HYDROFORMING OF BACK EXTRUDED NIOBIUM TUBES

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Abstract

The material investigation and hydroforming tests of back extruded seamless tubes with ID 78mm has been done to find out and optimize the fabrication parameters of TESLA shape seamless cavities.
Six categories with different tube production parameters and different purity (RRR300, RRR100) were taken into consideration. The microstructure examination, one dimensional tensile test and two dimensional bulging test were done. A neutron diffraction investigation of the crystallographic bulk texture of Nb tubes by means of pole figure method was done nondestructively.
A big anisotropy of the plasticity reserve as a function of angle to tube axis and azimuth about tube axis was detected. It was found out, that the strain before necking of niobium can be increased by using a periodic stress fluctuation. The history of the tube production steps play a very important role.
Several single cell cavities in reduced size (60% to TESLA cavity) were successfully produced without intermediate annealing and intermediate constraint.

MATERIAL INVESTIGATION

The fabrication by hydroforming of a seamless bulk niobium cavity of TESLA shape, with a ratio of equator diameter to iris diameter about three, is a challenging task and requires special development. It is expected, that this technology will not only reduce the production costs, but also improve the cavity's accuracy of shape and accelerating performance.
The material investigation and hydroforming tests of back extruded seamless tubes with 82x2,4x150 mm (supplied by the company HERAEUS) has been done to find out and optimize the fabrication parameters of TESLA shape seamless cavities. The chosen tube dimension allows to produce seamless cavities of proportional relation to TESLA shape in reduced size (60% relative to TESLA cavity) and save on development costs.
Six tube categories with different production parameters and different purity (RRR300 and RRR100) were taken into consideration. The microstructure examination, one dimensional tensile test, two dimensional bulging test as well as neutron scattering experiments were done to determine the maximum possible strain of the tubes.
The scheme of the bulging device (hydraulic expansion of the Nb disk into a round aperture) can be seen on Fig. 1. This method allows getting the true strain-stress characteristic of the material. The values of the stress σ and the strain ε at zenith can be found with help of the formulas

$$\sigma = \frac{pr}{2t} \quad \text{and} \quad \varepsilon = \ln\frac{t}{t_0}$$

The pressure p, radius of the curvature r and thickness t in zenith of the sample are measured during the deformation procedure with curvature sensor and ultrasonic device. The bulging procedure is computer controlled and can be done both stepwise and continuously.
Fig. 2 and Fig. 3 represent the results of the bulging tests and tensile tests of the samples prepared from the tubes. Three samples of each tube category were measured. Category 1,2,3 represents Nb300, and category 4,5,6 – Nb100.

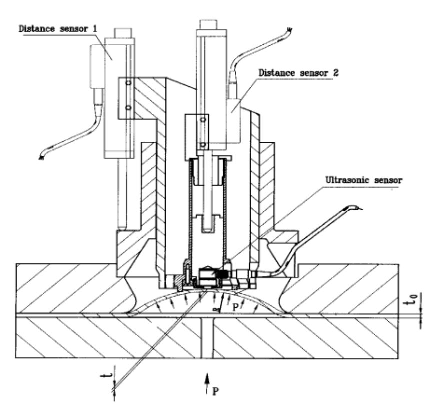

Fig. 1. Scheme of the bulging device

The variations of the properties from a sample to sample because of their non homogeneity can be seen in Fig. 2. Fig. 3 describes the mean results.

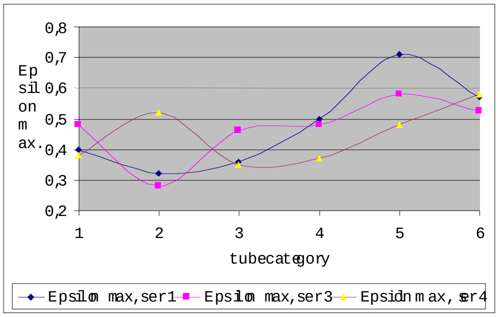

Fig. 2. Strain before breaking for three series of Nb samples from the tubes

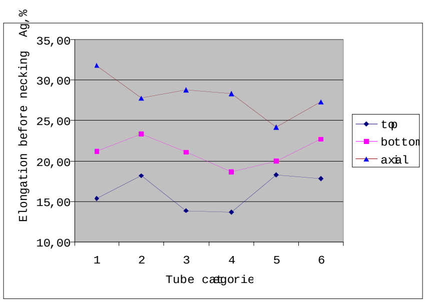

Fig.3 Average data of the traction test for three series of Nb samples from the tubes

The bulging test shows, that the Nb100 as a rule reaches higher breaking strain. The surface of the samples of the tubes with less purity (Nb100) after the test was smoother than for Nb300. A smaller grain size of Nb100 in comparison with Nb300 is detected by the microstructure analysis (compare Fig. 4 with Fig. 5).

