

IMPACT OF STRENGTHENING FLUIDS ON ROUGHNESS OF 3D PRINTED MODELS

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For some applications, 3D printed parts usually do not have satisfactory mechanical properties, so to broaden their usage, additive technologies should be combined with the well-known metallurgical processes, such as investment and others casting techniques. 3D printing developers persistently introduce new base materials and strengthening fluids which may cause different surface roughness. Therefore, in this paper, the authors have tested the roughness of 3D printed samples strengthened with common, but also with alternative fluids. Measurements proved that fluids do have significant influence on the roughness.

Keywords: surface roughness, strengthening fluids, 3D printing

INTRODUCTION

By engaging 3D printing for the accurate production of patterns for investment casting, the problems with wax pattern temperature shrinkage and expanding are mostly avoided [1, 2]. Additionally, when applying some of the additive technologies, the basic material for object building is not recyclable, or the process of recycling has not been developed yet, thus the process of ceramic shell dewaxing is not critical and complex, as with the use of classic wax patterns where the consideration about the impurities in wax should be taken care of, so the wax could be used multiple times [3].

The objects built with investment casting (IC) have much better mechanical properties compared to the objects made with some of the additive technologies (AT). The overall expenses in investment castings greatly depend on the necessary finishing operations which place the castings in measure of tolerance. In order to reduce the overall costs of production, there is a need to establish a connection between the surface roughness of object built with AT, and the necessity for classic technologies for finishing operations [3 - 6]. What kind of surface quality can be achieved for the models printed on a 3D printer? Could it comply with the user's requirements so that the 3D printed models could have a wide application?

Does the quality of the surface change if it inflicts some reinforcements? All these questions arose especially in the last few years, as the technology of 3D printing advanced, as well as the increased use of such objects in everyday life [7 - 9].

In this paper, the researchers tried to answer these questions with the study that was conducted on the specimens printed on a 3D printer. The base material for the models used in our study was plaster-based and the

models were reinforced with different infiltrates. Then we made roughness measurement on the original raw specimens using a suitable device, and again on the same specimens after sanding.

METHOD

The samples used in this study were printed on 3D Systems', previously Z Corporation 3D printer model ZPrinter 310 [10]. It is a low-cost monochrome 3D printer suitable for education or for small and medium sized companies. The printer firmware version was 10.158, and the test samples were prepared in a printer software ZPrint version 7.10.

The considered 3D printer combines a layered approach from the rapid prototyping technologies and the conventional ink-jet printing. It prints a binder fluid through the conventional ink-jet print head into a powder, one layer onto another, from the lowest model's cross-section to the highest (Figure 1). After printing,

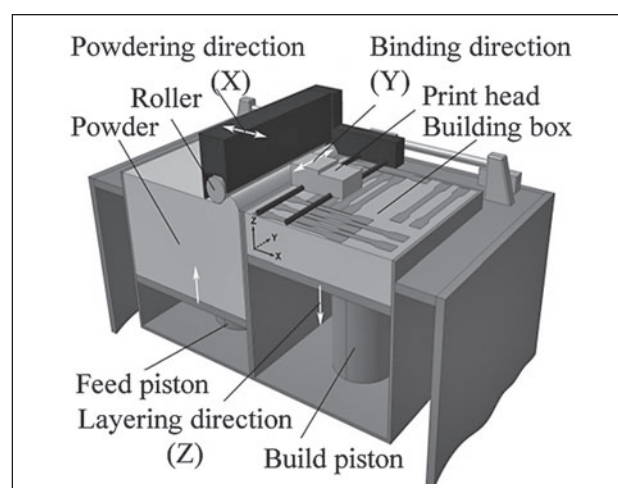


Figure 1 3D Printer - section view

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the printed models are dried in the building box, then removed from the powder bed, depowdered by compressed air, dried in the oven and infiltrated with the strengthening fluid for the maximum strength.

The base material, from which the samples were printed, was the ZP150 powder [11]. The following strengthening fluids were used: water based Epsom salt water solution; wax; acrylic resin Protektine [12]; cyanoacrylate Loctite 406 and epoxy resin Loctite Hysol 9483. One set of 3D printed samples was left without the strengthening fluids. Standard shape type 1A of tensile test samples was selected in order to reuse the samples in the planned further researches [13]. A device used for roughness measuring was Rugosurf 10G with the related equipment for calibration and with the software for data processing [14].

