Influence of 3D printing parameters

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Abstract. In this study, the influence of printing parameters have been investigated. The inner structure of 3D printed specimens were captured by a scanning electron microscope and these records were investigated by a CAD software. The mechanical properties of 3D printed parts can be determined by the size changing of failures between layers. Additive manufacturing technologies have become widely used, for this reason the influence of printing parameters must be well known. Optimisation of production time and mechanical strength is possible with this method.

1. Introduction
Additive technologies like Fused Deposition Modelling (FDM) became popular in the last decade. Because of the spreading of the technology the low-cost machines are affordable for everyone and by the help of communities the technology has been developing fast [1]. It can be used as a rapid prototyping technology and might can be used directly in custom prostheses production [2], [3] or in non-series manufacturing [4], [5]. The influence of printing parameters like temperature, speed, or layer height to the structure of the printed parts has been tested in many ways [6]. The optimal range of printing temperature is determined by the manufacturers, usually it means the best temperature range for the reliable production process. The time impact of the layer height also well known (in this case, the impact of layer height for the surface quality is not important) but the mechanical influence of these properties have not been exactly determined [7], [8]. For this applications the exact influence of printing parameters must be well known.

2. Method
In this study the layer height was investigated. AM technologies like FDM use thin layers of different molten polymers (FDM), photopolymers (SLA/DLP) and powder (SLS) to produce three dimensional bodies and parts. Connection between layers - intralayer bonding - cannot be perfect because of the imperfection of the technology.
Amabel et al. looked for an ideal test method for 3D printed specimens and observed significant failures between layers [9].
Air gaps and failures are observable between the rasters. Mouhamadou et al. studied the extruded material diameter and proved a high dependency on velocity and temperature. The higher the layer, the faster the molten polymer is and it can affect to the diameter of the lines also. This phenomenon can cause to shrink the lines and produce bigger air gaps. Tested material was a biopolymer named PLA. This is a biodegradable semi-crystalline polymer, which can be also produced from renewable resources like corn or sugarcane. It is the most popular 3D printer filament type because it is easy to print with it. It does not warp and it is relatively hard (its tensile strength is about 50 MPa). Its printing temperature is around 190-230 °C and heated bed is not required. This material is not an engineering polymer but the results can be implemented and used to other materials. The 3D printer was an affordable commercial FDM 3D printer, the Hephestos Prusa I3. It has many advantages and disadvantages against a professional one, for example the printing parameters are changeable separately. However, this machine is less precise (+0,2 mm in x and y directions). Layer height was changed during the manufacturing process and the other parameters were always the same.

| Number | Temperature (°C) | Layer height (mm) | Speed (mm/s) |
|--------|------------------|------------------|--------------|
| 1.     | 220              | 0,05             | 40           |
| 2.     | 220              | 0,1              | 40           |
| 3.     | 220              | 0,2              | 40           |
| 4.     | 220              | 0,3              | 40           |
| 5.     | 220              | 0,4              | 40           |

Table 1. Printing parameters

For this investigation a simple test specimen was designed by us. It had to be easy to reproduce and brake. The normal test-bars would have been needlessly oversized and they would have produced unnecessary spoilage. After the manufacturing and fracture making process, pictures were taken by SEM (Scanning Electron Microscope) and CT. Figure 2. shows a CT record from a specimen and it shows failures inside of the printed parts. These failures can reduce the mechanical strength of 3D printed parts. CT records were also useful to check if the size of gaps were influenced by the fracture making method.
Fractures were measured and exactly determined by a CAD software named Solid Edge. Modern CAD software use Non Uniform Rational Bezier Splines (NURBS) and the failures between the layers could be approximated by them. We had the possibility to set the SEM pictures in a draft document and then measure them by Solid Edge. In the Figure 3. a failure and its size can be seen.

As can be observed SEM pictures show similar results as it was expected based on Figure 1. The failures are relatively big compared to the layer height. The size of the failures has an effect on the printed parts and maybe they can influence the anisotropic properties.
Small gaps were compared to the nozzle diameter. By this method the relative failure size can be determined. This relation is more clear and understandable. Figure 5. shows the connection between layers.

3. Results
Our presumption was that the size of gaps will change if the printing parameters are changing. Every specimen have been analysed and more than 100 gaps have been measured by Solid Edge. The results are represented on this diagram. The statistical dispersion of the results is significant because the failures
have been directly measured. Statistical dispersion of conventional measurements like tensile test is less significant because in this case just the average failures can be measured.

![Figure 6. Relative failure size depending on layer height](image)

This diagram shows the changing of gap sizes according to the layer height. Layer height and failure size are in a relation of proportionality. Reducing layer height always increases the printing time and it can negatively affect costs [13]. Increasing layer height can lead to production of weaker parts, furthermore the gaps can raise the risk of infection in case of medical devices like orthoses and prostheses [2]. The highest recommended layer height is around 80% of the nozzle diameter [14]. In this case it is 0.32mm.

4. Discussion

Influence of printing speed and temperature also can be significant. Printing speed is usually a physical constrain, most of commercial printers can print around 80mm/s or less. Theoretically the smaller printing speed is better. The temperature is depending on the used material. Melting point of PLA is around 150-160°C [15], but the printing temperature is much higher, it is around 190-230°C. Different applications can require different printing temperatures at the same material. Influence of printing parameters can be determined by this method, but for the supervision a conventional tensile test needed.

Our study was about the influence of layer height. Spreading of additive technologies can help us to produce cheaper and better products. These technologies often used in production of custom orthoses and prostheses. In this case the price, strength and weight are really important [16]. The number of people who use orthoses or prosthetics expected to increase from 5.6 million in 1995 to 7.3 million by 2020 [1]. Nowadays the conventional prostheses are not perfect: “The prostheses are rigid and heavy. Installation is needlessly hard, this technology has been used for 20 years. The usage of bandage is not modern, hard and break down fast. The hand itself works well. Consequently, the hand is great but the
case is a nightmare.” – said Szabolcs Kollinger [17], who uses prostheses. For this reason to investigate new materials and methods are important and necessary.

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