HYDROFORMING TEST OF BACK EXTRUDED NIOBIUM TUBE

I. GONIN, I. JELEZOV, H. KAISER, W. SINGER
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

M. OEHRING, H.-G. PRIESMEYER
GKSS Research Center, Geesthacht, Germany

R. SCHNIEBER, H.-G. BROKMEIER
Institut für Metallkunde und -physik der Technischen Universität Clausthal, Clausthal-Zellerfeld, Germany

Abstract

The material investigation and hydroforming test of a seamless Nb tube has been done to check its deformability and the principal prospects of manufacturing TESLA shape seamless cavities from tube. The seamless tube OD83,6x2,8x100 mm was produced per back extrusion. The light microscope examination, raster electron microscope study of the microsrtructure and micro hardness measurement allowed to optimize the annealing parameters.

The investigation of the texture with neutron scattering was carried out in two ways. The first way was destructive on the samples cut out from the tube and the second one was nondestructive on the Nb tube, which was applied for hydroforming expansion.

The hydroforming experiment includes three steps: determination of the strain - stress properties of the tube material, numeric computer simulation of the expansion and the test itself. A hydraulic two dimensional bulging test of the Nb disk into a round aperture was done for determination of the true strain - stress diagram.

A 53% of diameter expansion was achieved in just one step in the hydroforming test. This expansion factor would be sufficient for expansion of a tube from OD138x4 mm to final equator diameter of the TESLA cell. The agreement between the predicted and observed equator growth is very good. A correlation between the intensity distribution of the (222) reflection at the perimeter of the tube and the roughness of inside surface is observed.

Introduction

Superconducting cavities of TESLA shape are produced at the moment from Nb sheets by forming of half cells and welding them together at the iris and equator edges. This fabrication method is rather expensive and can create some problems at the welds. One promising alternative method is hydraulic forming of the seamless cavity from the tube. A TESLA shape cavity from copper was already produced at the company BUTTING and also by DESY even without intermediate annealing, which proves the feasibility of this way. For Nb the decisive question is, whether the Nb tube has enough reserve of plasticity to survive such deformation.

Plasticity of metals depends not only on fundamental material properties bat also very strongly on the prehistory of material and half product manufacturing. The material investigation and hydroforming test of a seamless Nb tube has been done to check its deformability and the prospect of manufacturing of TESLA shape seamless cavities from the tube. The seamless tube OD 83,6 x2,8 x100 mm was produced by back extrusion from the pill /1/ at W.C. HERAEUS GmbH. The pill was produced in the usual way (EB melting, forging ... recristallization heat treatment /2/).

Study of the microstructure

It is well known, that metals have good deformability if the grain is small and the variation of the grain size is low.

The structure investigation of "as delivered" tube was done with light microscope and scanning electron microscope SEM. The samples were cut out, polished as usual with decreasing particle size, and then chemically polished. REM investigation was done before chemical polishing. The microscopic study was done in interference contrast. First of all it should be emphasized that the deformation grade reached by means of the back extrusion was in principle sufficient to get sufficiently small grain required for planned deformation (grain size corresponds to ASTM 5-6).

However the structure shows that the material is not 100% recrystallized. There are stripes with sometimes rather small and sometimes big grains. In some areas of the stripes of deformed material nuclei of new grains were observed.

The optimization of the annealing temperature and additional annealing allow to reach rather homogenous grain almost without the mentioned stripes. The grain structure of additionally annealed tube at 850°C, 2 hours is demonstrated in figure 1.

