COPPER PLASMA SPRAYED NIOBIUM CAVITIES

M.Fouaidy, J.Lesrel, S.Bousson, T.Junquera, A.Caruette
IPN (CNRS-IN2P3-Univ.Paris XI) Orsay, France
J.Marini , J.L Borne, J.C Bourdon, G.Bienvenu, C.Thomas
LAL(CNRS-IN2P3) Orsay
J.Gaiffier, H.Safa, J.P Poupeau
CE Saclay/DSM/DAPNIA/SEA

Abstract

A R&D program concerning new fabrication techniques of SRF cavities has started in a close collaboration between the three french laboratories. The technique is based on copper plasma sprayed onto thin wall niobium cavities. The ultimate goal is to produce 1.3 GHz hydroformed (or deep drawed and EB welded) multicell niobium cavities stiffened by the copper layer. A first series of 3 GHz cavities were fabricated by deep drawing and EB welding using RRR=40 niobium sheets of 0.5 mm thickness. The cavities were heat treated at 1200 °C with Ti gettering before Cu plasma spraying in the industry. In this paper we present the results of the first two cavities tested at 1.8 K before and after copper plasma spraying. 60 fixed thermometers were used to investigate anomalous RF losses around the equator region. The low field Q_0 are in the range $1.5\ 10^9$-$4.5\ 10^9$ @1.8 K and both cavities are limited by quench ($E_{acc}^{\max}$ ranging from 13.5 MV/m to 16.5 MV/m) . The quench fields measured before and after Cu plasma spraying are the same (cavity #4), or slightly decreased (cavity #5). The temperature maps have shown an identical quench location before and after Cu plasma spraying. In a separate experiment we have measured the global thermal resistance of the cavity wall (niobium-copper) and the results showed an increase of 16 to 34% when the plasma sprayed copper layer is added.

Introduction

Thermal Breakdown or quench is one of the main limitations to achieve reliably high gradients in superconducting RF cavities. To increase the quench limit of such structures, high initial RRR (≥ 300) and heat treated (1200 °C) Niobium with Ti gettering must be used. However, as the mechanical stability of heat treated structures may be critical for RRR $\cong 300$, TESLA 9 cells superconducting RF cavities are actually stiffened by means of rings welded around the irises of two adjacent cells. This method leads to some difficulties concerning the mechanical tolerance of the structure length. Moreover, for large scale applications, it is necessary to develop new methods for cavity production which should reduce the fabrication cost. A new method of cavity stiffening using plasma sprayed copper onto thin Niobium wall (Thickness: 0.5-1mm) is proposed. Taking benefit from the good thermal conductivity of the copper and the porosity of the plasma sprayed copper layer, a good cavity thermal stability is also expected. Finally, this method could also be combined with hydroforming technique using seamless Niobium tubes. The first results obtained with copper plasma sprayed Niobium cavities are discussed.

1. Plasma spraying process description

The copper layer is deposited onto the niobium cavity wall using the plasma spraying process. It is realized in the industry by a french company. The principle of the method is to create a high energy plasma to melt copper particles and spray them onto the substrate [1]. By heat transfer, the deposited particles cool down and re-solidify, forming a layer strongly bonded to the substrate. The plasma is created into a gun incorporating a cathode and an anode. A gap between the two forms a chamber in which a gas is injected. DC power applied to the cathode initiates an arc to the anode. The gas passing through the chamber is ionized by the arc, forming the plasma. The hotest region in the plasma could reach 15 000°C, a temperature high enough to melt almost any kind of materials. Typical values for the main parameters of the process are: current= 500 A, voltage= 50 V, particle size $\approx$ 50 μm, maximum particle velocity = Mach 1-2. Usually, the plasma gas is a mixture of Argon (or Nitrogen) with Hydrogen. To insure a good coating/substrate adherence, the surface is roughened by sand blasting. Moreover, a bronze/aluminium thin layer of high bonding properties is sprayed onto the substrate prior to copper deposition. The deposited copper layer is porous (microchannels), resulting in an increase of the heat transfer surface between Cu and He II. The actual process is realized under normal atmosphere conditions but plasma spraying is also possible under vacuum (or low pressure) or in presence of inert gas, and it will be studied in the near future.

