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EXPERIMENTAL VALIDATION OF 3D ELEMENTS WITH CUSTOMIZED INFILL PATTERNS AND OPTIMIZED STRUCTURE

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Abstract: With the continuous and steady development of rapid prototyping technologies and the use of personalized 3D printed parts obtained through these technologies, their optimization was the next step in order to maintain or even reduce the amount of material needed to print the various elements/parts, while maintaining, if not increasing their strength, as well as optimizing the time required to print the same or a larger number of elements/parts. Based on the results obtained in the previous paper, [1], we proceeded to the experimental validation. In this paper, it is proposed to 3D print the samples previously researched, respectively, the model with a predefined infill structure and the sample with an infill structure optimized to the expected stresses to occur during a normal exploitation and having an „ogive" type rib. Based on the stresses that are expected to occur during a normal operation, the laboratory experiments will be videotaped and the photo images extracted from these video materials obtained after the tests, will be use to check the possible deformations that appear on the samples. The deformations obtained by subjecting them to compression are then analyzed using the GOM Inspect and GOM Correlate programs. The favorable results will contribute to the development of an algorithm that will allow the generation of optimized infill patterns for different types of stresses expected to appear and possibly applying the custom infill structure concept to other rapid prototyping technologies. The rapid prototyping technology used in this paper is FFF/FDM (Fused Filament Fabrication/Fused Deposition Modeling), with an Ultimaker 3 Extended 3D printer.

Key words: Rapid Prototyping, Infill Patterns, 3D Printing, FFF/FDM, GOM Inspect, GOM Correlate.

1. INTRODUCTION

After fulfilling the growing demand for custom elements that are made using rapid prototyping technologies, because of the fact that 3D printed custom parts became a normal use in different industries, various opportunities and challenges appeared, such as: decreasing the printing time, increasing the strength of the parts or even keeping or increasing the strength of the 3D printed parts while using the same amount of raw material(s) and others [2-3].

Liu et al. (2023) use the path planning in order to achieve tunable and desirable performance from a weight point of view, [4].Yao et al. (2021), propose a 3D weaving deposit method to interlock and embed the neighbor slicing planes to improve the mechanical linkage within the layers, [5].

Ambati et al. (2022) developed a study regarding the influence of 3D printing parameters, as infill density and infill pattern, onto the mechanical properties of PLA printed parts, [6].

Koske et Ehrmann (2021), published a report based on previous study, investigating optimized infill designs which avoid breaking in 3-point bending tests for multiple repeated destruction and recovery cycles, [7].

Clausen et al. (2017), proposed a 3D topology optimization for designing shell structures with a porous or void interior resultingin significantly more robust structures than completely solid structures optimized under the same conditions, [8].

Schmitt et al. (2020), present experimental results and design considerations for 3Dprinted ABS components with non-solid infill sections. The paper experimentally determines and quantifies optimal infill configurations for ABS printed parts, [9].

Godec et al. (2022), analyse the influence of infill pattern on 3D printed parts compression properties, [10].

Tanveer et al. (2022), publish review of additive manufacturing techniques, focusing on the FFD and its process parameters, mainly infill pattern and infill density and its effect on the physical behaviour of 3D printed parts, [11].

In our paper it is proposed to validate through laboratory experiments if the 3D printed parts without and with a customized infill pattern or in other words with an infill structure adapted to the expected load that will appear during normal operation will present promising results [1, 12, 15].After printing the samples, using FFF/FDM technology and a 3D printerUltimaker 3 Extended, the samples underwent the same lab test to firstly see on a individual level what load they were able to sustain and ultimately to compare them and see which one present better results [14].This comparison allows the verification of the fact that the improved sample can ensure an increased resistance under the condition of using the same volume of material compared to the model with a predefined structure [13].In addition, conclusions can be drawn regarding the assured resistance of various infill patterns and the time required to print the parts. The favorable results create the premises of developing an algorithm that can allow the generation of some infill models optimized for different types of loads and eventually the possibility of applying the same concept of custom infill structure for other rapid prototyping technologies.

2. MATERIALS AND METHODS

The filament used for printing the parts was polylactic acid (PLA), a thermoplastic polyester made from renewable resources such as corn starch, tapioca roots or sugar cane, making it a very easy to use material.
We use the material, Inofill 3D, with a diameter of 2.85 mm ± 0.1 mm, colour signal yellow, with an indicated working temperature range of 200 – 220°C and with a weight slight above 500 grames.
Ultimaker 3 Extended is one of the most reliable dual-extrusion 3D printers available. Capable of carrying out complex projects and improved 3D printing performance, thanks to its unique automatic nozzle lifting system, professional combinations of building and support materials and interchangeable printing cores[16-17].
In order to make the comparison between the unoptimisedpart and the optimised part, both of them were: designed in CATIA as a solid model, exported in ".stl" format, inserted in a slicing program named Cura version 4.12.1, where a partial infill of 10% and grid-type infill were applied (Figure 1), with a thickness of all the walls of 2 mm and the thickness of the deposited layer of 0.2 mm[1].
The comparison regarding the deformation under the compressive force assumed to occur during normal operation was made by subjecting both samples to the same lab test.
The unoptimisedsample was the first one to be subject to the compression test. In Figure 1 the sliced unoptimisedsample is presented.
The dimensions of the part are 20×20×40 mm.

