and R.M. Hutcheon
AECL Research, Chalk River Laboratories
Chalk River, Ontario, Canada, K0J 1J0

Abstract

This paper summarizes a study of high-strength copper alloys to select a suitable material for new vanes on the RFQ1 accelerator. GlidCop AL-15 alumina-dispersion-strengthened copper has been chosen for its high strength, relatively high thermal and electrical conductivities and its ability to retain its strength through heating cycles. The results of a detailed test program to evaluate this material are also reported.

Introduction

In the design of the RFQ1 accelerator structure, low-carbon steel was used to provide structural strength. Inside surfaces, where appreciable rf currents flow, were copper electro-plated.[1] This design is complex, expensive to fabricate and difficult to modify. For the new vanes[2] it was decided to see if an improved design could be obtained by using a high-strength copper alloy. A test program was conducted on the selected alloy to verify some of the properties and required fabrication techniques.

Commercially Available High-Strength Coppers

Copper can be strengthened significantly by alloying, by precipitation hardening or by dispersion of a second-phase material in the copper matrix. Usually, alloying elements cause a significant loss in the electrical conductivity (e.g., brass and bronze). In the age-hardened condition, the precipitation-hardenable alloys (e.g., zirconium copper and chromium copper) offer higher strength than pure copper at room temperature and better electrical conductivity than alloyed copper.[3] However, extended exposure to temperatures above the initial aging temperature lower both the strength and conductivity. The dispersion-strengthened coppers provide both high conductivity and strength, and remain stable after exposure to high temperature.[4]

Several high-strength, high-conductivity copper alloys were considered for the RFQ1 application. Their yield and tensile strengths vary with the amount of cold-work, and are summarized in Fig. 1. Electrical conductivities are shown in Table 1.

Due to its high strength, good electrical conductivity and stability on prolonged exposure to high temperature, GlidCop AL-15 in low oxygen grade was chosen for the new vanes.

*This work was partially supported by Los Alamos National Laboratory under contract No. 9-X5D-7842D-1.

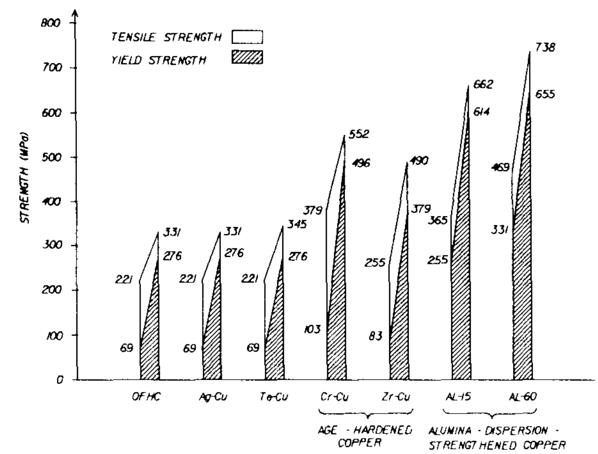

Fig. 1. Tensile and yield strength of coppers.

TABLE 1

Room Temperature Electrical Conductivity of Coppers

Material	DC Electrical conductivity (%IACS)
OFHC	101
Ag-Cu	96
Te-Cu	90
Cr-Cu	80
Zr-Cu	95
AL-15	92
AL-60	78

Evaluation of GlidCop AL-15 Copper

All our test specimens were machined from a low oxygen grade 31.75 mm (1.25") diameter AL-15 rod sample, which has a minimum yield strength of 317 Mpa (46 000 psi).

Plug Welding

In general, extensive welding of the material for joining structural components is not recommended. The large difference in density between copper and alumina will make the latter segregate in the melt and create non-uniformities in the properties of the welded joints. In our application, it is only necessary to make small welds to plug the ends of the gun-drilled cooling channels, and these are in locations where such variation of the material properties is not important. Sound and leak-tight joints have been demonstrated using helium-shielded tungsten-arc welds with 70% Cu 30% Ni rod and OFHC copper rod as filler materials, and also with electron beam welds.