2. Experimental set-up and cavity results

2.1 Cavity fabrication and treatment

Five 3 GHz cavities were fabricated. The five cavities are made from RRR =40 Niobium sheets (Wah-Chang) of 0.5 mm thickness. After forming (deep drawing), the cavity half-cells are degreased then EB welded. The cavities are prepared according to the procedure summarized in Table 1.

step	operation
1	degreasing and chemical polishing (removal of 20 μm surface layer from each side) with an acid mixture (HF, HNO_3 and H_3PO_4 with a 1:1:2 ratio)
2	heat treatment with Ti gettering at 1200°C
3	chemical polishing ($\approx$ 50 μm)
4	assembling of the cavity in a class 100 clean room
5	cold test (T= 4.2 K to 1.8 K)
6	copper deposition by plasma spraying (copper layer thickness $\approx$ 2 mm)
7	chemical polishing ($\approx$ 40 μm), but only for the inner side of the cavity
8	assembling in a class 100 clean room.
9	cold test (T= 4.2 K to 1.8 K)

Table 1 : Cavity preparation procedure.

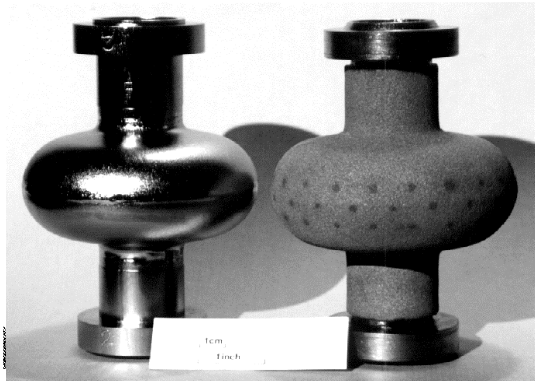

Figure 1 : 3 GHz niobium cavity (left) and copper plasma sprayed niobium cavity (right).

2.2 Instrumentation

Different devices are used as FE and anomalous RF losses diagnostic probes. To study FE, 16 photodiodes are placed all around each of the cavity irises for detecting and locating X-rays induced by impacting FE electrons. Outside the cryostat, a X-rays spectrometer could be placed. An array of 60 surface thermometers is mounted around the cavity equator. Four more thermometers are measuring the helium bath temperature. The thermometers are excited with a 20 μA current and calibrated during each run by comparison to a germanium temperature sensor. The thermometers signals are multiplexed (64 $\Rightarrow$ 4$\times$16), then amplified (Gain=10) before acquisition. For the measurements, we used a 16 channels data acquisition board mounted in a PC with a maximum sampling rate of 100 kHz allowing us to do fast transient measurements. All the instruments (frequency counter, oscilloscope, power meter, current source, thermometers multiplexing...) are controlled by the PC with a LabView program, and the whole experimental data (RF signals, thermometers and photodiodes signals, frequency, bath temperature, X-rays spectra...) are recorded.

2.3 Cavity results

Two cavities (#4 and #5) have been successfully tested before and after Cu deposition. The cavity #4Cu was tested twice: a) for the first test a 5 μm surface layer was removed by chemical etching, b) for the second test an additional removal of 40 μm surface layer was applied prior to the test. The maximum E_{acc} reached was limited by a quench for these two cavities. The corresponding results are summarized in Table 2. Field emission was observed only once on the cavity #4 before Cu deposition. After Cu deposition, E_{acc} max is the same (#4) or slightly decreased by 7 % (#5).

	Before Cu deposition	With Cu
Cavity # 4	E_{acc} max = 16.5 MV/m FE, X-rays	E_{acc} max = 16.5 MV/m (40 μm etching) no FE
Cavity # 5	E_{acc} max = 14.5 MV/m no FE	E_{acc} max = 13.5 MV/m no FE

Table 2 : Maximum electric field in cavities #4 and #5.

The cavity performances measured at T_{bath} =1.8 K are presented in Fig. 2 (Cavity #4) and in Fig. 3 (Cavity #5). The observed difference for the Qo level is due to a change of the cavity location inside the cryostat and a change in the magnetic shielding resulting in a different residual earth magnetic field. Note that the cavity #5 showed a Q-switch at 12.5 MV/m before Cu deposition.