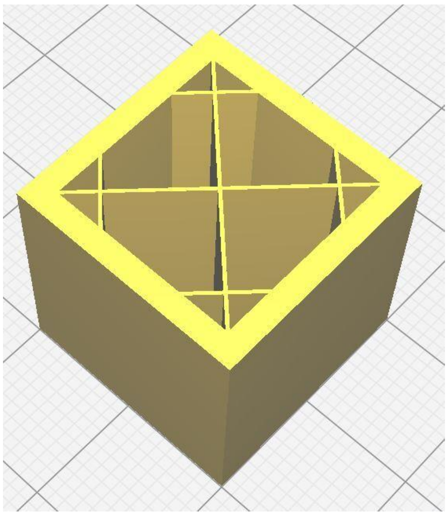

Fig. 1. Sliced view of the unoptimisedsample

A similar model was designed in CATIA, having the overall dimensions the same as the previous sample, 20×20×40 mm, but having the ribs adapted to the stress to which the sample will be subject during normal operation. The custom ribs have an ogive shape (Figure 2).
The internal structure of the sample was optimized by creating ribs in the form of ogives. The idea of applyingthese ribs started from the fact that the respective shape is recognized as the shape that provides the greatest resistance to compression. The volume of the ribs was calculated so as to correspond to the same degree of infillas the initial ribs, respectively 10%.

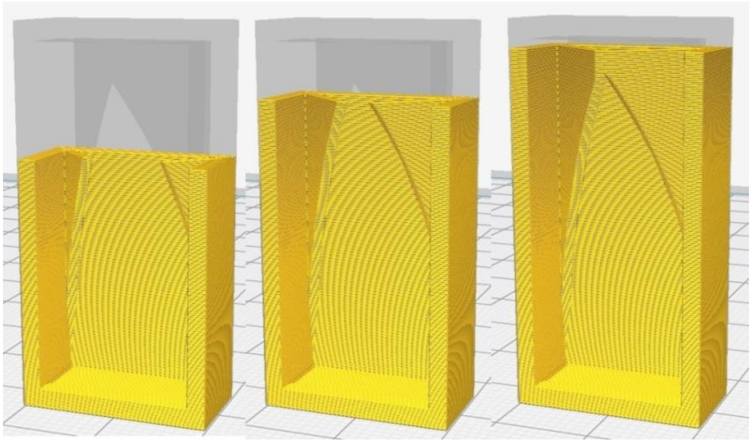
Fig. 2. Sliced views of the optimised sample

After printing the samples, they were spray painted by hand in order to make a cloud of points pattern on the side of each sample, they were placed (one at a time) inside the compression test device and two weights were placed one by one on the device and afterwards they were taken off (following the reverse steps of placing them on the device). The laboratory testswererecorded and multiple images were taken from the video tape in order for them to be imported in GOM Correlate and check the actual data related to the real resistance of eachpart.

3. RESULTS AND DISCUSSION

In GOM Correlate the main following steps were taken: creating the surface of the parts by selecting it and using the command Epsilon Y. The software will automatically compute and will display the changes that the sample will occure based on the number of images selected in this case.
In the figures below the comparison of the unoptimized samplewhen the maximum load is present and after it is no longer present can be seen. (Figure 3)

