I.FAST

Innovation Fostering in Accelerator Science and Technology

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DELIVERABLE REPORT

Additive-manufactured SRF cavities

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ABSTRACT

The aim of the deliverable D10.3 was to assess the manufacturability of seamless SRF cavities made of copper or/and niobium by Additive Manufacturing technology. In particular, the employed technique is Laser Powder Bed Fusion (LPBF).

For more information on IFAST, its partners and contributors please see https://ifast-project.eu/

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Delivery Slip

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Executive summary

The aim of the deliverable D10.3 was to assess the manufacturability of seamless SRF cavities mad of copper or/and niobium by Additive Manufacturing technology. In particular, the employed technique is Laser Powder Bed Fusion (LPBF).

The effectiveness of the process was successfully demonstrated both for copper and niobium. After intense studies for the evaluation of process parameters, the SRF cavities were produced. Surface treatments were performed in order to reduce the surface roughness of the Amplitude Modulated parts to achieve the surface roughness target value of 1 µm.

1. Objectives

Explored effectiveness of AM to produce RF cavities in pure Copper with roughness under 1 µm of the inner surface, printing samples and assessing surface treatments (both mechanical and chemical) in preparation for using pure Niobium.

2. Description of the work

The aim of Task 10.4 is to evaluate the reliability of AM as manufacturing technique to produce seamless 6 GHz superconducting cavities. Initial copper prints were done at DIAM (INFN – Padua Division). Half cavities were initially printed to evaluate different printing parameters and building direction (three horizontal halves, three vertical halves, and three complete cavities, printed vertically, see Fig. 1 a). Furthermore, the printability of such geometry was tested without using internal supports, since they would be detrimental for the surface finish and extremely difficult to remove. Then three complete cavities were printed without internal supports and provided with flanges at the extremities to perform leak tests and cryogenic tests (Fig. 1 b). A fourth half cavity (printed vertically) was also printed.

Pieces were then shipped to Rösler Italiana S.r.l., which performed the surface treatments: two out of four halves were subjected to mechanical treatments, while the other two were treated with chemical-assisted mechanical treatments. The roughness of the down-skin region and material loss was measured after each treatment step. Once the Ra value achieved was less than 1 µm, the specimens were shipped to INFN-LNL to be treated with SUBU5 (chemical polishing) and Electropolishing. Specimens were finally shipped at INFN – Padua Division and CMM analyses have been performed on each sample (Fig. 1 c). The measurements allowed comparing the real final geometry of the half cavities treated with the initial CAD geometry (Fig. 1 d). In such a way, the material loss due to the treatments was estimated.

Meanwhile, two copper cavities were printed by a company with a 515 nm wavelength green laser (Fig. 1 e), and other three copper cavities were printed at DIAM Laboratory (Fig. 1 f).

