New techniques for materials in high energy physics

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Introduction

Present high energy physics (HEP) experiments require specific materials and technologies. For example, the LHC high luminosity phase implies significant changes for LHCb in the upcoming upgrade 2. For the calorimetry system our main activities are concentrated on the upcoming upgrade of the electromagnetic calorimeter (ECAL), with changing the inner part of the present shashlik type modules in favor of the spaghetti type modules (SPACAL) [1]. Very inner part, with the highest expected radiation doses, is to be filled with radiation-hard crystal scintillating fibers (e.g., GAGG 1x1 mm² in cross-section) in pair with a Tungsten absorber, while the next region to be made of polystyrene fibers and lead-based absorber. In both cases the technology suitable for mass production is to be developed allowing precise positioning of the sensitive materials. For the lead-based absorber the special molding technique is under development. First prototype had been produced at NUST "MISiS" (Moscow) and equipped with fibers and tested at CERN in 2021. Next prototype is being produced and to be tested this year.

For the tungsten absorber a 3D printing technique has been developed and currently available at NUST "MISiS". First obtained samples meet the surface criteria for the experiment, and a prototype suitable for beam-tests to be produced soon

Lead-based absorber

Replacing Shashlik with Spaghetti type modules should give technological advantages, one of the most crucial one is – changing degraded scintillating fibers without moving/changing whole module (absorber), so called cassette assembly. Meeting mentioned technological feature is a challenging task, which requires precise techniques of obtaining absorbers, with straight (no tilt) holes. It was proposed to use casting method, where metal is melted and poured into precisely manufactured final-geometry vessels (fig. 1), which inside repeats the outer dimensions of the absorber (or other shape). For keeping holes free of melted metal, it was decided to use metal (or carbide) rods (fig. 2), which should give the absorber inner geometry (fig. 2), as well as control the tilt of the holes and pitch between their centers.

Lead was chosen as the main element for this absorber, for its numerous properties, as density, Moliere Radius (Rm), Radiation length (X0), etc. However, for more advanced mechanical properties Garth's alloy was picked as more suitable substitute (which is, indeed, a lead-based alloy Pb-Sb-Sn, 84-12-4%).

Absorber was produced and cut in 7X0 and 18X0 chunks, one can see the inner picture (fig. 2), which steadily repeats the pattern and has minimal tilt along the Z-axis.

Algorithm of Spaghetti module production: Casting, metal-vessel-rod separation, assembly

Fig. 1. Final-geometry vessel with metal rods assembled

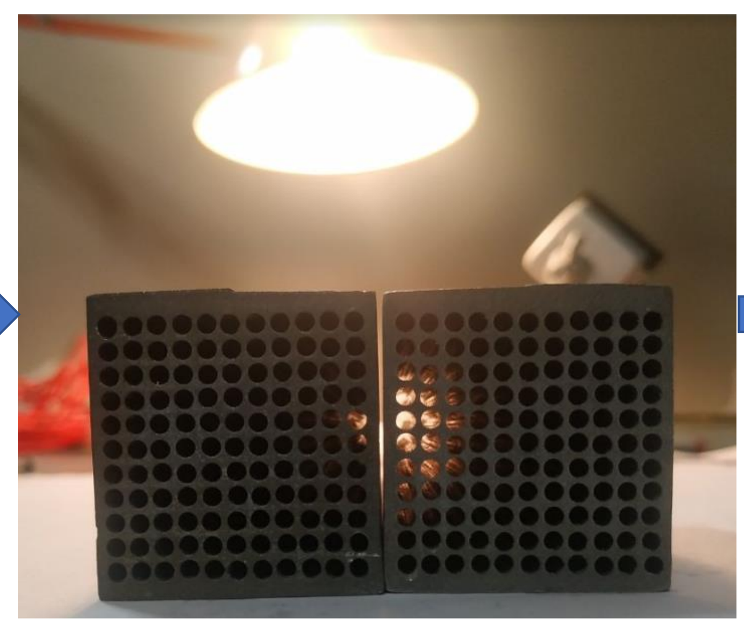

Fig. 2. Inner picture of obtained absorber

Fig. 3. Absorber with scintillators filled in underway

One of the key features of such technology is the temperature. Temperatures should be kept close to each other along the system: vessel – melted metal (alloy) – rods. Otherwise, difference in temperatures of several hundred degrees may cause uneven crystallization of metal after pouring and lower part (metal is poured from top to bottom) can solidify faster than it fills all the inner volume of the vessel.