Before the measurement, the device was calibrated to the corresponding standards and connected to a computer with the installed software Rugosoft 10G [15].

Roughness measurements were performed on every specimen, three times for each observed side of sample. The observed sides were named conveniently as: Front, Top and Side, as shown in Figure 3.

In doing so, the roughness on the top, i.e. the greatest upper side was measured in both longitudinal (L) and transversal (T) directions. On the device, the selected standard was ISO4287/JIS B0601 for measuring roughness with the cut-off length λ of 0,80 mm and the

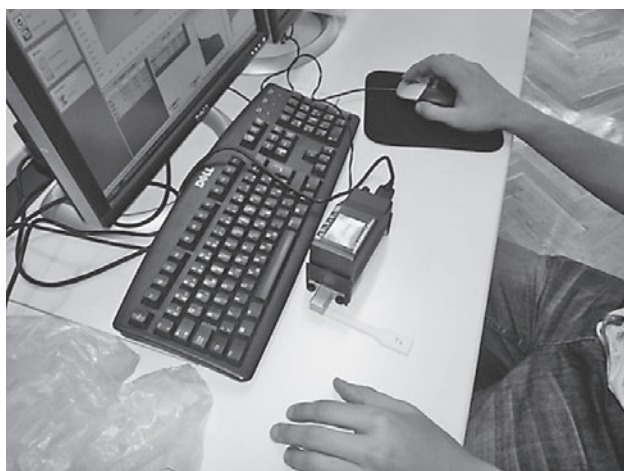


Figure 2 Measurement procedure

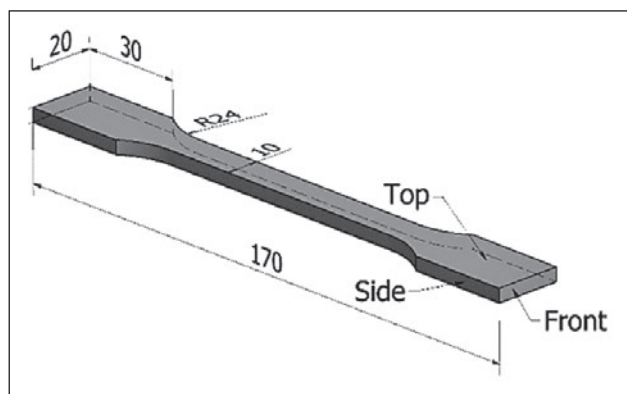


Figure 3 Test sample and side naming

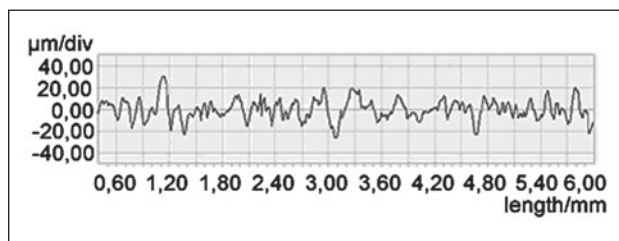


Figure 4 Roughness profile for sample N2 on top side in longitudinal direction

number of displacements 7. Such a combination gives an overall length of 5,6 mm on which the roughness was measured, Figure 4.

After the initial measurements, the raw samples were sanded with 800 grit sandpaper and the complete measurement process was repeated.

RESULTS

The results of measurements are as follows: the maximum height of profile R_z and the average deviations from the estimated profile R_a . The values presented in the following tables and following graphs are the arithmetic mean of the results obtained by three measuring processes for each sample and each side.

Table 1 Roughness of raw samples / μm

None		Top L	Top T	Side	Front
	R_a	8,43	8,03	15,88	14,72
R_z	46,03	44,55	76,93	73,46	
Water		Top L	Top T	Side	Front
	R_a	11,70	7,91	15,12	20,83
R_z	62,52	44,28	74,60	95,29	
Wax		Top L	Top T	Side	Front
	R_a	7,10	6,84	12,50	13,64
R_z	39,14	35,14	62,09	64,25	
Acrylic resin		Top L	Top T	Side	Front
	R_a	7,42	11,82	15,35	17,54
R_z	37,51	57,61	73,87	83,75	
Cyanocryl.		Top L	Top T	Side	Front
	R_a	5,32	6,65	8,29	9,47
R_z	25,42	32,16	38,28	45,32	
Epoxy resin		Top L	Top T	Side	Front
	R_a	11,72	9,47	16,01	18,49
R_z	62,33	49,85	75,59	88,96	

