RESEARCHES REGARDING THE STUDY OF THE DIMENSIONAL PRECISION OF THE GEOMETRICAL ELEMENTS OF TYPE SHAFT-HOLE OBTAINED BY FUSED DEPOSITION MODELLING

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Abstract: *This article presents some researches concerning the dimensional precision of the geometrical elements of type shaft-hole obtained by fused deposition modelling. In the paper, the FDM technology issues are exposed and the need to have a vision about the influence of some technological and geometrical parameters on the precision of the geometrical surfaces, internal or external. Firstly, two virtual prototypes were maids in Catia V5, one for experiment the influences for the internal surfaces and another for the external surfaces. After that, virtual prototypes were imported in the machine software in order to obtain the prototyping code. Based on the code obtained with the printer software, the parts were prototyped, used Ultimaker Tough PLA material. All elements were measured with a caliper and a database was created. The results were interpreted in order to establish the influence on the dimensional precision of the geometrical elements.*

Keywords: *dimensional precision, FDM, shaft-hole, 3D Printing*

1. INTRODUCTION

FDM is a process of making parts by 3D printing, using a continuous filament of thermoplastic material. In general, the thermoplastic material is located on a coil and advances toward a heated print end to the deposit area. The entire process is managed by a controller to ensure the desired shape is achieved.

2. FDM TECHNOLOGY ISSUES

Although it seems simple, FDM technology is quite complex. It is based on thermomechanical processes, on high speed and precise displacements [1, 2, 3], on materials with well controlled characteristics [4, 5, 6], etc. This complexity causes FDM technology to have a number of problems that are still unresolved, like: clogged extruder, layer shifting, weak infill, grinding filament, material stringing, overheating, inconsistent extrusion and so on [7].

In the experiments carried out at the University of Pitesti, we found, besides the problems presented in the specialized literature, a number of problems, such as: at the shaft-type parts, printed vertically, a significant decrease in dimensional accuracy as the height of the piece increases, reaching critical heights over which the part was compromised.

In order to determine the accuracy of the FDM process, an experiment based on the printing of two parts plates, one with holes and the other with cylinders (shafts) of different diameters, randomly arranged in order to avoid making patterns that would introduce influences in the studied phenomenon.

3. THE EXPERIMENT

The experiment was realized in the Design of Product Laboratory, at the University of Pitesti. First of all, two parts was created in CATIA V5, in order to have a virtual model, figure 1. The virtual models has saved in "*.stl*" format and imported in the printer software.

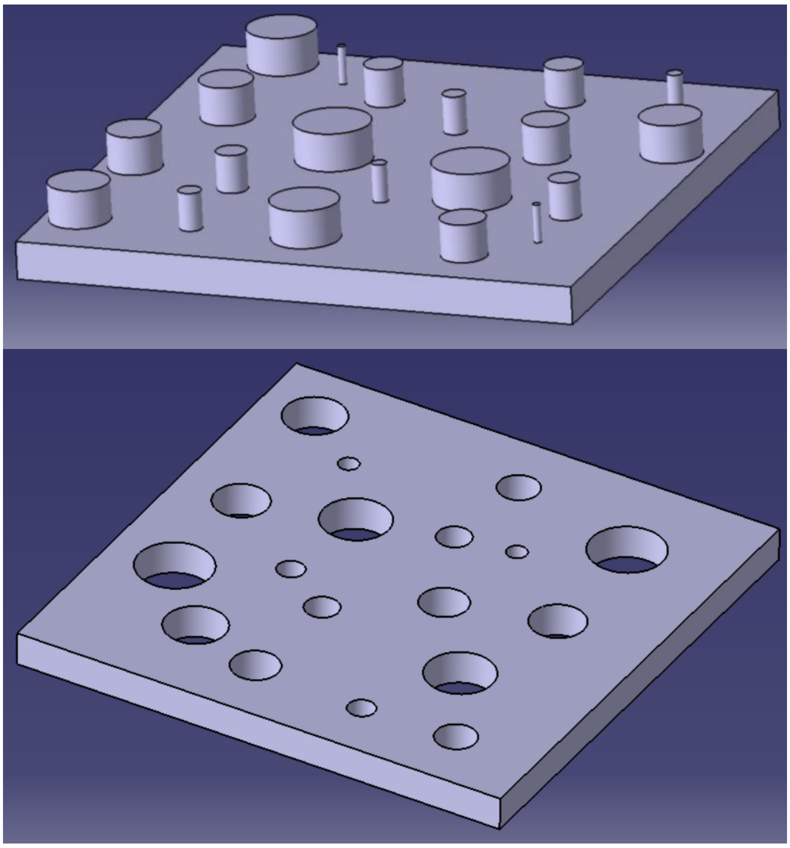

Figure 1: The virtual model of the parts in CATIA V5

The printing parameters are presented in table 1.

