DESIGN OF FORMING TOOLS FOR A LOCK COVER PART USING THE FFF 3D PRINTING METHOD

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Abstract

The 3D printing method is a widely used technology for industrial and domestic applications. This paper deals with the design of forming tools for sheet metal drawing made of PLA plastic, produced by the FFF 3D printing method, and used to create a lock cover part from DX56 sheet metal of 0.7 mm. First, a virtual model was created based on the pattern provided by company KERVAL a.s., which was used to design the tools' geometry and the shape of the input sheet. In addition, tensile and compression tests were performed on the PLA samples to determine their properties. The results of these tests were used to build a material model to simulate tool deformation. Then, a numerical simulation was created in the Simufact Forming software to verify the manufacturability of the part, and the suitability of the tooling geometry, and to rule out damage to the blank. In the numerical simulation, rigid and deformable tools were considered. The tools were then printed and used to verify the real pressing process. The results showed that the deformable tools were able to press the lock cover part to the required quality; however, during the forming process, there was significant damage to the tool. In conclusion, the causes of this result and recommendations for possible solutions to the problem are analysed. The use of FFF 3D printing technology can significantly reduce the development time and cost of prototype forming tools.

Keywords: Sheet metal forming, FDM/FFF, numerical simulation, PLA, stamping, Simufact Forming

1. INTRODUCTION

The Fused Filament Fabrication (FFF) 3D printing method is now a commonly used technology for industrial and domestic applications. In this paper, we investigate the use of FFF printing to produce cold drawing tools for sheet metal, an experimental use of plastic prints that are not yet commonly used. The material used was a commonly available filament made of PLA (Polylactic Acid) due to its low cost, good processability by FFF method and good mechanical properties in compression. The impetus for this work was a request from the company KERVAL a.s., which had lost its supplier for lock cover parts and needed to develop tools to produce the parts themselves. 3D printed tooling proved to be a promising option due to the very low purchase price of the machines, the low cost of tool production and the relatively quick tool production time. [1-4]

The second aspect of this article is to investigate in a broader sense the suitability of creating tools using the FFF 3D printing method for rapid prototyping purposes. This is because for prototyping in product development, the use of a 3D printed tool is a very cheap and fast option compared to the production of a conventional metal tool. Of course, due to the lower mechanical properties of plastics, this tool will be able to produce a much smaller number of parts before it is damaged, but for prototyping, the purpose of which is to create several test parts to verify the expected functionality of the part, the lower lifetime is not such a problem. Even if it is necessary to create more parts than a single printed tool can extrude, it will still be cheaper to print more tools than to produce a metal tool. This is assuming, of course, that the plastic tool, despite its inferior mechanical properties compared to metal, will be able to press the parts in question to the required quality. The stamping was made from DX56 sheet metal with a thickness of 0.7 mm. It is a lower grade of DX57 material. [1-6]

2. TEST OF MECHANICAL PROPERTIES

Prior to printing, tensile and compression tests were performed on PLA samples to verify the mechanical properties of this plastic and to determine how its properties change depending on the direction of printing and the volume and type of filler. The second reason for these tests was to obtain specific data, which was then imported into Simufact Forming to create a material model of PLA, as no plastic materials are found in the original libraries of this program. The samples were printed at a layer thickness of 0.3 mm with three perimeters, at a nozzle temperature of 210 °C and a bed temperature of 60 °C.

For the tensile test (**Figure 1**), a total of 9 types of specimens were created and classified according to two criteria. The first criterion was the orientation of the part with respect to the direction of printing, resulting in three types of specimens. Each type having print layers perpendicular to one of the Cartesian X, Y and Z axes. The second criterion was the type and amount of infill, where we tested samples with 50% infill and a rectilinear structure, 100% infill and a rectilinear structure, and 50% infill and a triangular structure. Three identical copies of each type were tested.