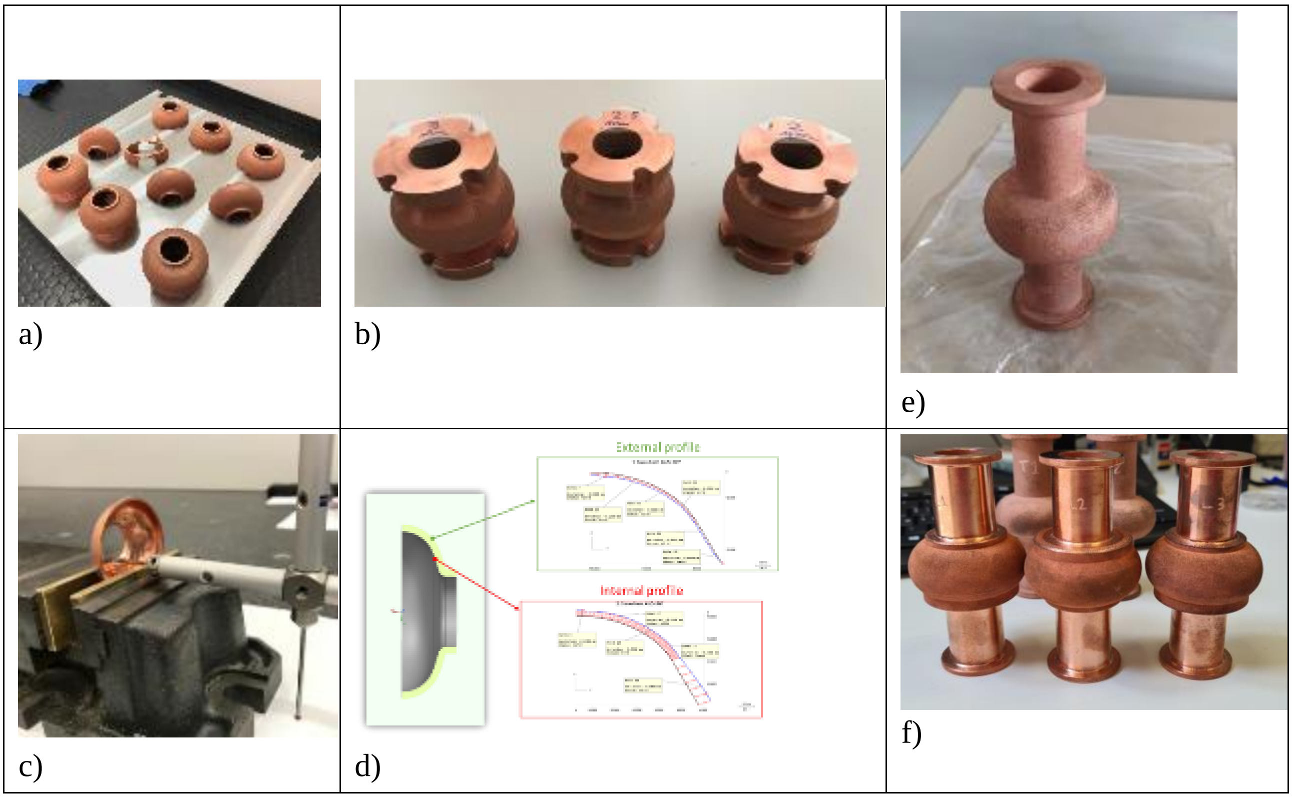


Figure 1: a) first print; b) flanged cavities; c) measurements performed with Zeiss Accura CMM facility; d) profiles obtained by the geometry measurements; e) full-length 6 GHz cavity prototype printed with green laser, f) full-length 6 GHz cavity prototypes printed at DIAM Laboratory (INFN-Padova).

Concerning niobium, samples were printed with different process parameters (Fig. 2 a), and densities were measured by Archimedes' method. Currently, the maximum relative density achieved is equal to 99.87 %. The printability of self-supporting inclined walls (Fig. 2 b) was also assessed, to determine the limit angle of pure niobium. Walls inclined with different angles were created, from a maximum angle of 50° to a minimum angle of 18°. From the first trial, only walls having angles higher than 35° were successfully printed, the other walls failed.

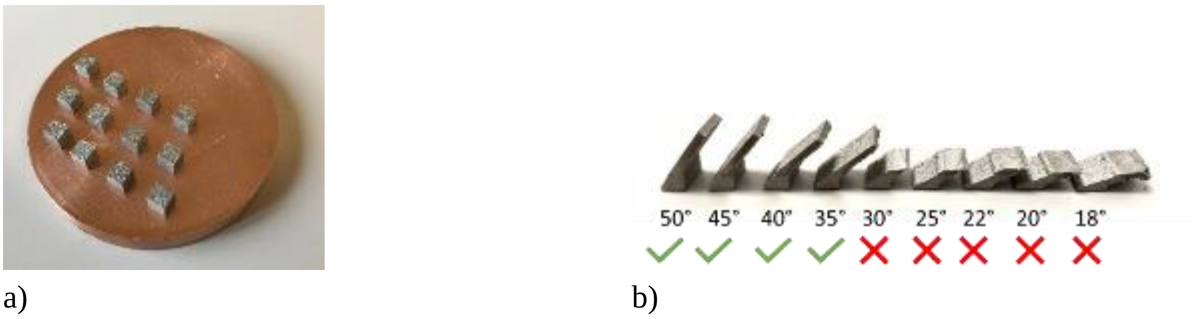
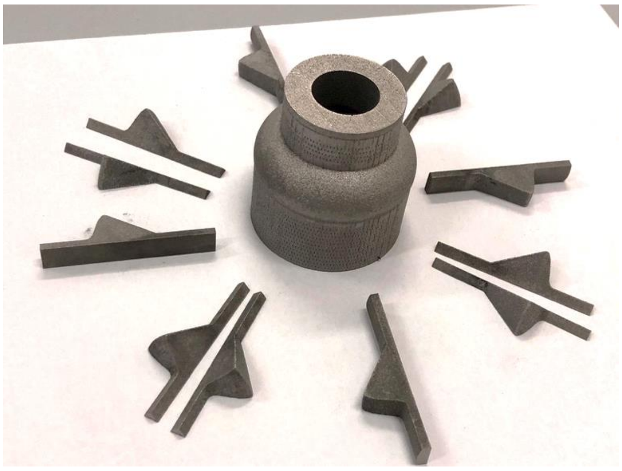


