Advancements in Low Z Materials: Comprehensive Characterization and Applications by the Mechanical and Materials Engineering Group at CERN

A. T. Perez Fontenla, S. Atieh, S. Sgobba, G. Arnau Izquierdo, A. Cherif, M. Celuch, J-P. Rigaud, S. Pfeiffer, M. Guinchard, O. Sacristan de Frutos, CERN, Geneva, Switzerland

The Mechanical and Materials Engineering group of the Engineering Department at CERN has gained in the last decade important experience in the comprehensive characterization of low Z materials, offering valuable insights into their properties and field of application. We focus on elucidating the unique challenges associated with low Z materials, encompassing their processing, welding techniques, and fabrication methods. Our expertise covers advanced non-destructive testing (NDT) methods as part of quality control to ensure the integrity of the materials, such as micro-tomography, High-Resolution X-Ray Diffraction (HR-XRD) or specially adapted Scanning Electron Microscopy (SEM) techniques for the investigation of light materials. We are also equipped with Focused Ion Beam (FIB)-SEM and instrumented nanoindentation as destructive techniques used during the post-mortem evaluations of, for example, HiRadMat specimens, fixed targets or beam instrumentation devices. By leveraging our state-of-the-art facilities, we provide essential support for an advanced understanding and application of low Z materials in a wide variety of projects at CERN.

TERMO-MECHANICAL TESTING at the Mech. Measurements Lab.

High Speed Strain Measurements

With the objective of assisting the users in their test campaigns the experts in the Mech. Measurements Lab. provide support in different competencies from experimental stress to thermo-physical analysis.

The thermos-mechanical response of the materials when subjected to highly energetic proton beams is studied via real-time data collection, as in HiRadMat Experiences. This effort contributes to the development of more robust constitutive models that will be used at CERN for advanced numerical simulations.

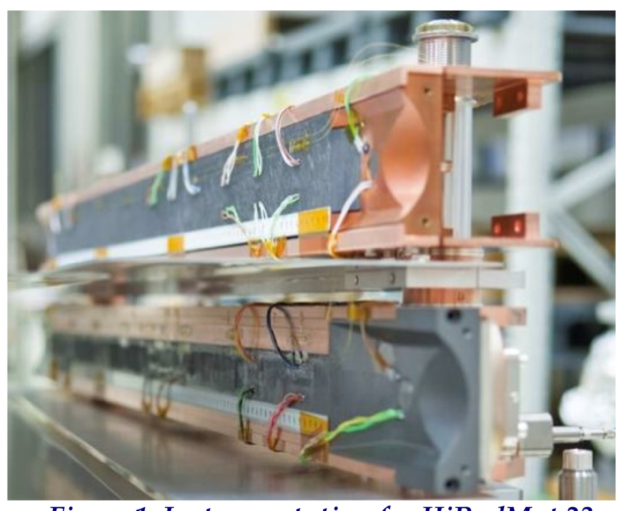


Figure 1: Instrumentation for HiRadMat 23

In this regard, an extensive R&D program has been launched at CERN to develop novel materials capable of replacing or complementing materials used for the new generation of beam intercepting devices, for which literature data are scarce or non-existing and hence, their thermo-physical characterisation from room temperature up to 2000°C is necessary.

DIMENSIONAL CONTROL at the Metrology Lab.

Autopsy of the LHC TDE Dump

Recently, the LHC External Beam Dump, also known as the TDE dump, was disassembled at CERN to facilitate the Low-Density Graphite (LDG) Post-Irradiation Examination (PIE). This initiative significantly contributed to a deeper understanding of the graphitic material's behaviour under beam conditions. Notably, this was the first time such an activity was carried out at CERN.

Figure 2: Portative 3D laser scanner mounted in a robot when the 318LN vessel was still on (images N. Solieri)

Overcoming challenges associated with component activation and dimensions (several-meter-long) and ensuring accurate sampling without exacerbating existing damage were crucial steps in assessing the actual beam damage.

The combination of 3D scanners with the use of robots permitted a detailed examination prior the jacket removal.

The specimens carefully extracted were then analysed by high resolution SEM and high-sensitivity EDS.