Table 1: The printing parameters

Parameter	Value
Layer height	0,1 mm
Infill density	60 %
Printing temperature	210°C
Build plate temperature	60°C
Print speed	45 mm/s

The material used for printing was Ultimaker Tough PLA. In table 2 the main characteristics of material are presented.

Table 2: The Ultimaker Tough PLA characteristics

Parameter	Value
Diameter	2.85 ± 0.05 mm
Tensile modulus	1,820 MPa
Tensile stress at yield	37 MPa
Tensile stress at break	37 MPa
Elongation at yield	3.1%
Elongation at break	3.1%
Flexural strength	78 MPa
Flexural modulus	2,490 MPa
Izod impact strength, notched (at 23 °C)	9 kJ/m^2
Hardness	79 (Shore D)
Melt mass-flow rate (MFR)	6 - 7 g/10 min
Glass transition	62°C
Melting temperature	151°C

For each diameter of the elements (hole/cylinder) two entities was realized. The measurement was realized with a caliper 0-150 mm, and the measurement mode is shown in figure 2: six measurements, three on the first entity and three on the second.

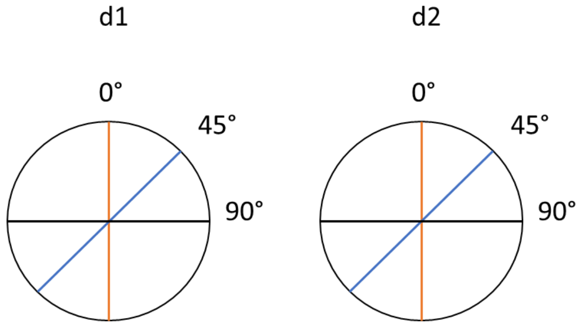

Figure 2: The measurement mode of the entities

4. RESULTS

In the case of the part with holes, after measurements, was recorded six values for each diameter of the hole. D-mean was calculated, relative deviation and the variance, table 3.

Table 3: The values for the part with holes

Designed diameter [mm]	D1-0	D1-45	D1-90	D2-0	D2-45	D2-90	D-mean	Relative deviation	Variance
6	5,73	5,8	5,55	5,78	5,51	5,77	5,69	5%	0,08
8	7,67	7,78	7,51	7,68	7,71	7,65	7,67	4%	0,04
10	9,55	9,63	9,55	9,68	9,62	9,93	9,66	3%	0,10
12	11,47	11,8	11,48	11,69	11,67	11,80	11,65	3%	0,11
14	13,51	13,6	13,58	13,7	13,72	13,64	13,63	3%	0,03
16	15,41	15,69	15,45	15,7	15,62	15,78	15,61	2%	0,11
18	17,66	17,6	17,53	17,58	17,61	17,58	17,59	2%	0,01
20	19,5	19,62	19,62	19,69	19,65	19,63	19,62	2%	0,02
22	21,63	21,76	21,59	21,63	21,66	21,70	21,66	2%	0,02

In figure 3, the relation between relative deviation for the diameter of the holes and their diameters is presented. Also, the equation and the mean squared deviation are determined.