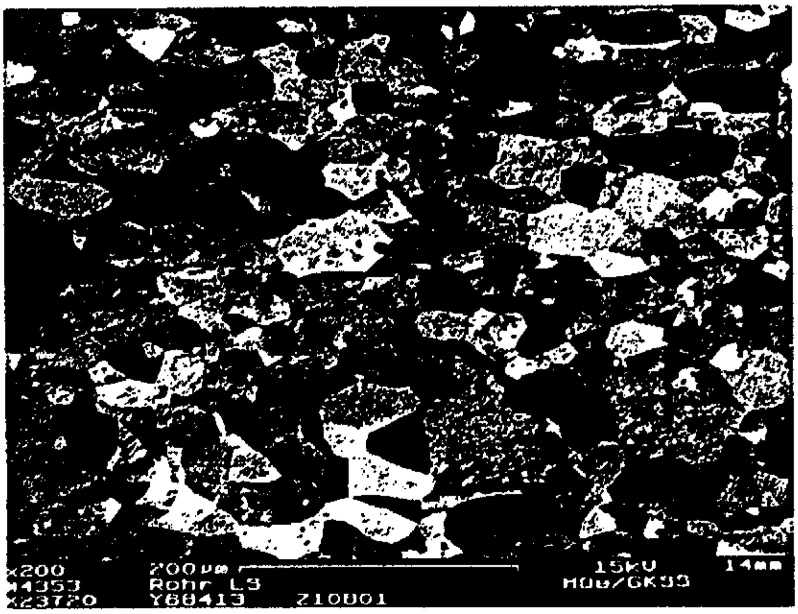


Fig. 1 The grain structure of the additionally annealed Nb tube

The variation of grain size was significantly reduced, at least by factor of 10.
A comparison of the microhardness profiles of additionally annealed tube with standard annealed Nb sheet (as delivered) prove the improvement of the tube structure. The scattering of the microhardness in the cross section of the tube is seen to be smaller than for the sheet material.

Texture investigation

The second important point for the deformability is the texture of the polycrystalline material. The individual crystallites which build up the material, are anisotropic. That means the plastic deformability depends on the crystallographic direction. If the crystals have a random orientation, then their anisotropy averages out and the plasticity is isotropic. If the averaging is not complete the plasticity depends on the direction of the deformation and the orientation distribution of the grains.
By the hydroforming of the tube the plastic deformation occurs in axial, radial and circumferencial directions. The main deformation is the circumferencial. From this point of view a texture, which provides maximal reserve of circumferential deformability would be desirable. At the same time the inhomogeneity of texture around the tube is not tolerable.
The investigation of the texture by means of neutron diffraction was done to measure the bulk texture. The samples for pole density measurement were cut out from a tube bent flat and for comparison from as delivered TTF cavity-production Nb sheet (Tokyo Denkai). Four section 10x10 mm² were cut out with consideration of orientation and pasted together in a cubic sample in both cases.

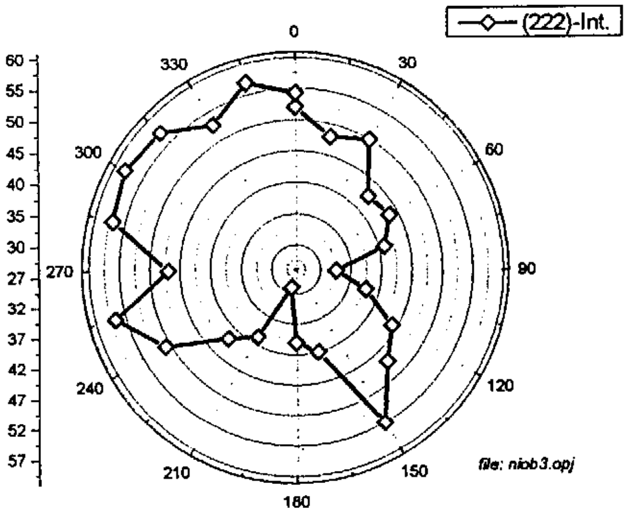


Figure 2 The intensity distribution of the (222) reflection in radial direction.

The texture was determined by the measurement of three pole figures, (110), (200) and (211). Each pole figure was covered by an equal area counting grid of 679 orientations. For background correction 16 points were measured one for each tilding.

It is known from texture investigations of deep drawn sheets that good deformability of cubic body centered metals can be achieved if the material has a preferred (111) orientation perpendicular to the surface. The analysis of the results from this point of view allowed to conclude, that the sample of the tube was more close to this aim. The pole figure of this sample demonstrates the (111) orientation relative to the radial direction.

The orientation grade was about 5.5 mrd. The sheet sample (Denkai) possesses a (111) orientation orthogonal to the surface too, but it was somewhat weaker. Moreover, the sheet shows an additional texture component a (100) orientation which is stronger than (111).

As a consequence of these results one can say, the texture of the tube is more suitable for the hydfroforming expansion. At the same time one should take into account whether the texture distribution is isotropic in the tube. It is important in our expansion symmetry to maintain the grade of (111) texture orientation in the complete perimeter of the tube.

