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KATONAI
KÖZLÖNY

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Effectivity Experiment of PA-12 Shaped Charge Liners

The application of 3D printing in blasting technology is a significantly under-researched area worldwide. Despite this, low-density materials hold importance in certain subfields among which cumulative charges stand out. In my research, I examine the efficiency of cones made from PA-12 material using powder bed fusion technology. During the tests, I demonstrate that in the case of this material, the component preventing backflow has a significant impact on perforation performance and cavity formation. I analyse and compare the results of a total of six charges, with three of each type, to verify my hypothesis regarding the aforementioned component.

Keywords: *additive, 3D printing, blasting technology, cumulative, charge*

Introduction

3D printing or additive manufacturing is a widely used technology today, found in individual households for hobby purposes as well as having established its place in the industry. It holds an invaluable opportunity for researchers, because it makes the production of prototypes incredibly inexpensive. However, the field has not yet reached its ultimate limits.

CAD[2] design and additive manufacturing are technically intertwined, although there are (mostly online) options that make designing objects significantly easier for amateur users. In research and industrial fields, however, this design process is carried out by engineers at high quality and optimised for the specific additive technology, enabling the realisation of structures composed of very complex components.[3] The next step is generative design, which can further enhance the efficient use of the technology. Today, our parts can be produced in build volumes as large as 1 cubic meter, with some advanced devices capable of building layers as thin as 20 micrometres.[4]

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2 Computer-Aided Design.

3 Gyarmati et al. 2022: 125.

4 Kajner et al. 2023: 4.

The widespread application and possibilities make it clear that we should also explore the potential uses in the military context, in line with the main research directions of military science[5] such as climate change, disaster relief operations[6] and applications of cutting-edge technologies. In this regard, the manufacturing of blasting technology components could be an area worth investigating, which may also have civilian implications in the future.

Focusing on this area, I chose cumulative charges as a potential research direction. Whereas cumulative linings usually emphasise high-density materials such as copper, I chose low-density materials, specifically polymers, as my main focus. Although these materials significantly lag behind copper in terms of perforation capability, immense penetration is not always necessary for the target object. In certain explosive ordnance disposal tasks,[7] it can be particularly advantageous if the charge only pierces the expected material thickness.

In my research I have examined various technologies and materials. In this testing phase I will investigate nylon cumulative cones produced using powder bed fusion technology. During the blasts, I will detonate a total of six charges in two types. All their parameters will be identical except the backflow preventer. This component maintains the stand-off distance between the target object and the liner. The truncated cone has a hollow design to ensure that nothing obstructs the formation of the cumulative jet.

My objective is to examine the impact of the aforementioned component on efficiency through three detonations each. I hypothesise that the charges without the component will underperform in terms of efficiency and the geometry of the resulting cavities compared to the other variant.

Selective laser sintering

The development of additive manufacturing or 3D printing is progressing at a rapid pace. Improved, enhanced and even robotics-integrated versions of prevalent technologies are continuously emerging. This constant change brings many advantages but also significant challenges in organising the field, so my writing can only provide a limited overview of these advancements.

The technology I plan to introduce is Selective Laser Sintering (SLS). This technology is also commonly referred to as powder bed printing (Figure 1), a name that more descriptively illustrates the manufacturing process. Compared to the widely used fused deposition modelling/fused filament fabrication (FDM/FFF) technology, the range of usable materials is significantly smaller. Typically, some form of polyamide (PA) serves as the base material, but polypropylene (PP) can also be used for making lighter parts, and thermoplastic polyurethane (TPU) may be utilised when flexibility is an important factor.

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5 Boda et al. 2016.
6 Padányi 2023: 101–119.
7 E.g. some improvised explosive device disposal tasks. Kovács 2012.

First, the powder material is transferred from a container to the build area, where it is spread in thin layers.[8] The evenly spread, smoothed powder surface is illuminated by a laser at the necessary points, where it solidifies and forms a layer of solid material. After the tray in the build area moves downward, a new thin layer of material is applied, which is also solidified by the laser. The process and the material require a consistently high and uniform temperature, which is a crucial element for the quality of the parts.[9]

Figure 1: Build chamber of Formlabs Fuse 1 SLS printer
Source: photographed by the author

Polymers in SLS technology – Additive manufacturing

The Faculty of Military Science and Officer Training (MSOT) at the Ludovika University of Public Service (LUPS) also possesses an SLS technology 3D printer. This is a Fuse 1 device manufactured by Formlabs, for which five materials are available, two of which contain fibre reinforcement. The composite materials are Nylon 11 CF (micro carbon fibre) and Nylon 12 GF (glass fibre). The conventional polymers are Nylon 11, Nylon 12, Polypropylene Powder, and an elastomer, TPU 90A Powder. The unique feature of SLS technology is that only one type of material can be used per machine. Switching to a different material is not impossible, but costly, and the quality of the products is questionable, as removing the powder from the internal parts and storage units is almost an impossible task.