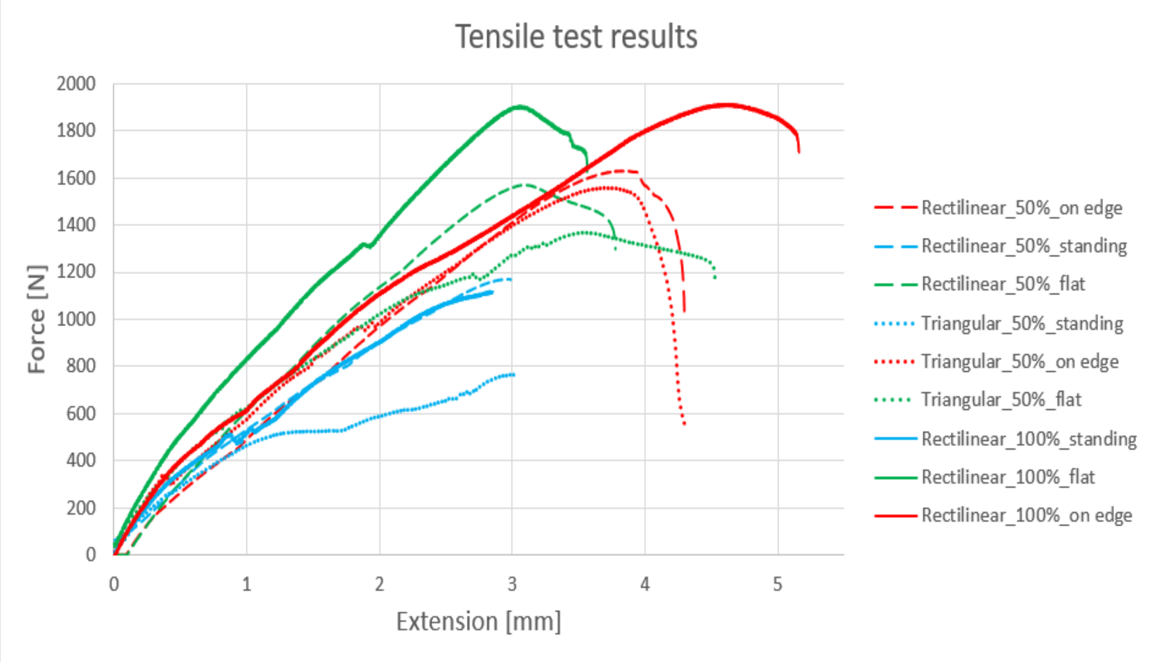


Figure 1 Tensile test results

For the pressure test, 12 types of samples were created (**Figure 2**), and 4 identical copies of each type were made, thus a total of 48 samples were tested. All samples were cube shaped with a 10 mm edge length. The samples differed in the amount of infill and the type of infill, which was chosen based on the percentage of infill. Samples with infill volumes of 10, 20, 30, 40, 50, 60, 70, 80, 85, 90, 95 and 100% were created. The gyroid type was used for the 10% infill volume samples. For the samples with 20 and 100%, the straight type was used and for the rest, i.e. 30 to 95%, the honeycomb type was used. The pressure test was carried out at a speed of 5 mm/min until the samples were compressed by a distance of 5.5 mm. As expected, the force required for deformation increased with increasing percentage of infill, however, it can be noted that while between 10 and 80% infill the strength increased significantly with each sample, above 80% the increase was much less significant.