Brazing

Because of the fine grain structure of AL-15 at brazing temperature, the silver constituent of the brazing alloys diffuses very rapidly away from the joints. Nickel or copper plating is recommended as a barrier to this diffusion.[4] The higher the brazing temperature the thicker the required plating layer. Nickel plating was used and test joints were made between two pieces of AL-15, and between AL-15 and stainless steel or OFHC copper.

Due to the slow heating rate of our radiant furnace (about 3.5°C/min near the brazing temperature) we encountered the above-mentioned diffusion problem even when using the manufacturer-recommended plating thicknesses. However, increasing the plating thickness and minimizing the holding time at brazing temperature to about 5 minutes yielded good results. Leak-tight joints were obtained using Cusil (liquidus = 780°C) and Palcusil 5 (liquidus = 810°C) with nickel plating thicknesses of about 0.013 mm (0.0005") and 0.025 mm (0.001"), respectively.

Mechanical Tests of the Racetrack-Shape Compressed Joint

The vacuum and rf seal between the RFQ1 vanes and tank are made by a compressed joint.[1] Tests of the strength of the sealing edge were carried out using GlidCop AL-15 samples in the as-received, highly cold-worked (deformed by a compression load of 1050 N/mm) and heat-treated (3 cycles up to a maximum of 900°C) condition, and compared with mild-steel ASTM A266 class 2.

Vacuum-tight joints were obtained for all AL-15 samples at a linear compression load of about 140 N/mm (800 lbs/in). The results of mechanical tests, performed in steps of increasing bolt torque, are illustrated in Fig. 2. The sealing edges on all samples increased in radius and were reduced in height by about the same amount, with most of the deformation taking place during the first loading cycle. Comparing the results obtained for different sample materials indicates that:

- Up to a load of 480 N/mm (2750 lbs/in), AL-15 in the as-received and heat-treated condition is comparable to mild steel,
- AL-15 in a highly cold-worked condition outperforms mild steel in the testing range, and
- The heat treatment has very little effect on the strength of AL-15.

The seal at the bottom of each RFQ1 vane is compressed by thirty-six 1/2-20 UNF alloyed-steel screws at 120 Nm (90 ft-lbs) torque. At this level copper would wear and gall; therefore, Helicoil inserts are used in all threaded holes. Such a screw was torqued to 220 Nm (160 ft-lbs) in a Helicoil insert in AL-15 with no apparent damage to the threaded hole or the screw itself.

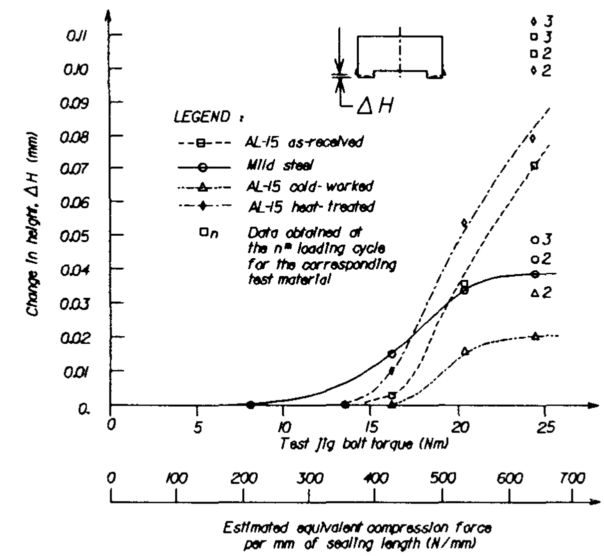

Fig. 2. Change in height of the sealing edges.