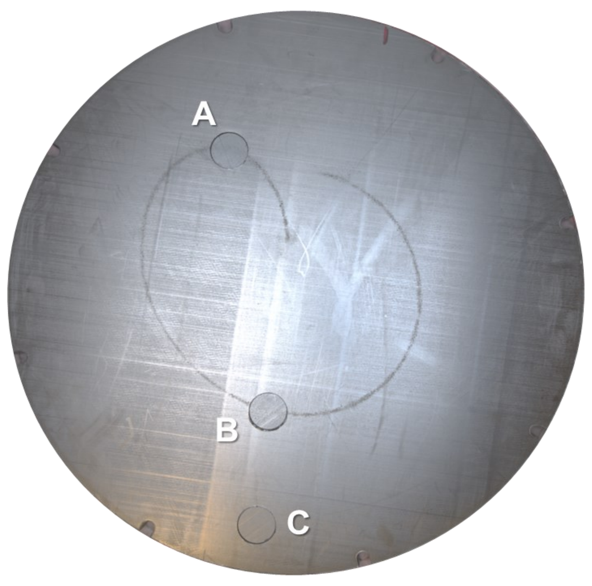
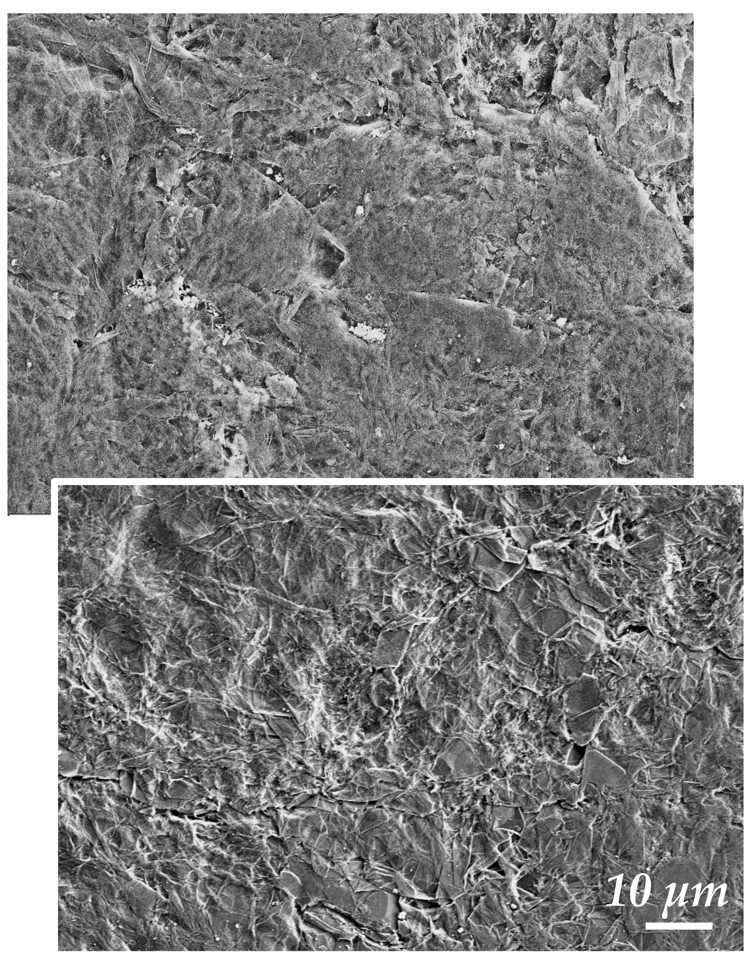


Figure 3: Upstream of graphite sheet with visible beam sweep. Different samples were investigated (A: Area of energy deposition peak; B: Control are; C: Reference

The aspect of the beam impacted zones was rougher and the chemical analysis showed that systematically there was a higher amount of O content on the spots indicating leaks presence. This was confirmed by FIB-SEM cross sectional view and surface-sensitive spectroscopic techniques (XPS) that pointed out also N incorporation.



