

Stress strain curves for thick electroformed Cu pieces

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ABSTRACT

Electroforming copper is a technology that allows manufacturing pieces with shapes difficult to achieve using other technologies, low amount of impurities and excellent mechanical properties that together with the heat conductivity of the material makes it ideal for some applications in the fusion and particle accelerator devices. Furthermore joining two independent parts can be done at room temperatures with material having the same properties than the base pieces.

The published data concerning the mechanical properties of electroformed copper are referred to the direction tangent to the surface of the mould on top of which the copper is deposited. Some researchers have suggested there could be non-isotropic behavior but, to the best knowledge of the authors there have not been tests to confirm or deny such suggestion.

The current article exposes the results of tensile tests carried out on specimens made of electroformed copper, machined in different directions with respect to the surface of the mould. The effect of heat treatments is also analyzed.

The different mechanical response depending on the direction of the specimens was first detected during the acceptance tests of samples corresponding to different parts of a dump for the deuterons accelerator LIPAC that is being installed in Rokkasho (Japan). Some modifications in the production of the dump were proposed as a consequence of such tests.

1. Introduction

The linear IFMIF prototype accelerator (LIPAc) ends up in a dump which stops a 9 MeV, 125 mA beam of deuterons in continuous wave. The Beam Dump (BD) is estimated to withstand a radiation of 1 MGy.

The BD is a cone made of copper electroformed on a stainless steel mandrel. The cone is 2500 mm long with varying thicknesses, from 5 mm (most of the wall) up to 30 mm in the flange (see Fig. 1). A second piece made of frustum cones used as a shroud coaxial with the previous cone, was made as well by electroforming.

The technology chosen to manufacture the cone was electroforming because of several reasons: (1) allows manufacturing of such geometry very difficult to obtain in other ways, (2) provides good mechanical characteristics due to its fine grain, (3) the copper is very pure and (4) the joint of the pieces is done at room temperature.

Compared to laminated copper, electroformed copper has the inconvenience of long times required for manufacturing and therefore it is more adequate for prototypes than for large batches of pieces.

The evaluation of this manufacturing technology has already been

published [1,2], for that study tensile tests were carried out with a range of specimens: specimens electroformed as a whole without any joint, specimens with a joint at the center electroformed in two steps and specimens with a joint at the center made of Cu and stainless steel.

During the manufacturing of the definitive pieces of the BD, acceptance tests were carried out including tensile tests which yielded different results depending on the direction of the specimen relative to the surface of electrodeposition. The plastic deformation was different for specimens tangent to the surface of electrodeposition (T) or orthogonal to the surface of the electrodeposition (O). The results of these tests and the effect of thermal treatments are the objective of this article and have not been reported before in the open literature to the best knowledge of the authors.

Electroformed copper in thick layers has already been used in linear accelerator dumps [3] (0.5 mm thickness) and it is as well used in the fusion field for some parts of the neutral beam injector system [4,5] (1.5 mm thickness). Agostinetti [4] presents an extensive analysis of tensile test results and fatigue test, deriving functional relationships including temperature as a parameter.

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Fig. 1. Electroformed BD cone and shroud.

Thick pieces of electroformed copper are also used in the field of astrophysics detectors [6,7], thicknesses in the order of 12 mm are manufactured. Overman [7] suggests the influence of anisotropy in the deformation and failure modes.

An extensive study of the different additives that can be used for electroformed copper and the application to the manufacturing of a thrust chamber of a rocket engine can be found in [8].

2. Testing procedure and materials

The tests were carried out with a MTS 810 universal test machine with up to 100 kN capacity, under stroke control at a displacement rate of 0.3 mm/min (corresponding to a strain rate of 4×10^{-4} /s). No extensometer was used due to the small size of the specimens. The crosshead displacement values were recorded and used to obtain both the uniform elongation and the strain. No machine compliance correction has been made and thus the values are only indicative but useful for the purpose of comparison. The tensile tests were carried out at room temperature and at 150 °C, being this last temperature the highest value expected at the BD during operation of the accelerator.