RF Conductivity Measurements

To measure the rf conductivity of AL-15 in the 300 MHz frequency range, an open circuit terminated one wavelength coaxial TEM resonator was fabricated (see Fig. 3). It comprises an OFHC copper cylindrical outer conductor (radius, r_o = 42.3 mm and 1.4 m long) and a centre conductor (radius, r_c = 12.6 mm and 1.0 m long) which is supported by two teflon discs. The test was performed by making measurements with an OFHC centre conductor and with a geometrically identical conductor made out of the test material. For this arrangement, the ratio of the conductivities as a function of the measured unloaded Q's (with the OFHC copper and with the sample centre conductors) is given by the following formula:

$$\frac{\sigma_{sample}}{\sigma_{OFHC}} = \left[\frac{Q_{OFHC}}{Q_{Sample}} \left(1+\frac{r_c}{r_o}\right) - \frac{r_c}{r_o} \right]^{-2}$$

Measured Q's and calculated conductivities are given in Table 2.

TABLE 2

Measured Q and RF Conductivity at 290 MHz

Sample type	Measured Q	$\frac{Q_{OFHC}}{Q_{sample}}$	$\frac{\sigma_{sample}}{\sigma_{OFHC}}$
OFHC copper	5493±20	1.000	100%
AL-15	5322±20	1.032	92%
Al 6061-T6	4166±20	1.319	50%

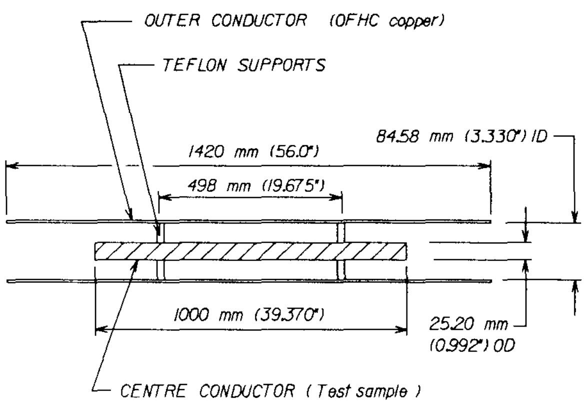

Fig. 3. Resonator structure for the Q measurements

Sparking Characteristics

To determine the rf sparking characteristics for this material would require a high-power resonant test structure. This would be as expensive to build as the new vanes, therefore this test will be part of the planned experimental program for the new vanes. However, DC sparking and conditioning characteristics are fairly easy to check and were carried out. These characteristics of AL-15 were compared with those of OFHC copper and aluminum. No significant differences were found. All could be conditioned to withstand 90 kV across a 6 mm gap and there was no sign of damage to the surfaces of the tested samples (cylindrical shape, diameter = 25.4 mm, corner radius = 3.2 mm, surface finish ≈ 0.0008 mm).

Discussion and Conclusions

The test results have confirmed that GlidCop AL-15 is a suitable high-strength copper to be used in the manufacturing of the new vanes. The use of this material will pioneer its application in the design and fabrication of accelerator components and will allow more flexibility in the RFQ experimental program.

Acknowledgments

The authors wish to thank G.E. McMichael for support and suggestions during the study and J.E. Anderchek, D.G. Hewitt, D.J. Disney, L.F. Birney, A.D. Davidson, G.W. Wood and R.A.Vokes for their help and assistance in preparing the samples and conducting the many tests.

References

1. G.E. McMichael, B.G. Chidley, R.M. Hutcheon and T. Tran-Ngoc, "RFQ1 Fabrication and Low Power RF Tuning", Proceedings of the 1987 IEEE Particle Accelerator Conference, IEEE Catalog No. 87CH2387-9, 3, 1857 (1987).

2. B.G. Chidley, G.E. McMichael, T. Tran-Ngoc and F.P. Adam, "New vanes for RFQ1", these proceedings.

3. OFHC Brand Copper News, Vol 5 No 1, June 1965, American Metal Climax Inc.

4. GlidCop Products Information Bulletin, SCM Metal Products Inc., 1988.