As shown in Figure 2, the modulus of the carbon fibre polyamide is up to three times higher, and the modulus of the glass fibre material nearly doubles compared to the fibre-free powder.

8 Typically, layers with a thickness between 50 and 200 micrometres are formed.
9 Gál–Németh 2019: 234.

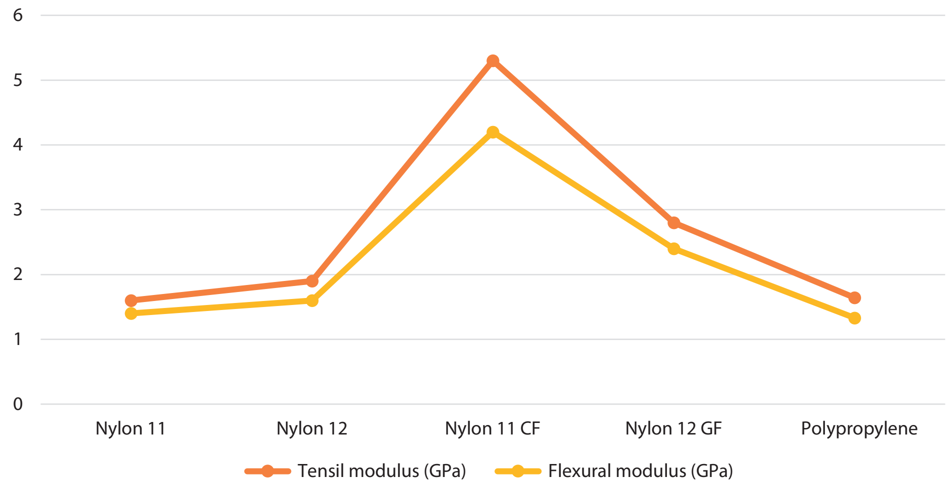

Figure 2: Modulus rates of Formlabs materials
Source: compiled by the author based on https://formlabs.com/store/materials/nylon-12-gf-powder/

The significance of carbon fibre is also evident when examining strength values (Figure 3). The flexural strength of carbon fibre-reinforced Nylon 11 is twice as high, and its tensile strength also significantly increases compared to fibre-free polyamide.

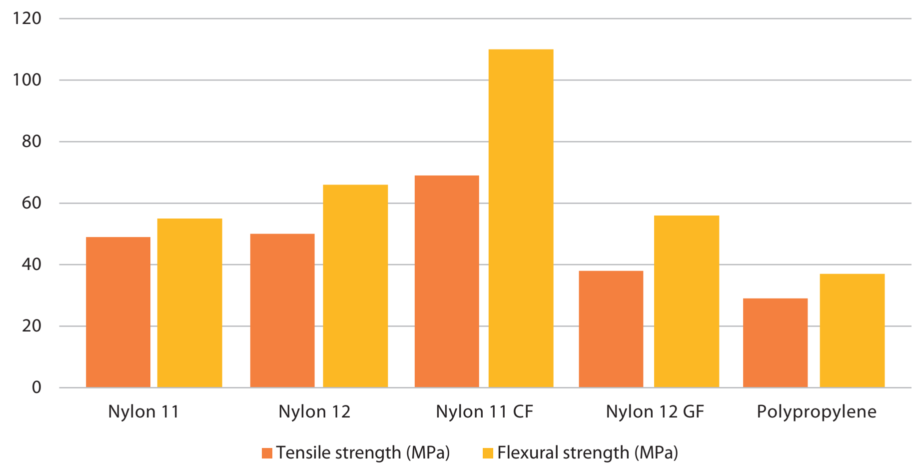

Figure 3: Tensile rates of Formlabs materials
Source: compiled by the author based on https://formlabs.com/store/materials/nylon-12-gf-powder/

If the goal is to manufacture lightweight, high thermal stability, and repeated force-resistant parts, the best choice is the carbon fibre mixed Nylon 11 powder. If thermal stability and heat resistance are critical factors, the glass fibre mixed Nylon 12 is the advantageous solution.[10]

Elongation is also an important property. In this case, fibre reinforcement does not meet the expectations. Nylon 11 and Polypropylene materials show particularly good values in this area (Figure 4).