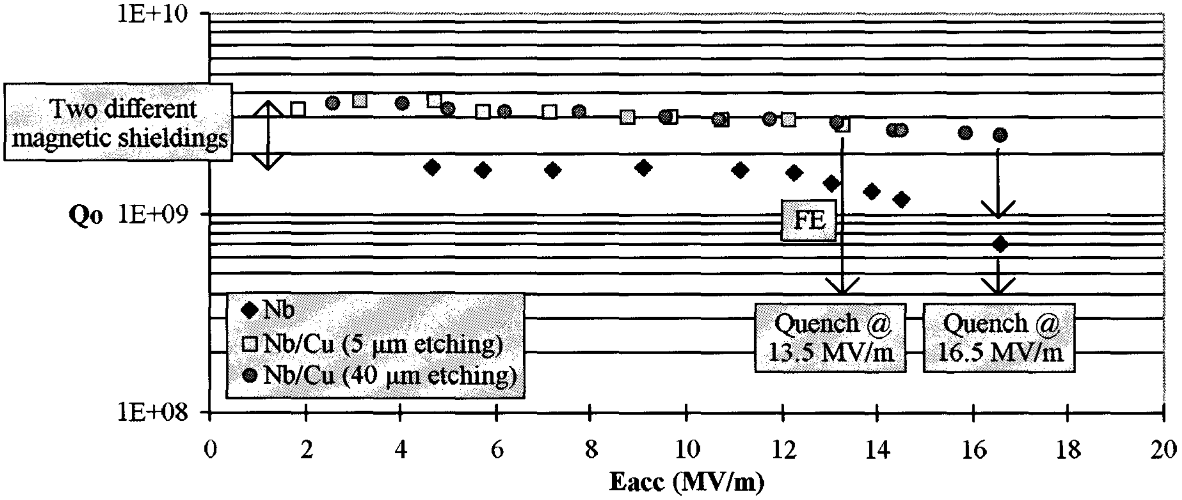

Figure 2 : Cavity #4 RF performance at 1.8 K.

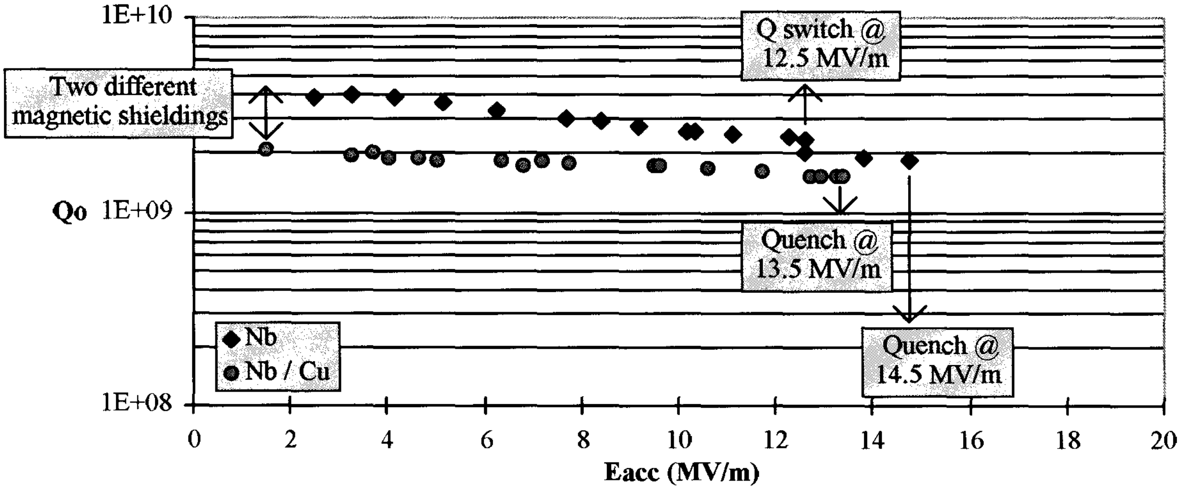

Figure 3 : Cavity #5 RF performance at 1.8 K.

As the Cu deposition process was not yet optimized to achieve the best thermal characteristics suited for accelerating cavities, these first results are very encouraging and the technique is still promising.

2.4 Thermometry results

For both cavities #4 and #5, the quench region was on the equator and at the same location before and after Cu deposition. The heating observed at the hot spot region during the quench of the cavity #5 before the Cu deposition is presented in Figure 4 : a maximum heating ΔT = 3.2 K is observed. Note that the Q-switch observed on the Q vs. E_{acc} curve is clearly detected by the thermometer #26.