The specimens were obtained from samples with thicknesses in the order of centimeters and with different orientations with respect to the mould surface (tangent, orthogonal and inclined). The dimensions of the specimens are shown in Fig. 2. These specimens are obtained by

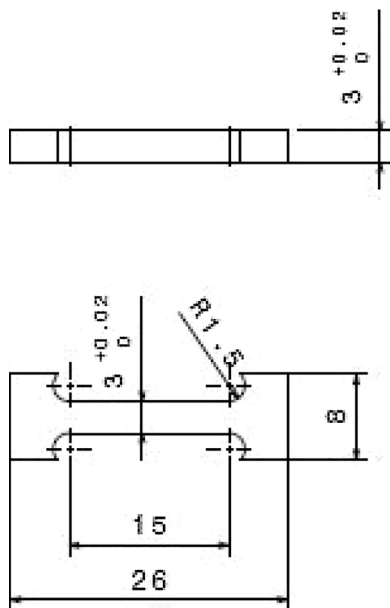


Fig. 2. Tensile test specimen.

wire electrodischarge machining with no further surface finish applied. The use of these reduced specimens yields results that are equivalent to those of standard size concerning engineering stress and engineering strain [9].

The main goal of these tests was to compare values of yield strength ($R_{p0.2}$), ultimate tensile strength (R_m) and plastic behavior in different orientations. The yield strength ($R_{p0.2}$) is obtained from the stress-strain diagram drawing a parallel line to the straight part of the curve at a distance 0.2% in elongation axis and calculating the intersecting point of such line with the test curve. The ultimate tensile strength (R_m) is determined as the ratio between the highest measured load and the initial section of the specimen.

After electroforming the samples to obtain the specimens, the material underwent a vacuum baking treatment ($180\text{ °C} \times 3\text{ h}$ in a vacuum oven), except for a batch of specimens that was tested without such treatment for comparison. This heat treatment is compulsory for the final manufactured pieces that will have surfaces in ultra- high vacuum.

Different materials have been tested:

A) Laminated bar (named LB):

Specimens from a laminated bar were tested in order to use them as a reference for comparison. These were the only specimens from non-electroformed copper. The diameter of the bar is 63 mm, with treatment “hard”. The certificate of the manufacturer includes the values $R_{p0.2} = 280\text{ N/mm}^2$ and $R_m = 288\text{ N/mm}^2$. The material is Cu OFE with a content of 99.998% of copper. Fig. 3 shows the location of the samples in the bar. The specimens were cut in both the longitudinal direction (LB_L) and orthogonal in the shape of discs (LB_D).

B) Electroformed Cu (named BI02), used to check anisotropy:

A sample of electroformed copper was manufactured on top of a plastic flat support painted with silver paint. The diameter was 125 mm and the thickness reached 47 mm. From such sample specimens were cut in two directions: T (tangent to the surface of the support) and O (orthogonal to the surface of the support). Identification of the specimens tested (BI02_T and BI02_O).

For some of the specimens, thermal treatments to improve ductility were applied, at temperatures 200 °C and 250 °C for 5 h in a vacuum oven and then tensile tests were performed at 150 °C. The identification of the specimens tested is the following: BI02_T_HT200, BI02_T_HT250 for specimens from the tangent slice and BI02_O_HT200, BI02_O_HT250 for specimens from the orthogonal slice (Fig. 4).

C) Electroformed Cu cylinder (named SAM03):

A copper bar was manufactured rotating a stainless steel cone and enlarging it with a copper piece of cable (see Fig. 5). The manufacturing process required several steps for smoothing the outer surface. The diameter of the final piece was 48 mm. Five discs were cut from the ending part corresponding to the copper cable and from each disc, 3 specimens were obtained. These specimens, identified as SAM03_O, are basically orthogonal to the surface of the electrodeposition.

D) Electroformed Cu, inclined discs (named CON01):

A sample was electroformed on top of a plastic flat support covered

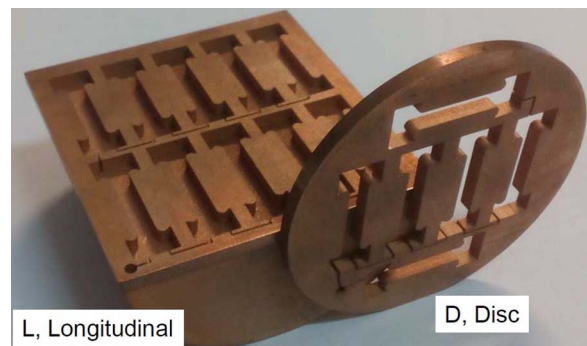


Fig. 3. Tests specimens from laminated bar.

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