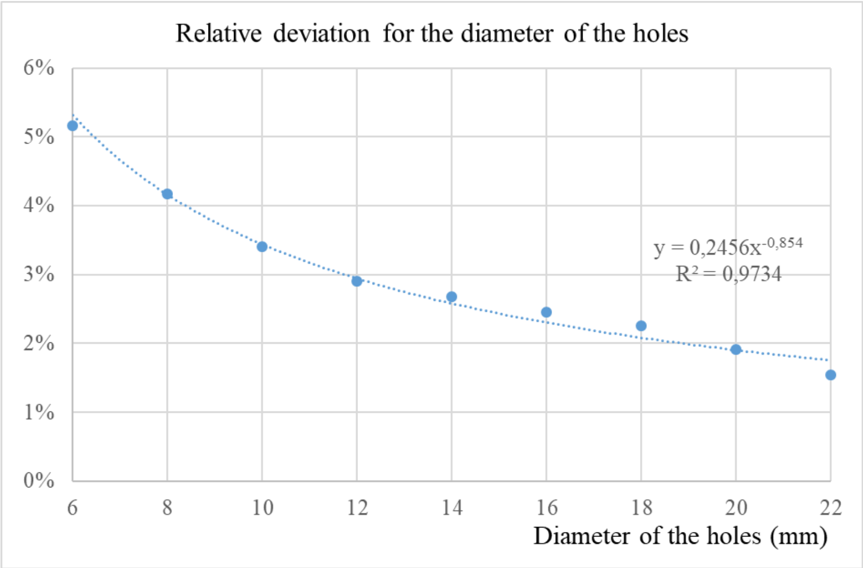

Figure 3: Evolution of the relative deviation with diameter of the holes

In the case of the part with cylinders, after measurements, was recorded the same type of values, table 4.

Table 4: The values for the part with cylinders

Designed diameter [mm]	d1-0	d1-45	d1-90	d2-0	d2-45	d2-90	d-mean	Relative deviation	Variance
2	2,25	2,32	2,47	2,42	2,31	2,48	2,38	19%	0,04
4	4,19	4,33	4,28	4,26	4,43	4,32	4,30	8%	0,03
6	6,15	6,28	6,25	6,26	6,18	6,16	6,21	4%	0,02
8	8,07	8,30	8,06	8,25	8,11	8,23	8,17	2%	0,05
10	10,01	10,16	9,98	10,29	10,06	10,08	10,10	1%	0,06
12	11,96	12,23	12,02	12,24	12,03	12,08	12,09	1%	0,07
14	14,06	14,20	14,02	14,20	14,13	14,11	14,12	1%	0,03
16	16,00	16,16	16,04	16,25	16,20	16,05	16,12	1%	0,05
18	17,98	18,25	18,02	18,21	18,06	18,15	18,11	1%	0,06
20	20,02	20,33	19,99	20,30	20,11	20,22	20,16	1%	0,10

In figure 4, the relation between relative deviation for the diameter of the cylinders and their diameters is presented. Also, the equation and the mean squared deviation are determined.

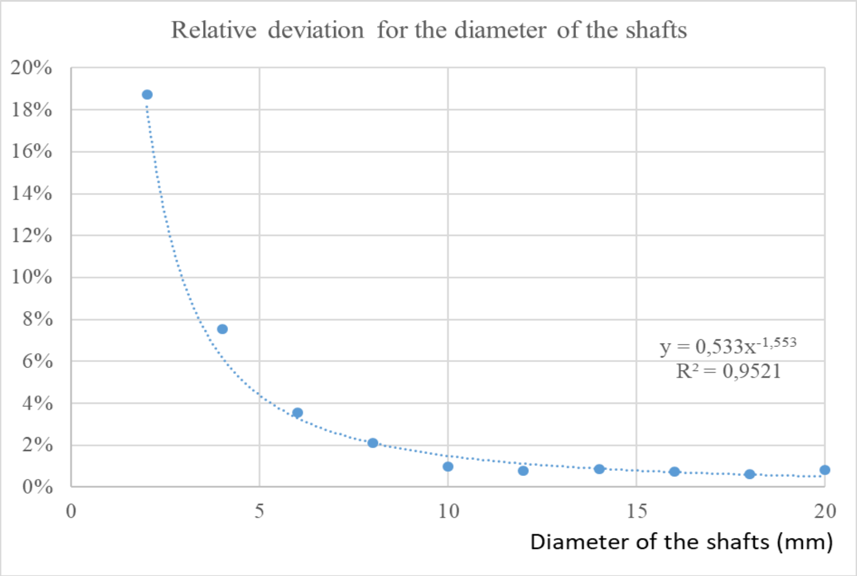

Figure 4: Evolution of the relative deviation with diameter of the cylinders

For the designers, it is interesting to know how is the designed values in case of parts with holes or shafts, in order to obtain a certain value of a diameter after 3D printing.

Taking into account the values obtained in both cases for the average diameters obtained by 3D printing, depending on the designed diameter, two functions could be established allowing the appropriate choice of the designed diameters to obtain certain values of them.