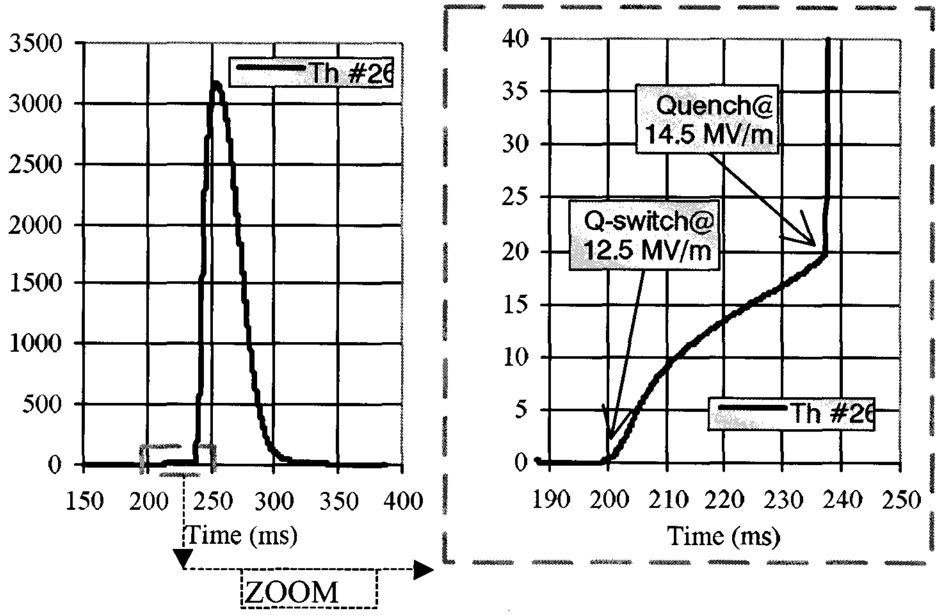

Figure 4 : Heating observed during the quench of the cavity #5.

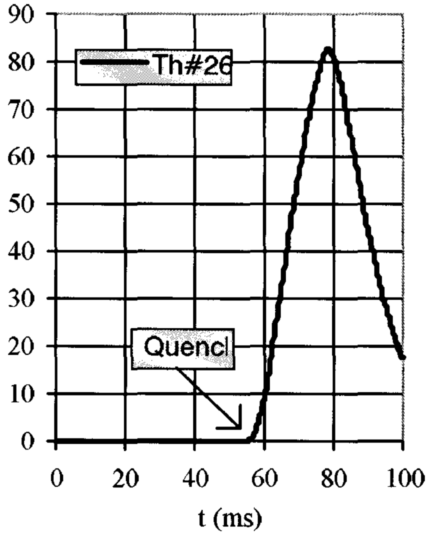

Figure 5 : Heating observed during the quench of the cavity #5Cu (after Cu deposition).

While the hot spot location (quench region) was the same after Cu deposition (Fig. 5), the measured heating for the Nb/Cu cavity is much lower as compared to the Nb cavity. This lower heating is attributed to the heat spread due to the radial diffusion in the 2 mm thick copper layer. Moreover a study [2] of the time response of the thermometers showed that they are not fast enough to follow the temperature increase during a quench.

3. Kapitza resistance experiment

3.1 Test cell description

The purpose of this experiment (Fig. 6) is to measure and compare the thermal resistance between Niobium and superfluid helium on naked Niobium samples or Niobium samples coated with a plasma sprayed copper layer. The test-specimens are 4 Niobium (RRR $\cong$ 100) rods Joule-heated at their top extremity and equipped each with three calibrated thermometers (Th_1,Th_2 and Th_3).