Tungsten-based absorber

Another key component of the future upgrade of LHCb ECAL is its core – central section of modules, where the most of radiation load is located, and will increase to levels unsustainable by shashlik type of modules [2]. Hence tungsten-crystal combination is used. Tungsten is known for its challenging mechanical properties, as well as highest melting point, therefore different techniques were used to produce expected geometry of SPACAL absorber. One of the most promising technology is 3D printing using Selective Laser Melting (SLM) method, where laser melts and fuses metal powder, creating 3 dimensional objects. Printing allows various alternative applications. Currently, research is conducted on the special 3D printed anti-scattering tungsten grating – an object for the X Ray imaging, aimed to reduce background from the scattered photons [3, 4]. Figures 4-6 given below demonstrate iterations "left to right – from coarse to fine", where different modes of both printer and 3D modeling techniques were tested and lead us to the final product (fig. 6) of very thin-walled (~ 100-200 µm) matrix, with non-trivial center-oriented geometry, which, all features combined, would be nearly-impossible to create without 3D printing.

One of the most important part in printing is the powder quality, as well as laser's power and printing chamber dimensions. In our case we were limited with the 3x3x7 cm parallelepiped, hence the mounting cylinder, made of steel and dimensions of MVP. First attempts were aimed to identify the most suitable working conditions of printer, which has more than dozen degrees of freedom, in terms of parameters (e.g., laser power, laser trace, 3D model properties, etc.).

Rough illustration of one R&D cycle: first coarse attempts, testing extreme points, obtaining MVP

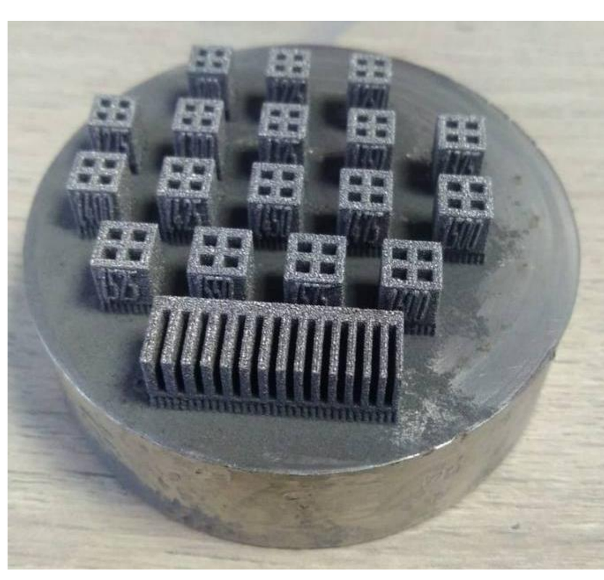

Fig. 4. First iteration of printer with different thicknesses of walls

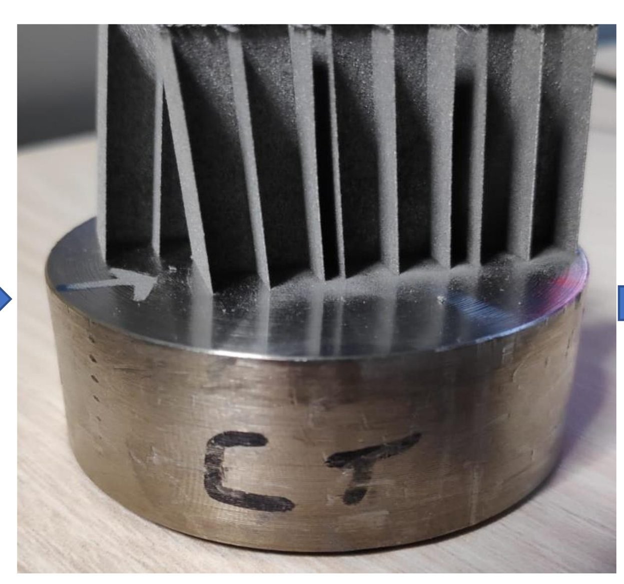

Fig. 5. Testing the incline stability with respect to different angles (0-6°)