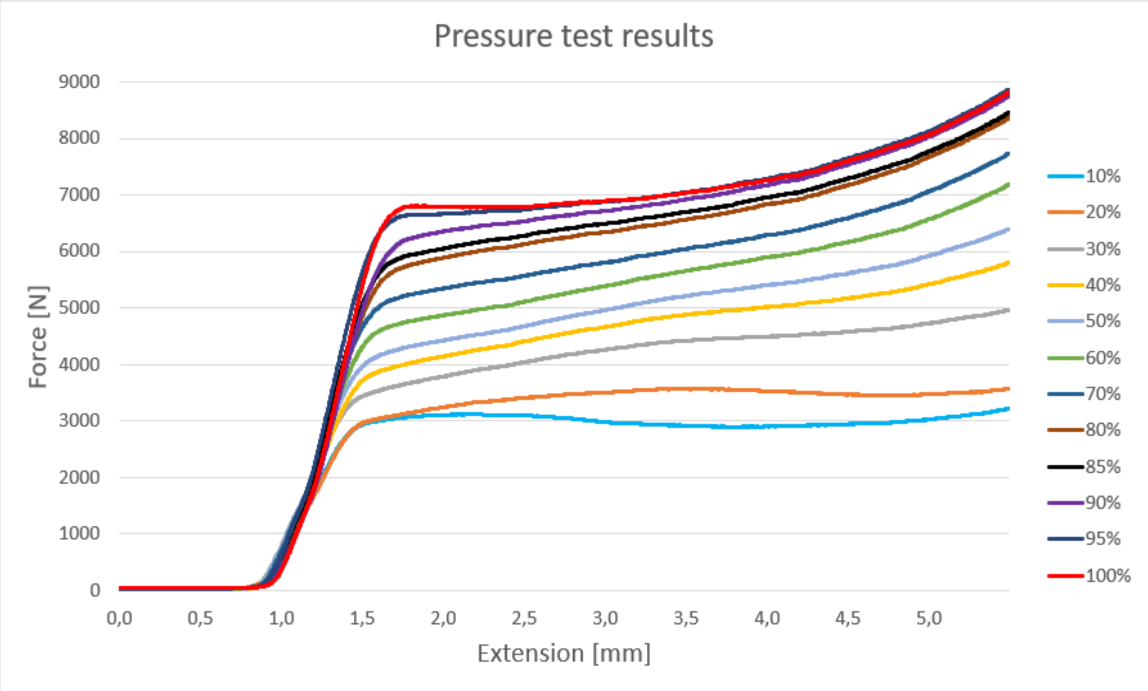


Figure 2 Pressure test results

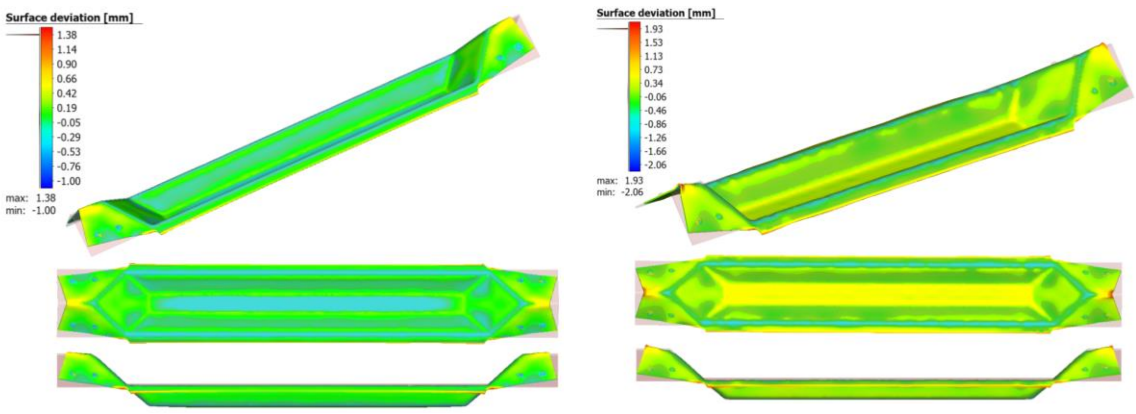
Based on the results of the pressure test, we selected an infill percentage of 80% for the tools because there was no significant improvement in mechanical properties above this volume. The tensile test showed that the worst mechanical properties in tension are found in samples that are printed standing up, i.e. have print layers perpendicular to the direction of the loading force. However, since the tools will be loaded in compression and not in tension, we decided to import the results from these samples into Simufact Forming software to define the PLA material model, and we also chose this printing orientation for printing the tools.