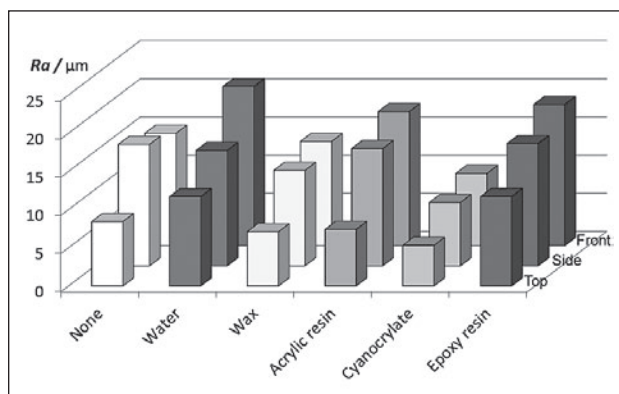


Figure 5 Average roughness of raw samples

Table 2 Roughness of sanded samples / μm

None		Top L	Top T	Side	Front
	R_a	13,75	12,89	9,40	11,20
Water		Top L	Top T	Side	Front
	R_a	6,18	4,23	12,44	12,99
Wax		Top L	Top T	Side	Front
	R_a	5,84	3,17	5,88	5,17
Acrylic resin		Top L	Top T	Side	Front
	R_a	6,64	8,31	13,65	10,80
Cyanocryl.		Top L	Top T	Side	Front
	R_a	4,75	7,48	9,43	3,92
Epoxy resin		Top L	Top T	Side	Front
	R_a	6,50	3,89	10,38	6,18
		Top L	Top T	Side	Front
	R_z	35,01	35,01	22,60	33,97

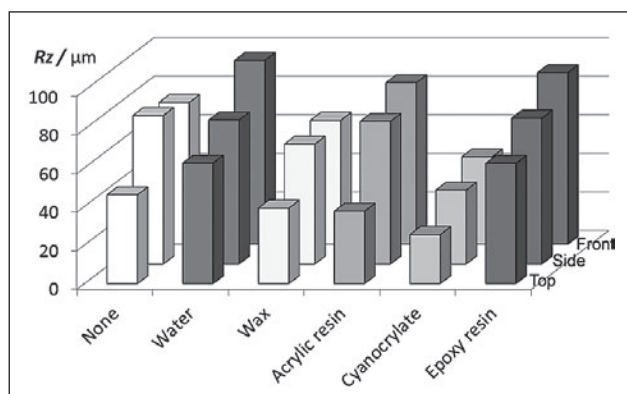


Figure 6 Maximum profile height of raw samples on top face in longitudinal direction

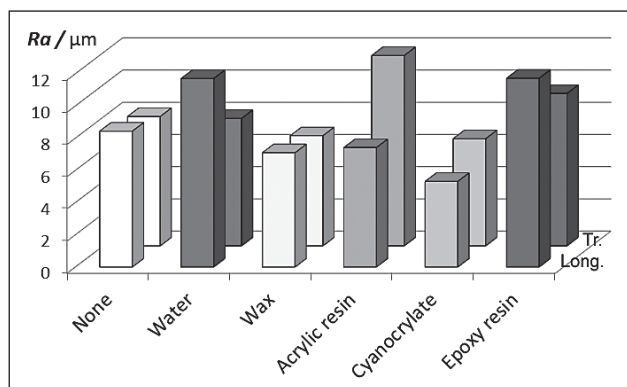


Figure 7 Average roughness of raw samples on top face in longitudinal and transversal directions

DISCUSSION

In the next few charts, we can see the relationship of measured values due to the variety of reinforcements and surface condition (raw/sanded).

A comparison of average roughness of raw samples on the top face in the longitudinal and transversal directions reveals significant deviations for all samples, except for those strengthened with wax. The following charts show a comparison of values R_a and R_z for the sanded samples.