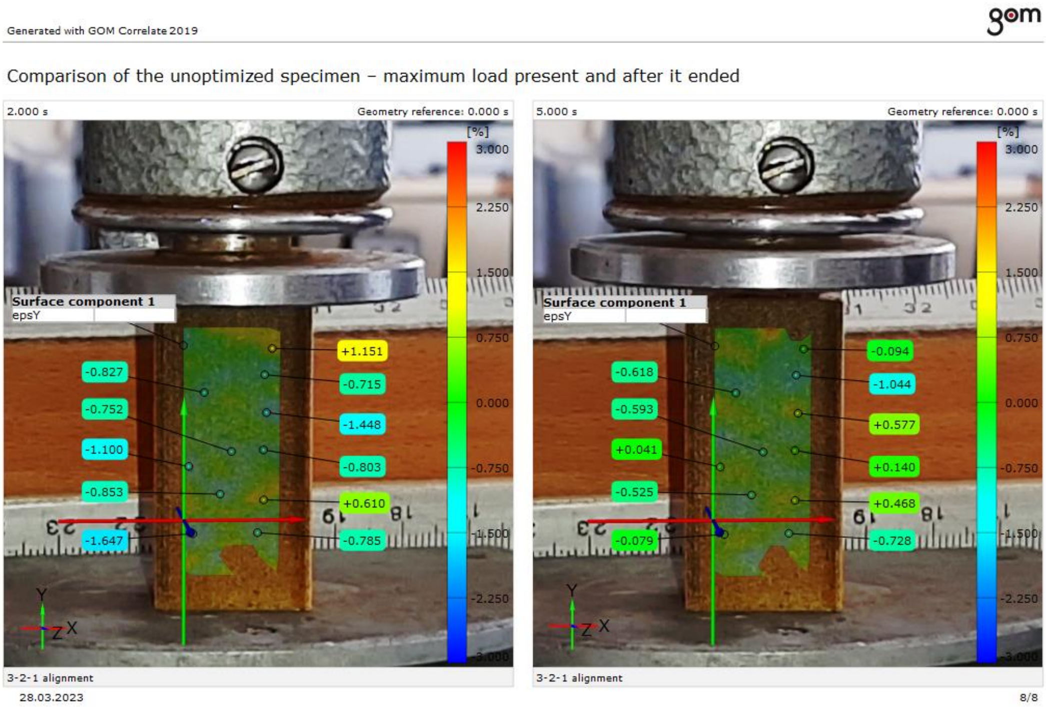

Fig. 3. Comparison of the unoptimized sample – maximum load present and after it ended

As it can be seen in Figure 3, the unoptimized sample under the maximum load has a reduced resistance to compression and after the load stops the sample will present some minor deformations.
In the figures below the comparison of the optimized sample when the maximum load is present and after it is no longer present can be seen, (Figure 4).

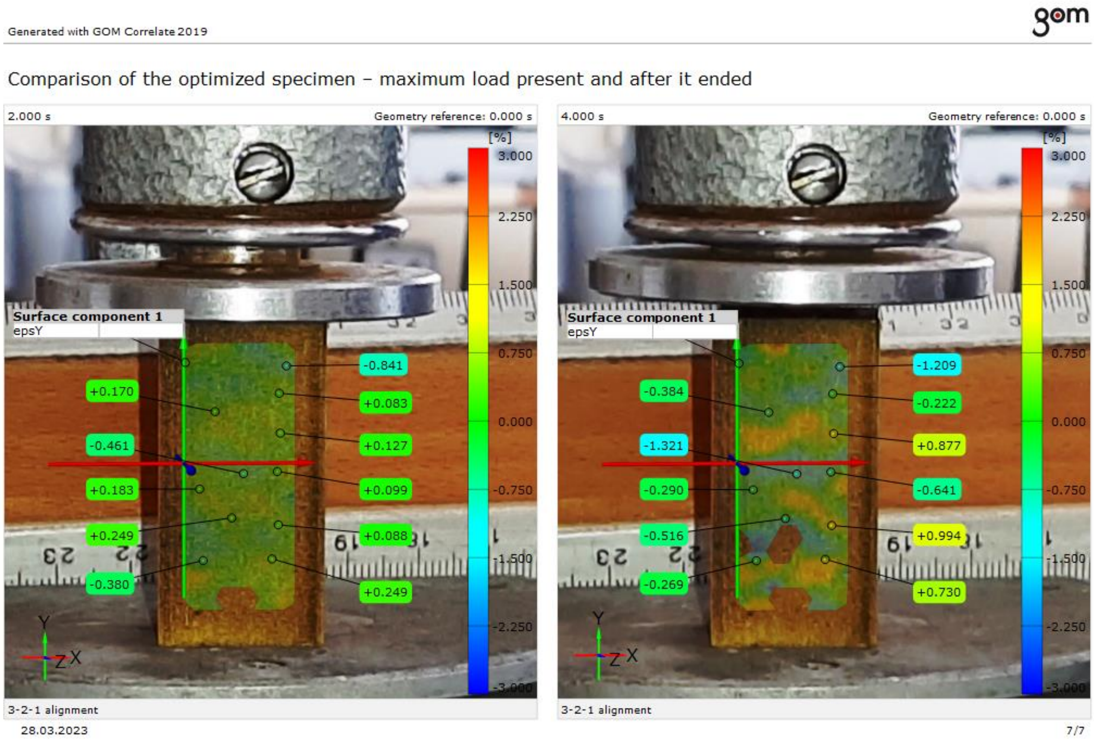

Fig. 4. Comparison of the optimized sample – maximum load present and after it ended

In Figure 4, the optimized sample has an increased resistance to the load when is subject to it and after it stops. In the figure below the comparison between the unoptimized sample and optimized samplewhile the maximum loadis present are illustrated side by side (Figure 5).