3. NUMERICAL SIMULATION

With the geometries ready, the next step could be taken, i.e. the creation of numerical simulations to test the forming process. The numerical simulations were created in Simufact Forming 2021, which uses the finite element method for calculations. The simulated forming process is performed by a single stroke, which takes place in the negative Z-axis direction by a distance of 23.5 mm at a speed of 6 mm/s. First, a simulation with rigid tools was created to confirm that this tool shape does not cause cracks or other defects. In a second step, simulations with deformable tools were created in order to exclude tool damage during the forming process. Below you can see the results of the surface deviation from the ideal shape, the effective plastic strain and the equivalent stress for both numerical simulations.

The result of the surface deviation (**Figure 3**) shows that the largest deviations from the ideal shape are at the edges of the cover, which are deviated in the Z-axis direction compared to the rest of the part. This problem could be solved by increasing the pressing force or by modifying the shape of the tools so that the incompleteness of the bending of these ends is compensated by a theoretical fold of a larger angle. However, the surface deviation in these areas of the stamping is not critical to the functionality of the part, and even such deflected edges meet the requirements. For the simulation with deformable tools, the deviations are much larger, with maximum of 0.55 mm in the positive direction and 1.06 mm in the negative direction. The distribution of the deviations on the surface is similar in both simulations except for the locations at the apex of the bends of the two edges of the cover. At these locations, the sharp bending had probably caused intense hardening and the deformable tool was not able to compress these sharp hardened edges.

Simulation with rigid tools | Simulation with deformable tools

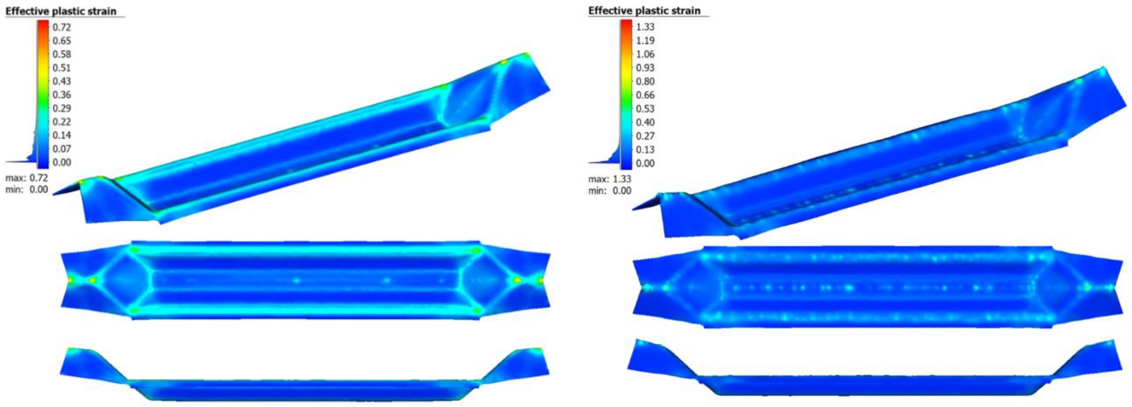


min: -1,00 mm max: 1,38 mm | min: -2,06 mm max: 1,93 mm

Figure 3 Surface deviation results

The effective plastic deformation in the simulation with rigid tools is greatest at the bends of the sheet metal, i.e. at the points where more intensive forming has taken place. The greatest strain is at the tops of the outermost parts of the cover. In the simulation with deformable tools, the effective plastic strain is 0.61 larger and there is not such a significant concentration of stress peaks at the bending points. Although the maximum strain is higher than in the previous simulation, most of the component surface is in lower regions of the colour scale than in the simulation with non-deformable tools (**Figure 4**).

Simulation with rigid tools | Simulation with deformable tools



min: 0,00 max: 0,72 | min: 0,00 max: 1,33

Figure 4 Effective plastic strain results

The distribution of the equivalent stress is similar for both simulations (**Figure 5**). In the rigid tool simulation, the stress maxima are slightly more concentrated at the bends of the part. For the simulation with deformable tools, the stress maximum is 38.92 MPa higher, but there are fewer areas of significant stress (in yellow). Neither the stress nor the strain reaches critical values at which cracks would form, so this tool shape and material could be recommended for the actual forming process.