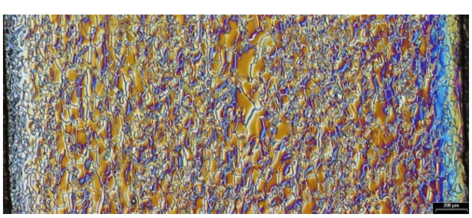

Fig. 4. Microstructure of the sample RRR100 from the top of the tube

The tensile test allows to point out the following aspects: the elongation before necking for samples cut along the axial direction is higher in comparison with the circumferencial direction; the elongation before necking for samples cut from the top of the tube is smaller as for the bottom, where “top” and” bottom” refer to rim and bottom of cup-shaped back extruded tube. Smaller grain size of the bottom in comparison with the top of the tubes was noticed at the metallography control.

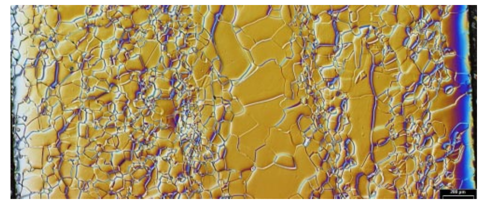

Fig. 5. Microstructure of the sample RRR300 from the top of the tube

In addition it was found out, that the strain before necking can be increased by using a periodic stress fluctuation (pulse regime). This can be clearly seen in Fig. 6. The elongation before necking is almost of 30% higher by application of a pulse method in comparison with conventional tensile test. Probably the pull-release regime of the deformation artificially locally increases the work-hardening of Nb in low-yield strength regions and therefore postpones fracture.

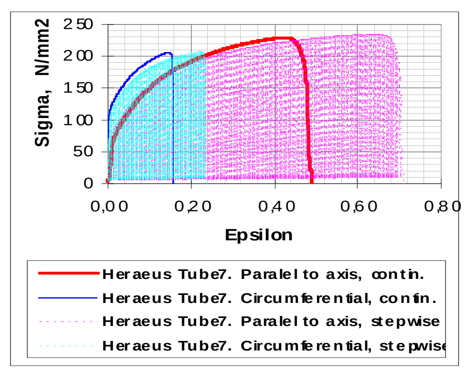

Fig.6 Comparison of the traction test in continues and pulse regime

In addition, an investigation of the crystallographic bulk texture of Nb tubes by means of neutron diffraction was done nondestructively. The pole figure method was applied /1/.The Lankford-parameter (R-value) as a reserve of plasticity was calculated on the basis of these results.
For the traction test of a strip sample of width w and thickness t the R-value can be described by the formula:

$$R = \frac{\ln(w_0/w)}{\ln(t_0/t)} = \frac{\varepsilon_w}{\varepsilon_t}$$

The formula makes clear, that the highest possible and everywhere constant R-value in the tube wall is required for successful hydroforming fabrication of components. One example of R-value behavior as function of angle to tube axis and azimuth (from 0^o till 180^o) represents Fig. 7. A big anisotropy of R-value as function of angle to tube axis and azimuth about tube axis can be clearly seen.

The reason of the texture deviation from rotational symmetry may be found in the tube fabrication procedure. The tubes were produced by back extrusion. Evidently the procedure of the preparation of the pills for back extrusion was not sufficiently

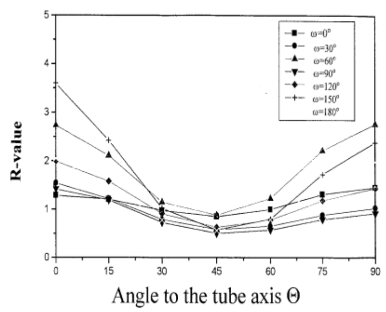

Fig. 7.R-value behavior as function of angle to tube axis Θ and azimuth (from 0^otill 180^o)

symmetrical. Generally the reason of high non homogeneity in Nb is its high purity. The impurities play an important role in the grain growth of the material. They appear

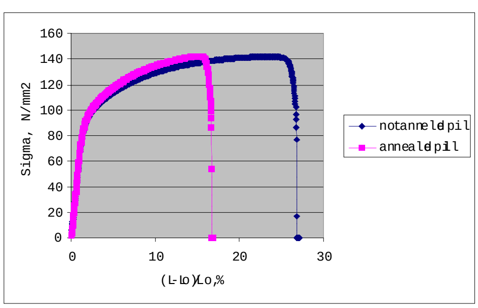

Fig. 8. Strain-stress behavior of samples from the tube with annealed and not annealed pills.

as centers of new grains at the re crystallisation annealing and reduce the grain size. Moreover Nb does not have a phase transition in the complete temperature interval between room temperature and melting point. This fact excludes any other mechanism to get a small grain due to a special thermal treatment, like in steels. The last remaining possibility to get a small grain is to produce a high and uniform deformation degree in the Nb bulk before re crystallisation annealing. Considering that the initial grain in the Nb ingot is several centimeters in size, the task to get small and uniform grain in the final product becomes very difficult.