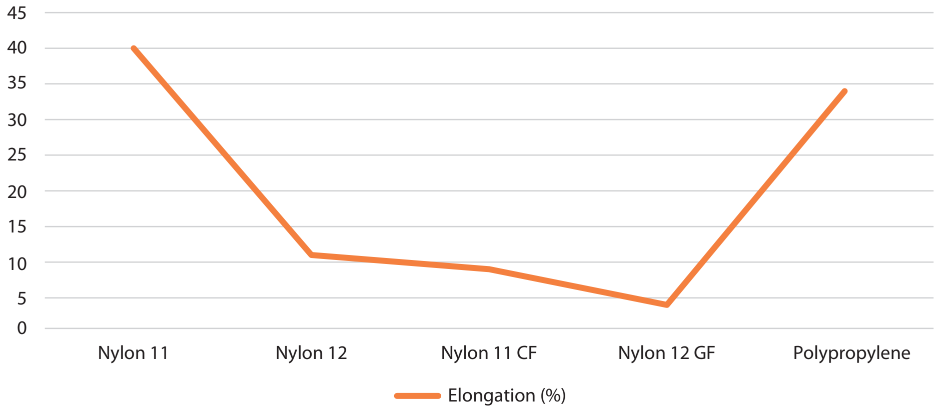

Figure 4: Elongation of Formlabs materials
Source: compiled by the author based on https://formlabs.com/store/materials/nylon-12-gf-powder/

Manufacturing of shaped charges

The designs for all parts were created using FreeCAD 0.20, a free, downloadable and open-source application. I already have experience with the software used for this purpose.[11] The dimensions of the shaped charges were determined using several methods,[12] applying my own parameters[13] that have proven effective in multiple tests.[14] During the design, I considered the manufacturing characteristics, although in our case, supports were not significant because the SLS technology does not require them, allowing for greater design freedom.

The completed electronic forms were virtually arranged in the build area using the cloud-based PreForm software. This preparatory application has the significant advantage of not requiring deep material science or manufacturing technology knowledge to operate. Various parameters are pre-set, and the user only needs to focus on filling the space. This is particularly important for material economy. While the application can optimise this for us, I did not use this feature because it changes the orientation of the objects in space. This

10 See: https://formlabs.com/materials/?print_technology%5B0%5D=SLS
11 Ádám–Ember 2022a; Ádám–Ember 2022b.
12 Ember 2022a.
13 Lukács 1992: 29–40.
14 Ember 2022b; Ember 2022c; Ember 2022d; Ember 2022e.

likely would not cause significant differences in the blast results, but I insisted on identical arrangements to ensure comparable results from all aspects.

The material for the cumulative cones used in the investigations was always Nylon 12 powder, and they were printed on the same printer with identical orientation. The printing process encountered no issues or stoppages. I successfully removed the finished products and cleaned them of residual powder. I paid special attention to the inner cavity of the cones, where residual material tends to adhere strongly near the tip. Various plastic-bristle brushes were used for cleaning to avoid mechanical damage.

In summary, the parts were manufactured relatively quickly and easily. The only difficulty was the cleaning process, due to the necessary use of protective equipment. This is, of course, an unavoidable part of the technology, as the powders require, among other precautions, the use of an appropriate mask.

Preparation for blasting

The tests were carried out with the assistance of the demolition soldiers of the Hungarian Defence Forces (HDF) 1st Explosive Ordnance Disposal and River Guard Regiment (HDF 1st EOD&RG Reg.) in Táborfalva, at the designated blasting area of the HDF.

Figure 5: Types of exploded charges
Source: photographed by the author

During the tests more charges were detonated than those described in this study. Multiple blasting series were conducted; however, the electrical network was configured in a series connection using the standardised electric detonators and wires of the HDF. Due to the required performance of the explosive placed in the charge housing, a brisant military type[15] was chosen, although an industrial version[16] could have been conceivable as well. An interesting question is how insensitive explosives currently under development for military use

[15] Lukács 2017: 26.
[16] Daruka 2016: 35–40.

would behave under similar conditions?[17] Regarding properties, a plastic or liquid type, which could be binary or multi-component, would be preferable.[18] This is why I chose Semtex-H plastic explosive. A significant number of fragments were not expected due to the special implementation of the blasting.

We dug pits in the ground, each with a base area of 30 × 30 cm and a depth of 50 cm, where the target objects with the attached charges were placed. The pits were spaced far enough apart so that the detonation shockwave and other effects would not influence the investigation. In practice, this meant a distance of approximately 3 metres. The detailed parameters of the configured charges (Figure 5) can be seen in Table 1.