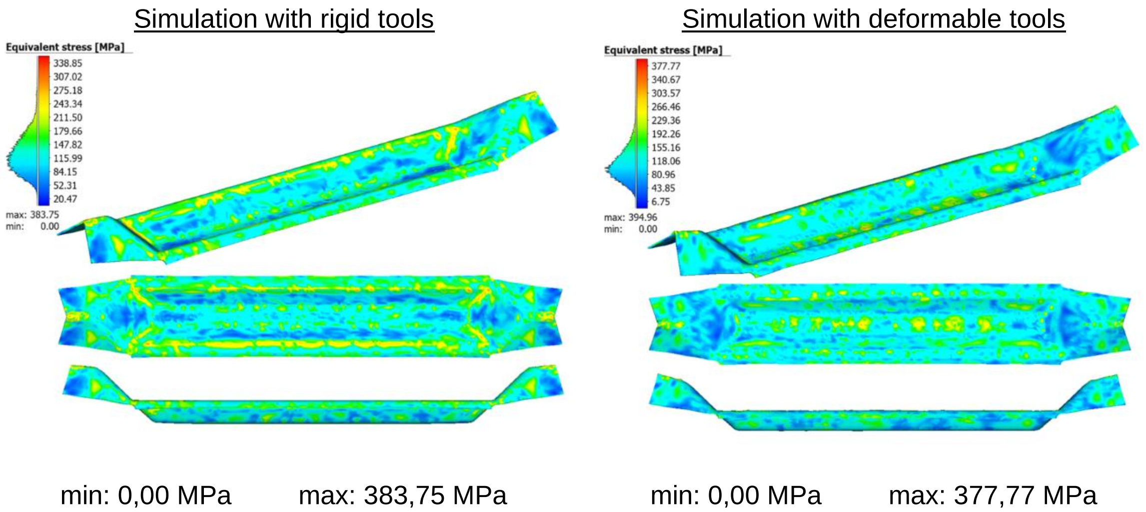


Figure 5 Equivalent stress results

The equivalent stress on both tools corresponds to the stress distribution on the stamping as seen in **Figure 6**. Critical areas on the lower tool are visible due to the insertion of the hardened sharp edge of the stamping. On both tools, the greatest stresses are on the edges involved in bending the blank to its final shape. It can be seen that the stresses on both tools are significantly less than the stresses on the blank.

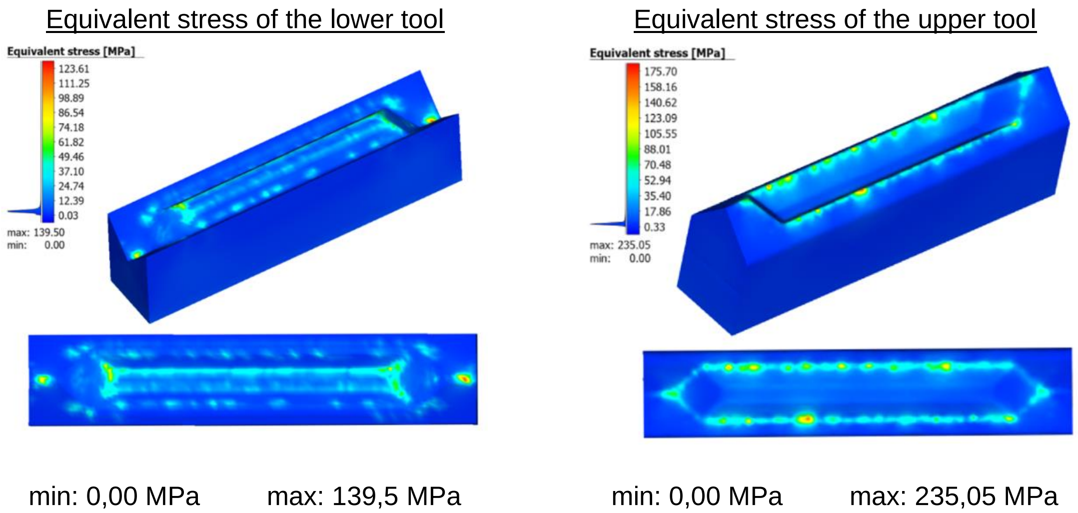


Figure 6 Equivalent stress of tools

The results of the plastic deformation of both tools showed that the tools can deform during the forming process, especially in the area of the corners of the lock cover. In other areas the deformations are elastic and should not cause deformation of the tools.