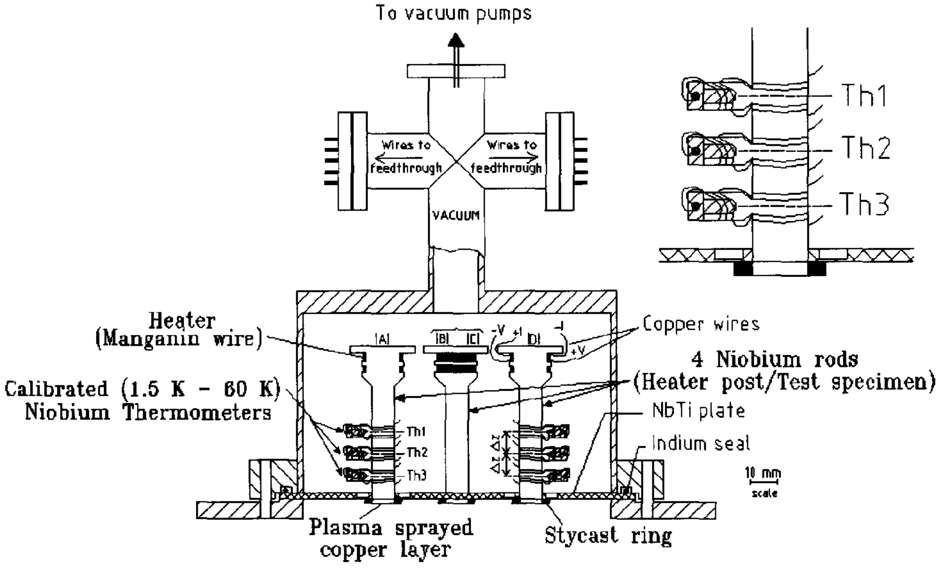

Fig. 6 : Kapitza resistance experiment test-cell

The temperature profile T(z) along each Niobium rod is measured as function of the heat flux : these measurements are performed before and after the copper layer was plasma sprayed onto the Nb (Copper layer thickness : 1-2.5 mm). The experiment was performed at T_{bath}=1.8 K.

From these experimental data we deduced :

- the Niobium thermal conductivity,
- the Niobium cold surface temperature (i.e at the Nb-He II interface or Nb/Cu interface),
- the corresponding thermal resistance between Niobium cold surface and superfluid helium .

In the case of the naked Nb rods (i.e without the copper layer) this resistance is the Kapitza resistance at Nb-He II interface. In the case of the Nb rods with the plasma sprayed copper layer, the resulting thermal resistance include : the Kapitza resistance at

Nb-Cu interface, the effective thermal resistance of the copper layer including He II microchannels and the Kapitza resistance at Cu-He II interface.

3.2 Results and discussion

As illustrated in Fig. 7-Fig. 8, when the samples are coated with the plasma sprayed copper layer, the temperatures along the Niobium rods are higher as compared to the naked Nb samples. This temperature rise is the result of an additional thermal resistance including two contributions : the interfacial thermal resistance between Nb and Cu and the global thermal resistance of the copper layer.

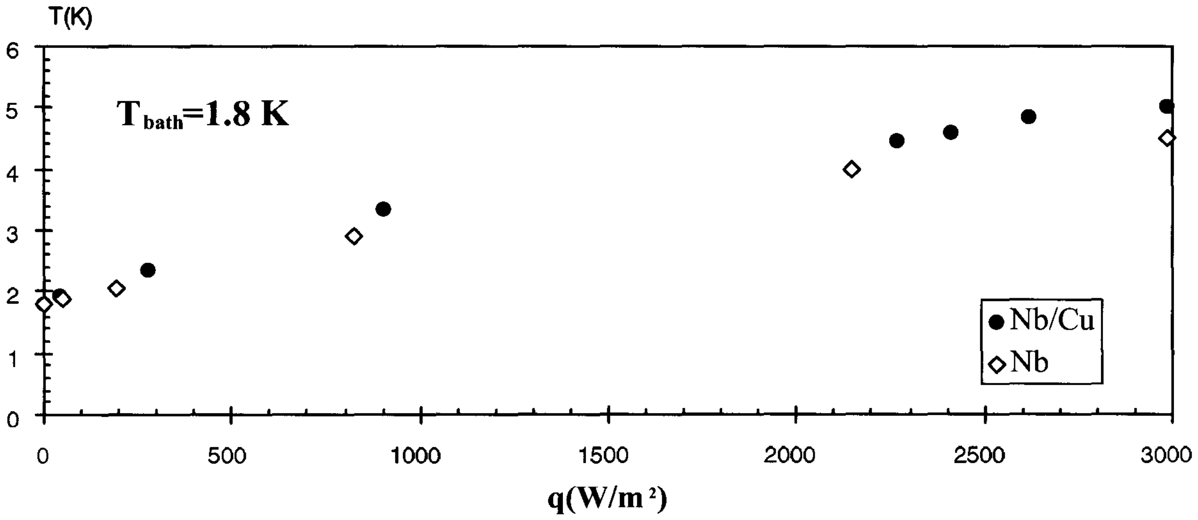

Fig. 7 : Niobium rod A temperature (Th#3) variations versus the heat flux.