Figure 2: a) Samples for density estimation; b) inclined walls.

Despite the positive results on the preparatory work, Task 10.4 has experienced considerable delays related to slow reaction of companies during the Covid-19 pandemic and to the shortage of base materials, with increase in price. The copper powders for printing were received late, and the low-contamination niobium powders for final printing were not yet received. The consequence was that this Deliverable has been submitted with a delay of 8 months (M20 instead of M12).

After the initial copper cavity production, the research was mainly focused on LPBF of cavities made in pure niobium. Further trials have been performed: several printing tests were carried out with the aim of improving the downward-facing surface quality. Down-skin and contour parameters were studied in deep, and innovative contactless supporting structures were developed. The only use of optimized parameters did not allow to reach overhang surfaces having angles lower than 30°. By using contactless supports, it was possible to go below this limiting angle, and at the same time, the surface roughness was considerably decreased. Thanks to these innovative structures, three pure niobium 6 GHz cavities were successfully printed: one cavity having a height of 50 mm and two cavities 88 mm high (Fig. 3).



a)

b)

2.

Figure 3: Pure niobium 6 GHz SRF cavities produced via LPBF at DIAM laboratory: a) 50 mm high Nb cavity; b) 88 mm high Nb cavity.

Leak tests and RF measurements were carried out for two of the Nb cavities produced (the one 50 mm high and one of the two with the height of 88 mm): the tightness revealed to be excellent and a leak rate <10-12 mbar*l/s was successfully measured. The frequency was measured at room temperature and in as-built conditions: the results are reported in Table 1. A Tc of 9.2 K (identical to bulk Nb) was measured on a small sample of Nb by inductive method.

Internal inspection showed that the as-built surface quality is good inside the cell and the use of contactless supports guarantees a homogeneous internal surface roughness.

Table 1 Frequency of the niobium cavities produced via LPBF (as built).

Cavity	Frequency [GHz]
50 mm	5.999
88 mm	6.027

Concerning the copper cavities, there are 8 prototypes up to now (2 full-length cavities printed with the green laser, indicated as T1 and T2 in the following Table 2, three full-length cavities, indicated as L1, L2, and L3, and three flanged cavities, indicated with P1, P2, and P3 abbreviations). Before any treatment, the resonant frequency was measured at room temperature and data are available in

Table 1. Internal inspection was carried out, too, and images of cut-off, iris, and equatorial regions were taken. These prototypes were subjected to the same surface treatments developed by Rösler Italiana S.r.l. mentioned above. The target surface roughness (Ra) value of 1 µm has not been achieved yet.

Table 2: Frequency of the printed copper cavities at room temperature, in as-built conditions.

Cavity	**Frequency [GHz]**
T1	5.9871875
T2	5.986250
L1	5.9956250
L2	6.0015625
L3	6.0043750
P1	5.9481250
P2	5.9418750
P3	5.9390625

The printability of copper and niobium seamless 6GHz SRF cavities has been proven, Additive Manufacturing (and specifically Laser Powder Bed Fusion technology) is a suitable technique for their production. Concerning the niobium cavities, three seamless cavities have been successfully produced and the internal inspection and resonant frequency measurement have been conducted. The goals of the Deliverable have been achieved.