4. PRODUCTION OF TOOLS AND STAMPING

The tool models were imported into PrusaSlicer, which produced a hollow structure with 80% infill from the full models. Also, all printing parameters were defined in this step. The slicer then divided the solid part into layers and based on this, created the G code that the print head would move according to during printing. The tools were printed on a modified Ender 3 PRO printer. Using the printed tools, the first stamping was then made on a Holzmann WP45H hydraulic press. The shape of the stamping corresponds to the theoretical assumption, except for a slight asymmetry of the part, which was caused by imperfect centring of the stamping. This asymmetry does not impair the function of the part, as the main dimensional constraint, i.e. a door frame width of 27,15 mm, has been met. The part would be welded in this door frame in the next step.

However, the condition of the tools after forming was not good as seen in **Figure 7**. Forming process confirmed the results of the simulation, which claimed that deformation of the bottom tool would occur in the area of the corners of the lock cover. These indentations occurred at the locations where the simulation predicted the extremes of the actual stress on the tool. At these points during the forming process, the blank will form a sharp tip reinforced by the previous bending, which will then penetrate the tool due to the low hardness of the plastic. This is of course a negative phenomenon, both in terms of tool life and the shape of the stamping, which is unduly deformed in the area of the resulting groove, which reduces the accuracy of the part and increases the susceptibility to cracks in these areas. The pressed part can be seen in **Figure 8**.

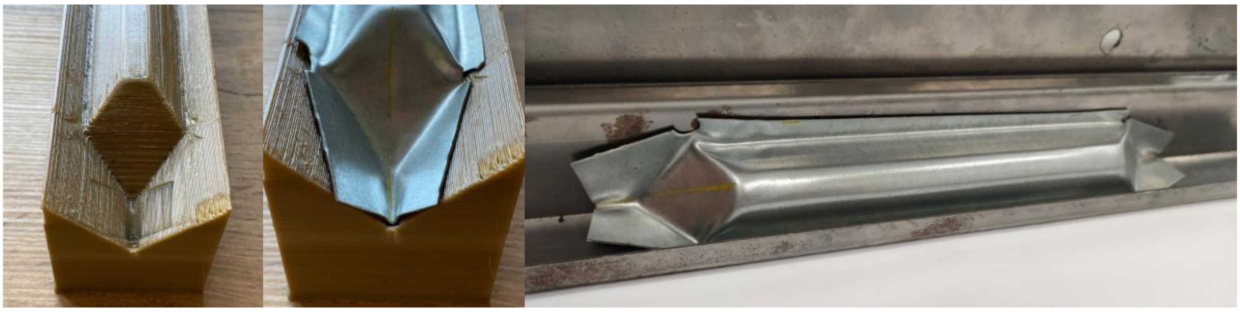


Figure 7 Damage of lower die with lock cover in door frame

Figure 8 Pressed part of the lock cover

5. CONCLUSION

Using the printed tools, we successfully managed to stamp a part of the lock cover that meets the geometric requirements. However, the tools were damaged during the stamping process, which prevents reuse. The tool was designed to handle the forces during forming, however, intense stresses were applied to small areas where the sheet metal penetrated the tool material, causing the tool structure to break through and create indentations at critical locations. Clearly, the issue of plastic tooling still needs to be investigated in more detail. A numerical simulation of a hollow structure with 80% volume generated by a slicer could provide a better understanding of the problem encountered. Also, it would be possible to print a tool with 100% infill and see if it will have better resistance to structure puncture. An experiment that printed the tool with different print layer orientations and compared the effect on tool deformation could provide useful results. Finally, the formation of dents on the tool could be resolved by inserting a sheet metal inlay into the printed part to compensate for the low surface hardness of the plastic at critical locations.

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Research of mechanical properties of new materials after technological processing.

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