In figure 5, the relationship between real diameter of the shaft and the designed diameter is presented and the case of hole is presented in figure 6.

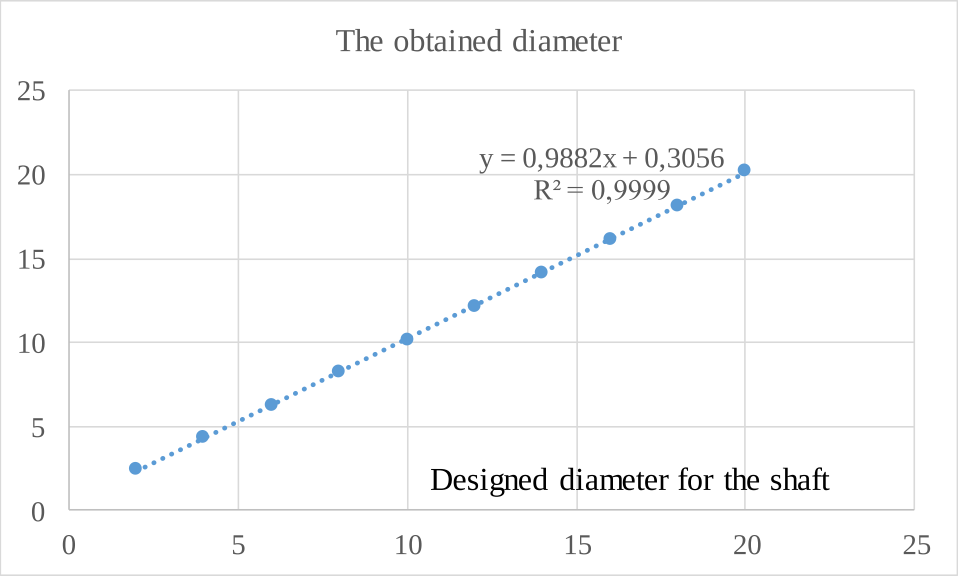

Figure 5: The relationship between real diameter of the shaft and the designed diameter

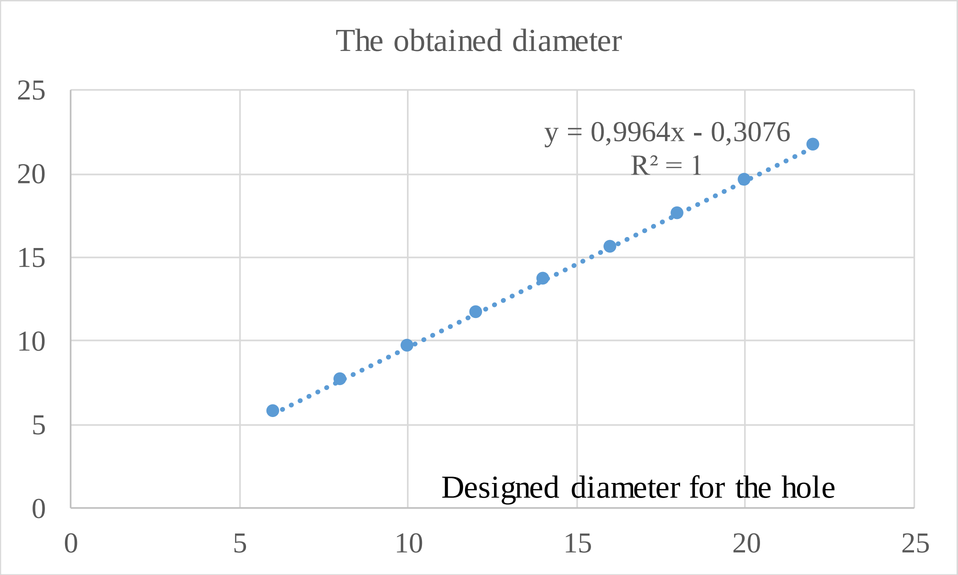

Figure 6: The relationship between real diameter of the hole and the designed diameter

5. CONCLUSIONS

In case of holes, the obtained diameters are a little small compared to the designed diameters, but in the case of shafts this are a little bigger compared with those designed.

The general conclusion is that the parts made by 3D printing technology exhibit dimensional deviations from the designed parts. As a result of the results of this study, the relationships presented in the paper can be applied, during the design phase, so that we can obtain pieces with dimensions as close to the desired ones.

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