For the nondestructive investigations of the Nb tube the neutron time of flight Fourier Spectrometer was applied. The scanning in 10 degrees intervals over a complete perimeter was done for the detection of the whole diffraction pattern at each tube position. The intensity distribution of the (222) reflection in radial direction is represented in figure 2.

A comparison of the measured spectra with a theoretical powder spectrum of niobium indicates a preferred orientation of (111). That agrees with the texture measurements described before. In order to study the very important texture variation over the perimeter additional investigation are necessary.

Actually it is interesting to check the correlation between the intensity distribution of the (222) reflection in radial direction and the inner surface roughness distribution, which appeared often after hydriforming test. In order to check it out the same piece of the tube was hydroformed.

Hydroforming test

The hydroforming experiment generally consists of three steps: determination of the strain - stress properties of the tube material, computer simulation of the expansion and the test itself.

The strain - stress diagram as result of one dimensional tensile test represents normally the mechanical properties, with stress and strain referred to the initial values of cross-section and length of sample. The curve of true strain-stress relation, that is needed for the computer simulation can be determined by this test also, but it is not customary. However the strain - stress diagram in tensile test becomes more uncertain at high deformation because the stress distribution in the sample deviates from ideal one dimensional conditions.

We applied the hydraulic two dimensional bulging of the disk into the round aperture, which attracts more attention recently especially for inspection of sheet metal /3/. This method allows getting a high values of two dimensional uniform stress at the zenith and getting the true strain-stress diagram by following considerations.

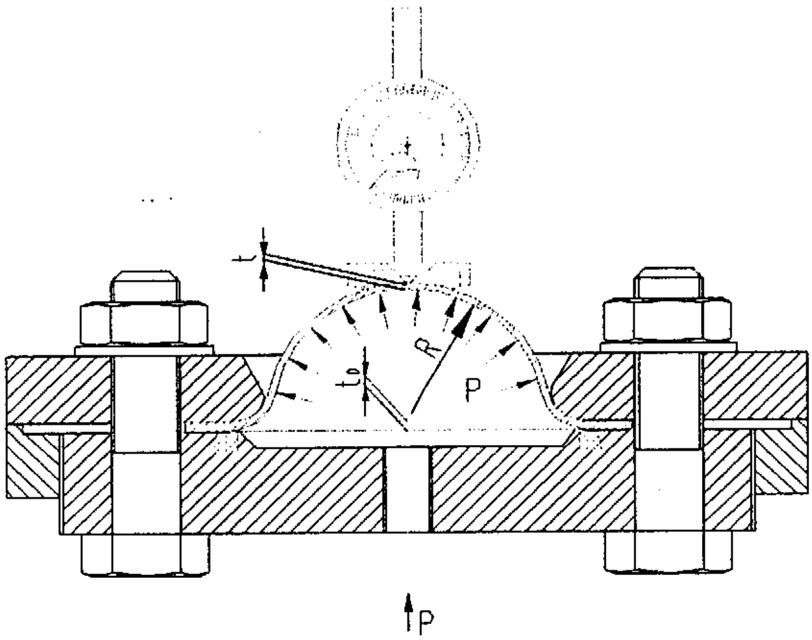


Fig. 3 Scheme of the bulging device

Generally the intensity of the stress σ_v and the strain ε_i by high plastic deformations can be expressed through the main components of the stress and the strain.

$$\sigma_{eqv}=\frac{1}{\sqrt{2}}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2} \qquad (1)$$

$$\varepsilon_{eqv}=\frac{\sqrt{2}}{3}\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2} \qquad (2)$$

As true deformation we understand the logarithmic deformation, for example

$$\varepsilon_1=\int_{l_0}^{l}\frac{dl}{l}=\ln\frac{l}{l_0}$$

which allows to describe the condition of the constant volume during the deformation in view

$$\varepsilon_1+\varepsilon_2+\varepsilon_3=0$$

If we will take into account the symmetry of the test, we can assume that in the zenith of the bulging $\sigma_1=\sigma_2;\sigma_3=0;\varepsilon_1=\varepsilon_2$. In this case it is easy to find from formulas (1) and (2), that $\sigma_1=\sigma_{eqv};\varepsilon_3=\varepsilon_{eqv}$.

This means, that the relationship $\sigma_1=f(\varepsilon_3)$ represents the true strain-stress diagram of the material. The values of the stress and the strain can be determined from formulas

$$\sigma_1=\frac{pR}{2t}=\sigma \quad \text{and} \quad \varepsilon_3=\ln\frac{t}{t_0}=\varepsilon$$

The pressure p, radius of the curvature R and thickness t in the zenith of the sample are measured during the deformation procedure for deriving of the strain stress plot.