No doubt, the history of the production procedure plays a very important role. The fewer the number of the intermediate annealings, the better. For example, it turns out, that the reserve of plasticity strongly depends on the heat treatment of the pills before back extrusion. Tubes from un annealed pills show much better performance at the hydroforming. The tensile test (Fig. 8) shows a big difference in the breaking elongation.

A less expensive way of cavity fabrication can include the following two steps: cavity production by hydroforming from the less pure Nb tube (for example Nb100) and then an additional refining of the cavity by purification annealing /2/. The content of refractory metals (like Ta, W) in such tubes should be not higher than in Nb300. The interstitial impurities H,O,N,C can be removed during purification annealing.

This possibility was tested in our work using Nb100. The measured RRR value of these tubes was about 110, impurities content: H=1ppm, O=8-12ppm, N=20-30ppm, C=2-5ppm, Ta<500ppm, W<50ppm. The test has shown, that after annealing at 1400°C for 4 hours with Ti the RRR reaches the values 450-500. The grain size of this material is approximately 2 times smaller, than of RRR300(Fig.4, Fig.5). Finally it was easier to hydroform these tubes and the surface of the cavities was smoother.

Despite of a big anisotropy of the plastic properties, not only the tubes of Nb100, but also the tubes with Nb300 are suitable for hydroforming. The numerical computer simulations/3/ have shown, that for successful cavity fabrication the value of εmax has to be higher than 0,3. The results of the bulging tests Fig. 2 demonstrate, that only one sample does not fulfill this requirement and in principle almost all tubes can be successfully hydroformed to the 0.6 scale TESLA shape cavities.

HYDROFORMING TESTS

The hydroforming experiments were done in the HYDROFORMA machine. In principle the hydroforming is an expansion of a seamless tube into a mold by the internal liquid pressure. The computer operation of the machine allow to hold under control the radial growth as function of decrease of tube length in accordance with FEM computer simulations. Further correction of the expansion parameters can be done on basis of comparison of the theoretically and experimentally achieved tube diameter. The diameter reduction at the tube ends before expansion was done with the help of a profiled ring.

Several single cell cavities in reduced size were successfully produced without intermediate annealing and intermediate constraint from the back extruded Nb100 and Nb300 tubes. Some of them can be seen in the Fig.9. The application of the pulse regime in addition was very helpful. The maximal reduction of the wall thickness takes place at the equator (from 2,4 to 1,75 mm) and corresponds the maximal strain achieved during hydroforming of $\varepsilon r=0{,}32$. This proves, that the cavity of the TESLA shape can be produced from the seamless tube without intermediate annealing, if the bulging test of the tube results in $\varepsilon r>0{,}35$.

It turns out, that the initial tube length is a very critical parameter for hydroforming. If the length foreseen for hydroforming is too short, the pronounced rise of the internal pressure at final stage of expansion is unavoidable. A small increasing of this length (of about 2-3mm) can stabilize or even reduce the internal pressure at the end of expansion. The right choice of the tube length allows to carry out the expansion without significant change of the internal pressure at end of forming.

Fig.9 Single cell cavities in reduced size (60% of TESLA shape) produced by hydroforming without intermediate annealing and intermediate constraint

CONCLUSIONS

1. An anisotropy of mechanical properties between top and bottom, axial and circumferential direction was observed in back extruded tubes. An anisotropy of R-value as function of angle to tube axis and azimuth about tube axis take place too. Further improvement of the tube quality is very desirable. Reduction of the number of intermediate annealing during production steps is needed.
2. The hydroforming experiments have shown, that despite of big anisotropy of the plastic properties of the back extruded tubes, the fabrication of the seam less TESLA cavity without intermediate annealing is possible. Application of the pulse method is very helpful in this procedure. One very critical parameter for hydroforming is the initial length of the tube.
3. Hydroforming of less pure Nb (RRR100) in combination with subsequent purification annealing of the cavity can be a reasonable way of cavity fabrication.

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