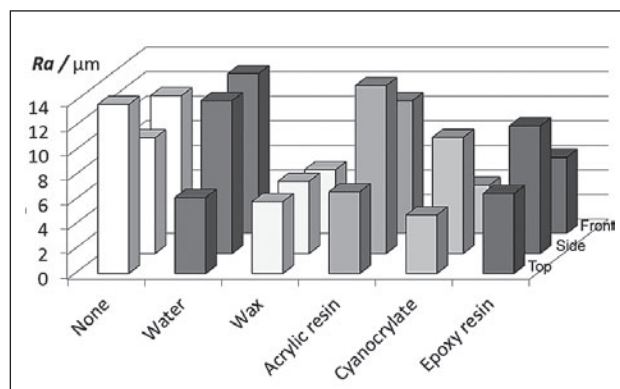


Figure 8 Average roughness of sanded samples

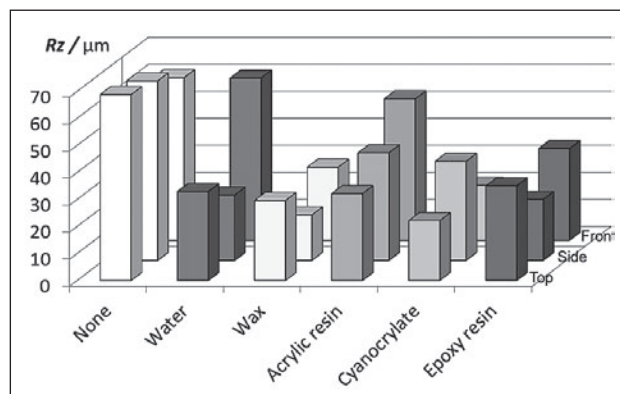


Figure 9 Maximum profile height of sanded samples

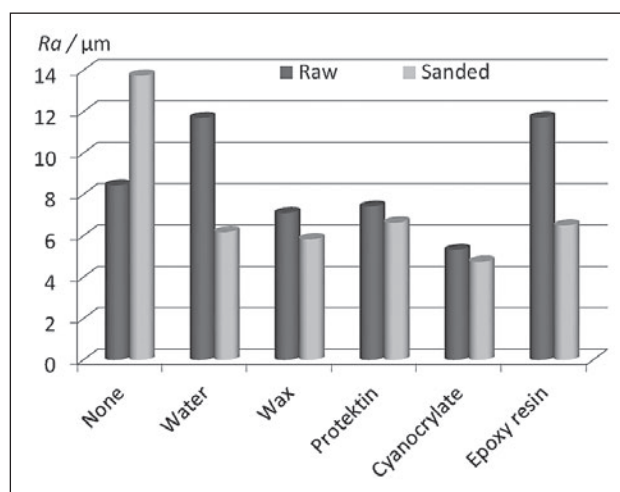


Figure 10 Comparison of average roughness for raw and sanded samples, top face, longitudinal direction

From the previous figures, a decrease of both average roughness and maximum profile height could be noticed after the samples were sanded. The only exception is the sample that was not treated with the hardener, since in this case, the roughness increased, compared to the raw state. For the better evaluation, a comparison is presented in separate Figure 10.

A graph in Figure 10 clearly shows a significant difference between the average roughness of raw and sanded specimens. However, the average roughness of unreinforced sanded sample is greater than of the original raw sample. This phenomenon could be explained

with the appearance of the lamellas during sanding of the unreinforced samples. It occasionally leads to the removal of multiple layers of material and the surface becomes wavy.

CONCLUSION

Strengthening fluids have a significant influence on the roughness of 3D printed model. Therefore, it is necessary to carefully select the appropriate fluid if the roughness is the required dominant property of model. The best surface roughness for 3D printed models provides cyanoacrylate, followed by wax and then other fluids. Sanding provides better surface quality, especially for the faces printed in the direction of layer deposition (here: faces are named Front and Side). However, here one should pay attention to the other properties of 3D printed models. It is possible that with the desire for higher quality of surface, sanding removes too much reinforced material and therefore decreases other mechanical properties. In order to avoid the undesired degradation of other properties, a cross-section of 3D printed models should be investigated under the microscope to determine how deep the selected fluid penetrates. Such a research will help to determine whether sanding leads to a significant decrease in mechanical properties.

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Note: The person responsible for proofreading is Željka Rosandić, prof. (Mechanical Engineering Faculty in Slavonski Brod).