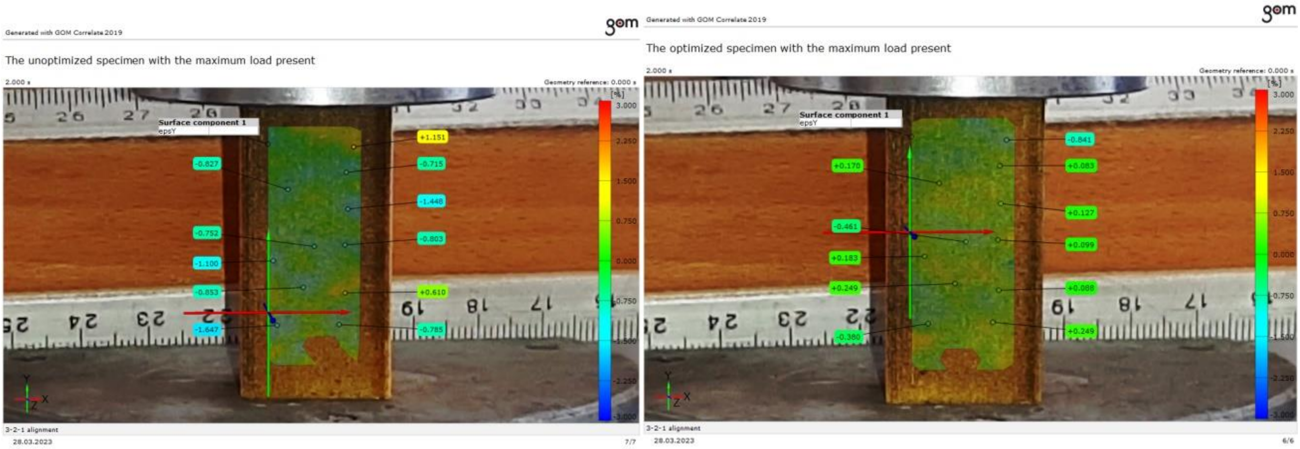

Fig. 5. Comparison between the unoptimized sample and optimized sampleunder the maximum load

The values of the displacements in the selectedpoints on the surface of both samples, are centralized in Table 1. The values of the displacements allow us to conclude that the deformations in the sample with the optimized infill structure are smaller than in the initial sample. Column 3 of Table 1 shows the displacements measured in various points, displacements given in absolute value.

Column 4 of the same table shows the relative reductions in displacements for the points measured on the surface of the sample with the optimized structure compared to the sample with the predefined structure.

Table 1. Comparison between the unoptimized and optimized samples under the maximum load

No. Crt.	Values for the unoptimized sample[mm]	Values for the optimized sample[mm]	Absolute improvement of displacement[mm]	Relative improvement of displacement[%]
1.	-0.827	0.170	0.657	3.865
2.	-0.752	-0.461	0.291	0.631
3.	-1.100	0.183	0.917	5.011
4.	-1.647	-0.380	1.267	3.334
5.	1.151	-0.841	0.310	0.369

6.	-0.715	-0.083	0.632	7.614
7.	-1.448	0.127	1.321	10.402
8.	-0.803	0.099	0.704	7.111
9.	-0.853	0.249	0.604	2.426
10.	0.610	0.088	0.522	5.932
11.	-0.785	0.249	0.536	2.153

4. CONCLUSIONS

By optimizing the structure of the sample for the stress expected to be subject to, the "ogive" shape ribs aim to increase the strength of the sample while maintaining the condition of using the same volume of material [1]. This increase in strength allows the shape and external dimensions of the sample to be preserved, as well as the weight and volume of material used. The possibility of modifying the infill structure is a feature of additive manufacturing technologies and paves the way for material savings, while maintaining the functional characteristics of the 3D printed parts.

Comparing both samples that were subject to the same compression test, it clearly proves that the optimized sample has an increased resistance to the stress expected to occur during a normal exploitation as it is visually presented in Figure 5 and back-up by the values inside Table1.

The displacements measured in the same points on the surfaces of the two samples demonstrated that the displacements are smaller in the case of the sample with the optimized infill structure (with ogive-type ribs), in the conditions where the degree of infill remained constant (10%), as well as the force with which the samples were stressed.

This does allow us to conclude that it is possible to imagine an optimal infill structure for each case of loading for a part, which allows maintaining the weight of the part and the volume of material used to make it in the conditions of growth resistance to the loads that appear in operation.

During the compression test the ogive shape sample has a tougher structure and does not present any outstanding deformations, proving that the optimized sample even if a similar amount of raw material was used for printing this type of sample by simply having an optimized infill structure the durability improved significantly.

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