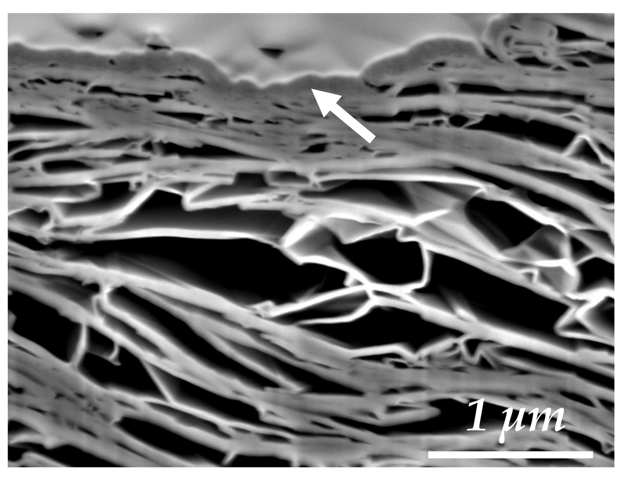


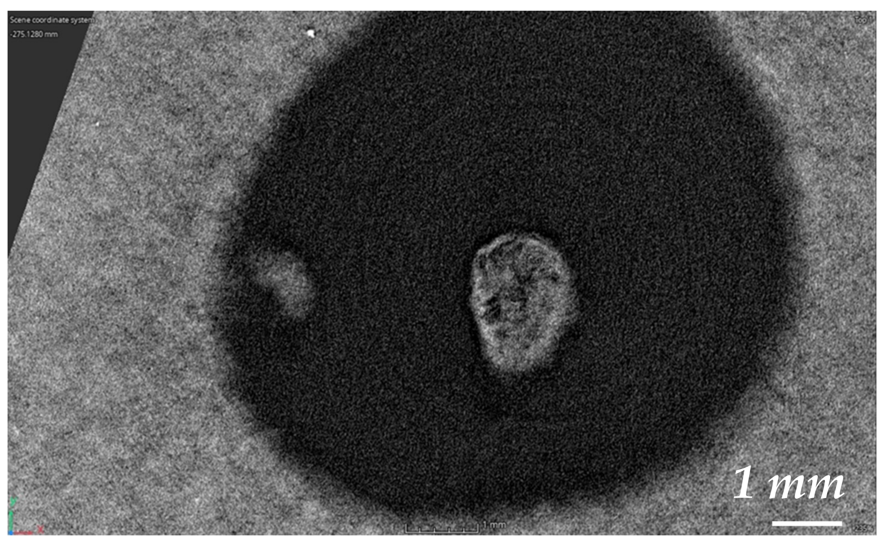
Figure 4: FIB-SEM on reference sample (up) and sample A (down)

COMPUTED TOMOGRAPHY (CT) at the NDT Facilities

Sigraflex specimens after irradiation

The micrometric resolution of the CT system available at the Dimensional Metrology facilities allows the volumetric inspection of the samples with a resolution up to 7 μm voxel size and allows the comparison of the material features before and after irradiation. That was the case in the study performed for HiRadMat56 where various Sigraflex samples were impacted at different doses and number of pulses.

The samples correspond to discs with approximately 30 mm in diameter and 2 mm thickness.



In the shown example the material was impacted three times at the centre and one time 3 mm from it with a beam spot size of 0.34 mm (in a N_2 atmosphere of 1.05 bar).

CT revealed a local swelling of the material and an important delamination through the full thickness.

Figure 5: CT images of Sigraflex specimen after HiRadMat56 (top view and cross-sectional view)

MATERIAL EXAMINATION at the Microscopy Lab.

After micro computed tomography (CT) examination, further microscopic examination was requested to better understand the local swelling visible on the surface at the irradiation location. At this aim, cross sections were prepared on a reference region (non-affected) and the central spot by FIB and then imaged by SEM.

When observed at low magnification both cross sections present the typical graphitic structure in layers and the main difference is the separation between them (delamination) and a larger pore size in the irradiation spot region than in the reference.