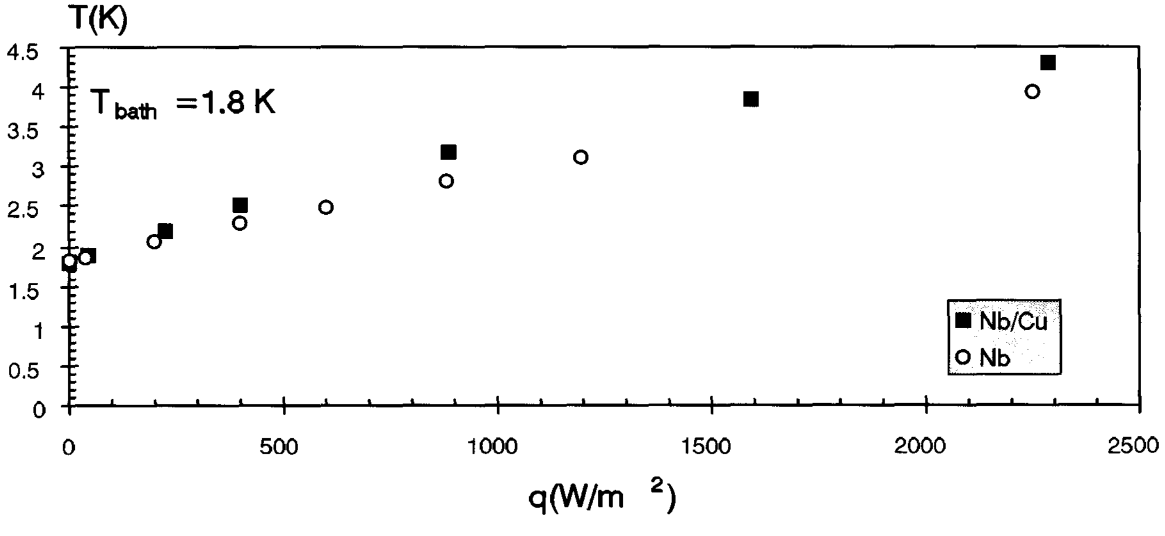

Fig. 8 : Niobium rod D temperature (Th#3) variations versus the heat flux.

The analysis of the data for the Niobium rod D leads to the following results.
Before the copper coating the Kapitza resistance at Nb-He II interface is :

$$R_{K1} = 5.610^{-4} \; \frac{K.m^2}{W} \qquad @ \; T_{bath} = 1.8 \; K$$

After the copper coating the global thermal resistance between Nb and He II is :

$$R_{K2} = 6.5\,10^{-4} - 7.5\,10^{-4} \; \frac{K.m^2}{W} \qquad @ \; T_{bath} = 1.8 \; K$$

Consequently, the plasma sprayed copper coating increases the thermal resistance between Niobium and superfluid helium by 16-34%.

4. Conclusion

A new fabrication method for SRF cavities is presented. The principle is to stiffen Niobium cavities with a copper layer deposited by plasma spraying process. The comparison of the RF performances obtained with the two first cavities tested before and after copper deposition showed that the maximum accelerating field reached was not (or very slightly) decreased. In order to improve the mechanical and thermal properties of the plasma sprayed copper layer, the influence of the main deposition parameters will be studied on samples : copper powder particle size and size distribution, substrate surface state initial conditions and pretreatment before plasma spraying, substrate temperature during spraying. Two plasma spraying techniques will be considered : under normal atmosphere conditions and under vacuum spraying. Different physical parameters like RRR, mechanical properties, adherence, thermal conductivity, porosity and permeability will be measured on samples. A new Kapitza test-cell will be used to measure the total thermal resistance of Nb/Cu samples. Once optimum deposition parameters are determined, several 1.3 Ghz monocell and multicell cavities will be fabricated from RRR=200, 1 mm thickness Nb sheets and stiffened with the plasma sprayed copper layer.

References.

1. F. Brossa and E. Lang "*Plasma spraying : a versatile coating technique* " in Advanced techniques for surface engineering, W.Gissler and H.A. Jehn (Ed.) pp199-234, Kluwer Academic Publishers, The Netherlands,1992.
2. J. Lesrel et al. " *Study of thermal effects in superconducting RF cavities* ", this workshop.