The hydraulic bulging test was done with stepwise increased pressure. The mentioned three parameters were measured at each step of deformation. A bulging device was build for this aim, which is schematically shown in the figure 3.

This method has another additional advantage. It allows to detect the anisotropy of the sheet properties, which appears as necking lines. Same examples of the stress-strain characteristic can be seen in figure 4.

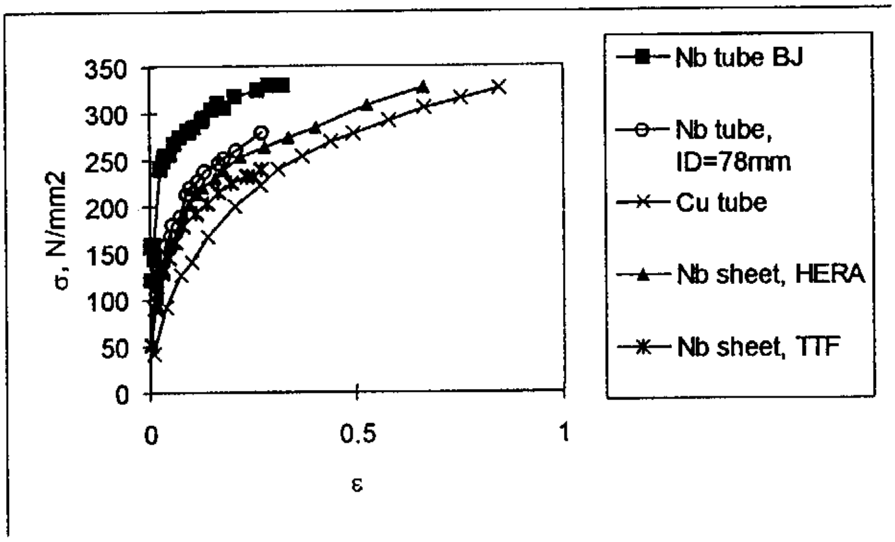


Fig.4 Some strain-stress characteristics defined by bulging test

One of the dia. 78 mm tubes was sacrificed for the hydraulic bulging test, cut open and bent flat. The plot can be seen in the figure 4. The plastic properties are not very different from those of the flat sheet of the same producer.

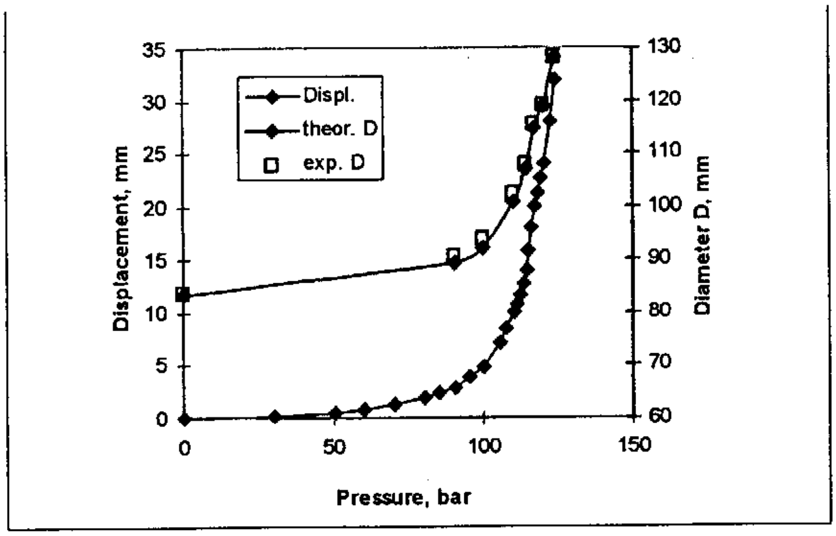


Fig. 5. The pressure-displacement relationship and the growth of diameter D during expansion test.