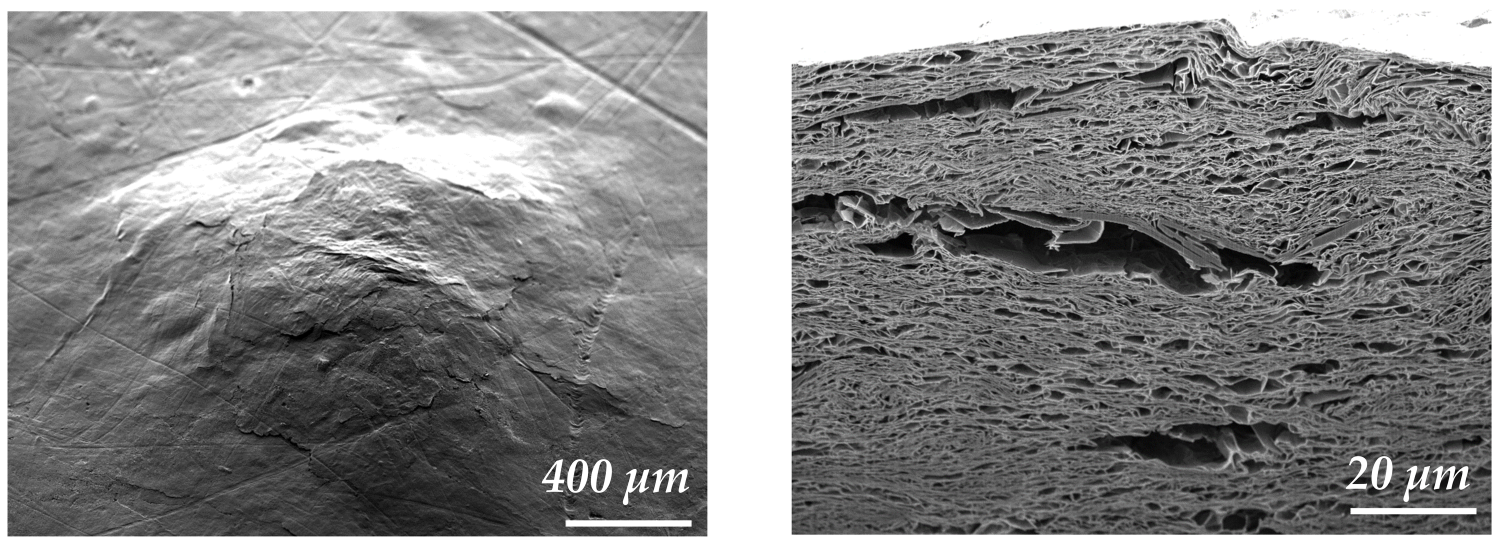


Figure 6: SEM images of Sigraflex specimen after HiRadMat56 (top view and FIB-SEM cross-sectional view)

Microscopy techniques were also employed in other experiments aiming to compare the behaviour of different low Z materials to be potentially used at CERN for window applications (i. e. glassy C or Be).

The SMAUG study alternated vacuum and air chambers (windows experimented pressure gradient) and included pressure sensors in vacuum to detect window leaks to identify failures like the one on a Be window on the SEM image (right)

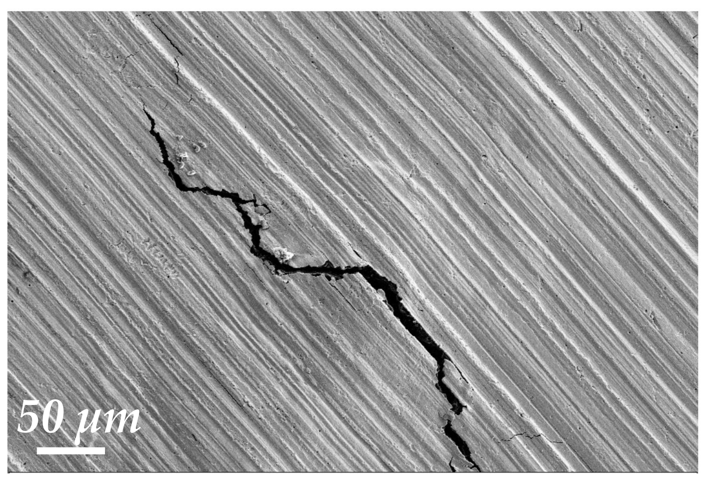


Figure 7: SEM image of Be window after failure at the area of beam imprint. The fracture progressively propagated from air to vacuum side (cyclic phenomenon that appeared in both occurrences only after ~50 high-brightness shots