Some of the copper cavities are ready to proceed with the internal Nb sputtering, while the remaining ones are completing the surface treatments stage. The tightness and the resonant frequency in as-built conditions have been checked, in addition, an internal inspection has been conducted (Table 3) to assess the surface quality after printing; other tests to evaluate the performance of the specimens will be done in the next months.

Surface treatments are presently being performed, to smooth the internal surface also for Nb 6 GHz cavities, then the remaining tests will be carried out.

Table 3: Internal inspection of two different cavities, T1 was printed with a green laser, L1 with a low-power red laser.

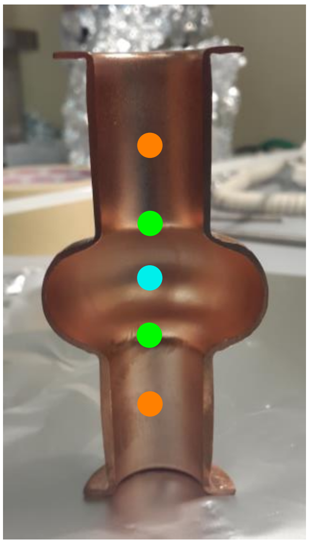
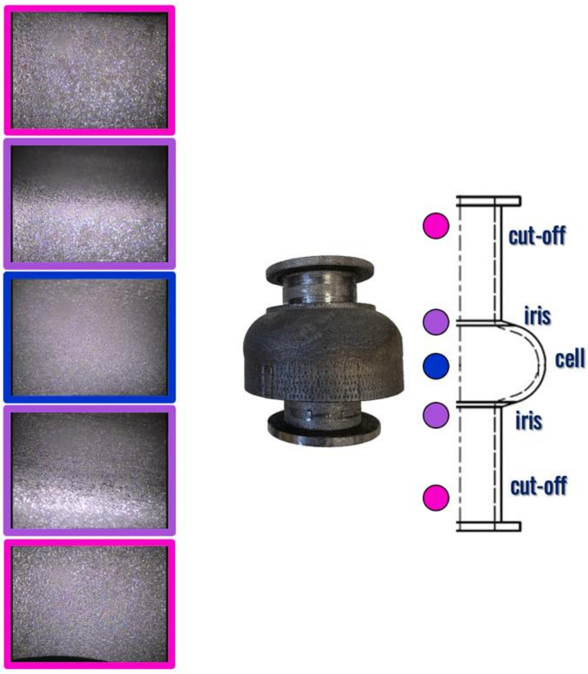
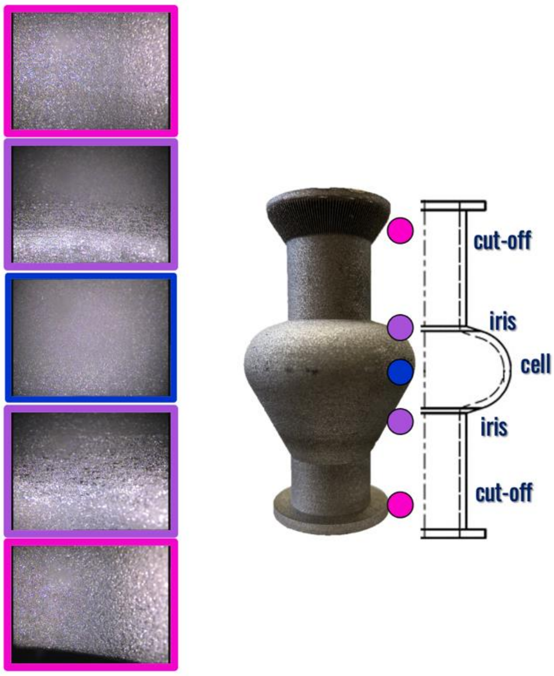
	T1	L1
 **Indicative Image**		
		
		
		
		

Table 4: Internal inspection of Nb cavities.

3. Future plans / Conclusion / relation to other IFAST work

Additive Manufacturing revealed to be a suitable technology for the production of copper and niobium SRF cavities. The performance evaluation of the cavities will be assessed for the upcoming Mttailestone MS46. Niobium coating on copper cavities and other treatments and tests will be done.