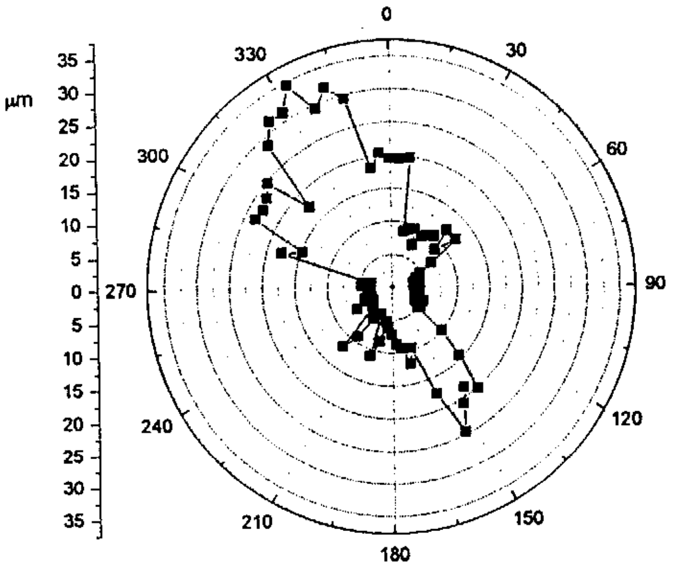
The numerical simulation of the hydraulic expansion of the tube was done in the finite element code ANSYS in accordance with the procedure described before /4/. Nonlinear elasto-plastic behavior in accordance with stress-strain curve and isotropic hardening rules are taken into account. The main task was to find the optimal relation of applied internal pressure against axial displacement (path of the expansion). The best theoretically acceptable pressure-displacement graph is demonstrated in figure 5. The maximal stress (about 250 N/mm2) is located in the equator area and does not exceed the critical stress of the material (280 N/mm2).

The expansion experiment was done in the HYDROFORMA machine presented in the work /5/. A new die was constructed and integrated into the machine. The deviation of the internal pressure from prediction was not higher then 3 bar. The outside diameter of the tube was measured during the hydroforming test. The comparison of the experimentally achieved diameter at equator and that determined from modeling calculation is represented in Fig. 5. The achieved coincidence is very good, which demonstrates the accuracy of numerical simulation.

The expansion ratio defined as the following

$$\psi[\%]=\frac{D_1-D_0}{D_0}\bullet 100;$$ D_o-initial diameter, D_1-final diameter,

was observed to equal 53%, which was reached in only one step, other then /6/, where several intermediate matrices and annealings were needed.



file: Niob_xls_mechanisch

Fig.6 Surface roughness R_t inside of the expanded tube in the equator area

One of the reasonable versions of TESLA cavity fabrication from the seamless tube is to start from the tube with intermediate diameter (OD about 140 mm). The diameter reduction in the iris and end tube areas should be produced mechanically and the final shape by means of hydraulic expansion. The hydraulic expansion is about 50% in this case and our test proves that this expansion can be achieved without an intermediate annealing. The remaining task is to achieve the diameter reduction, which amount in this case is about 50% also.

An interesting point was to compare the results of the rotational symmetry of the texture reflexes with distribution of the roughness, which can be seen inside of the tube after expansion. The surface roughness Rt was measured inside of the expanded tube at the equator area (figure 6).

A correlation between (222) reflex and surface roughness Rt inside of the expanded tube can be noticed. The reason of the texture deviation from the rotational symmetry should be found in the tube fabrication procedure. Evidently the pills production procedure is non symmetrical. The results can be improved if by the choice of the tube production steps one will reach adequate rotational symmetry of the plastic properties.

References

1. K.Lange: Umformtechnik, Band 2: Massivumformung, Springer-Verlag 1990.
2. M.Hoermann: The Production of High Thermal Conductivity Niobium on a Technical Scale for High Frequency Superconductors. WC.Heraeus GmbH.
3. K.Lange: Umformtechnik, Band 3: Blechbearbeitung, Springer-Verlag 1990.
4. I.Gonin, H.Kaiser, D.Proch, W.Singer: Finite Element Simulation of the TESLA-Cavity Hydroforming Process. Proc of the 7th Workshop on RF Superconductivity, October, 1995, Gif sur Yvette, France.
5. H.Kaiser, D.Proch, W.Singer, S.Esin, L.Kravchuk, I.JelezovV.Samohvalov, A.Stepanov,: Some Technological Methods for Superconducting Cavity Manufacturing. EPAC-96, Abstracts, P. 129.
6. J.L.Kirchgessner: Forming and Welding of Niobium for Superconducting Cavities. Proc. of the Workshop on RF Superconductivity, CERN, 1984, 533.