Table 1: Data of exploded charges

<table>
<tr><th>No.</th><th>Type</th><th>Cone weight (g)</th><th>Explosive weight (g)</th><th>Target material</th></tr>
<tr><td>1</td><td rowspan="3">Cone: 20 mm, PA–12, 60^0
Charge body: 40 mm stand-off, backflow preventer</td><td rowspan="6">2.9</td><td rowspan="6">33</td><td rowspan="6">30 mm wide, steel disc (sawed from a single steel pole)</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td rowspan="3">Cone: 20 mm, PA–12, 60^0
Charge body: 40 mm stand-off, without backflow preventer</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
</table>

Source: compiled by the author

The process of preparing the charges:

1. Assembling the charge housings
2. Filling the charges with Semtex-H explosive
3. Creating the space for the detonator
4. Attaching the charges to the target objects with superglue
5. Placing the detonator support cap
6. Inserting the secured charges into the blasting pits prepared for detonation
7. Placing the electric detonators in the charges

Results:

For the charges equipped with backflow preventers, it can be stated that the penetration fell short of my expectations. However, increasing penetration was not among the test objectives. Nevertheless, the target objects present a uniform appearance, indicating that efforts to achieve consistent design were successful. A rim is visible around the formed holes, with the maximum height from the target surface ranging between 3.5 and 3.7 mm. The upper part of the cavity is wider at the rim formation stage, followed by a relatively uniform diameter section down to the bottom of the hole. The diameter of the uniform section ranged between 12.5 and 13.3 mm. Penetration depth measured on the target objects was between 11.47 and 12.82 mm, which are also very close values.

17 Daruka 2023: 15–18.

18 Kugyela 2020: 58–71.

Figure 6: Target objects of charges with backflow preventer
Source: photographed by the author

The penetration of the charges made without backflow preventers was visibly significantly below expectations. Despite this, the target objects also presented a uniform appearance in this blasting series, indicating that the charges were consistently constructed. The holes formed had rims with irregular geometry. Their maximum height from the target surface ranged between 5.6 and 6 mm. The rim formation phase at the top of the cavity was not clearly identifiable. The diameter of the cavity ranged between 17.2 and 20.2 mm. Penetration depth measured on the target objects varied between 6.6 and 9.8 mm, which shows a noticeable spread.

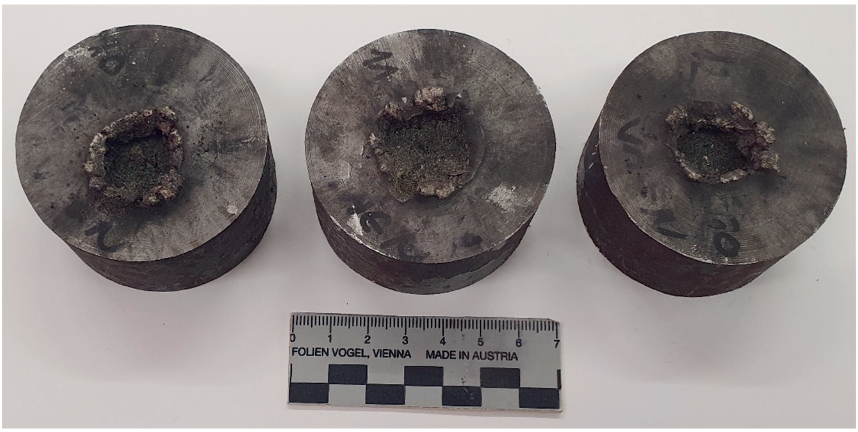

Figure 7: Target objects of charges without backflow preventer
Source: photographed by the author

Since the design of the above charges can be considered uniform, I also consider the measured results to be evaluable and acceptable. In the case of charges with backflow preventers, the target objects present a uniform appearance, which is immediately evident to an expert eye as forming a characteristic cavity. In the absence of the aforementioned component, the difference is also visible to the naked eye. The irregular cavities and significantly reduced penetration depth demonstrate that it is worth further investigating the topic and the impact of the backflow preventer on the efficiency of liners made from low-density materials.

Summary

The presented tests provide a clear visual indication, even at first glance and to the naked eye, which supports my earlier hypothesis. I achieved my objectives. I tested three charges each, which were identical in design, with the only difference being the presence of the backflow preventer.

The results confirm that the absence of the aforementioned component significantly deteriorates the cavity formation geometry and considerably reduces penetration. In the presence of the component, cones made from low-density material (nylon) exhibit significantly better efficiency. The improved penetration depth is likely due to the well-formed and guided jet, which reduces material reflection from the target, potentially impairing perforation capability.

I want to avoid presenting misleading data and drawing far-reaching conclusions on this topic. Currently, I would like to state that the backflow preventer plays a significant role in enhancing the efficiency of PA–12 material liners made using SLS technology.

My caution is justified by the fact that in other technologies, similar geometry liners can have up to 33% greater mass. This also means significantly higher density, which can seriously affect the efficiency and formation of the jet by itself. Furthermore, I should point out that different materials, or the same material manufactured by different technologies, may have different material properties, strength and elongation properties, all of which can affect the beam forming process and thus the penetration geometry.

I intend to further investigate the effectiveness of the presented component in liners produced using FDM technology and with different materials. This is because it can be assumed that the impact of the backflow preventer on efficiency will not be equally significant for all materials.

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