Fig. 6. MVP for testing in laboratory environment 30x30x50 mm

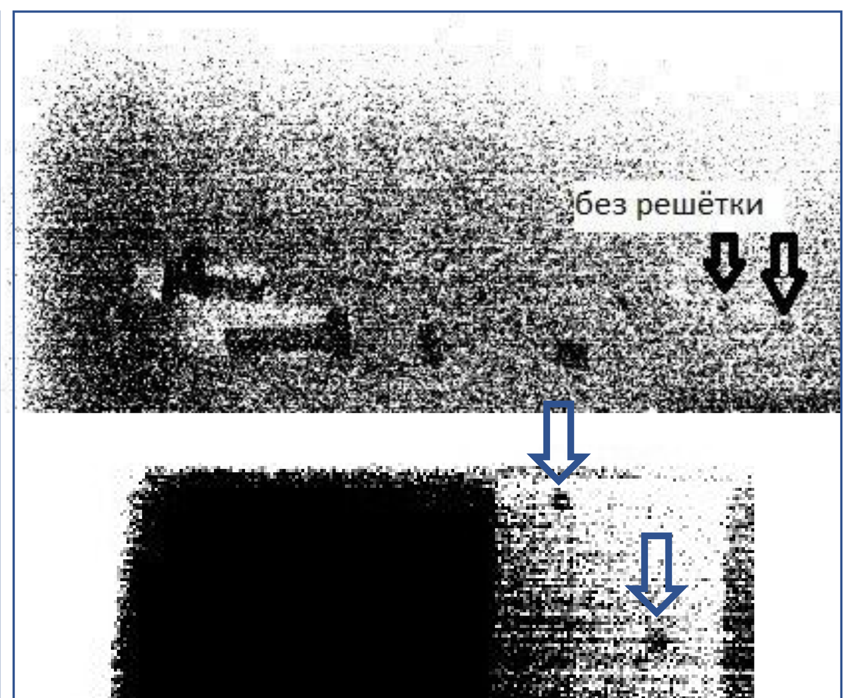

Fig. 7. Top – X-Ray image of targets without tungsten grating. Bottom – X-Ray image with tungsten grating.

After obtaining the model it is necessary to cut off the "main body" from the mounting cylinder. Electro erosion was the most used case, in pair with high pressure water cutting. It is highly recommended to fill the holes with some sort of support, which could be deleted later (e.g., paraffin), due to (surprisingly) extremely low thickness of walls of produced product, which resulted into brittleness. This could be seen by untrained eye (fig. 6).

Experiments with MVP grid show its significant anti-scattering effect – background reduced, and targeted region is clearer for observer, whereas neighboring region is shielded – completely black (fig. 7). The geometry of the examined sample is good, with all faces facing the source. When mounted correctly, the grid has high angular selectivity. And the wall thickness of 200 microns was considered as satisfactory.

Summary

New methods and techniques of working with different materials for HEP purposes are being discovered and utilized.

Casting gives us enormous versatility in terms of geometry and precision. Its first results were already obtained and tested at CERN facilities with good results and next iteration of new absorbers are being produced, utilizing casting techinque.

Tungsten is highly valued element in HEP, due to its characteristics as well as challenging in terms of production. Nevertheless, it was shown, that 3D printing, using SLM with pure tungsten powder is capable of handling most of the shortcomings of this metal and create unique shapes with non-trivial geometry.

References

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