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EFFECTS OF PROCESSING PARAMETERS ON HARDNESS OF 3D PRINTED PARTS

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ABSTRACT
Development of rapid prototyping systems and materials causes their wider implementation in many areas of human activities. Three-dimensional printing technique, invented in Massachusetts Institute of Technology and developed by Z Corporation, nowadays is asserting itself in both a direct and indirect production of parts and assemblies of any complexity. However, like any rapid prototyping technique, it has significant limitations, mainly in available materials and material properties. Owing to a poor material properties, all three-dimensional printed models need to be post-processed.
Poor material properties open possibilities for a various researches of the effects of processing parameters on printed models. In this paper we are presenting research of the effects of the layer thickness, building direction and post-processing on the hardness of three-dimensional printed models. In our research we found that the variations of considered parameters do not have a significant influence on the hardness of the three-dimensional printed models.
Keywords: 3D printing, process parameters, post processing, hardness

1. INTRODUCTION
Three-dimensional printing (3DP) technique is one of the rapid prototyping (RP) techniques which offers very good ratio between a price, application and a quality of printed models. Our recent researches of the process properties show that 3DP is best for use in cases where speed and price have priority versus application of printed model [1].
Main driving factors in a real-life application of the printed models are their mechanical properties, dimensional precision and surface texture quality. Selections of powder and infiltration material are the main factors for the mechanical properties of printed parts. Furthermore, it is possible to achieve significant variations of the mechanical properties with variations in processing and post-processing parameters for same powder.
In this paper we are presenting research of the effects of the layer thickness, building direction and post-processing on the hardness of three-dimensional printed models.

2. RESEARCH FRAMEWORK
In a research framework we embraced the printer model, base material and variations of processing and post-processing parameters. For of processing parameters we considered variations of a layer thickness and model orientations regarding a building direction of the printer. For post-processing parameters we considered variations of infiltration material and oven drying as heat treatment. 3D printer used in our research was model Z310 Plus from Z Corporation [2].
Used software i.e. printer driver, ZPrint for selected base powder type zp130 allows two values of the layer thickness: 0.0875 mm and 0.1 mm. Therefore, limited variation numbers of the layer thickness are also

considered as research constraints. First value of layer thickness was labeled with D1 and second with D2. Considered model orientations regarding building direction of the printer are explained in presented illustration (Figure 2.1). Axes of coordinate system indicate the travel direction of the main printer units. Axis X indicates the gantry direction of travel, axis Y indicates the binder cartridge direction of travel and finally axis Z indicates invert building piston direction i.e. layer building direction.

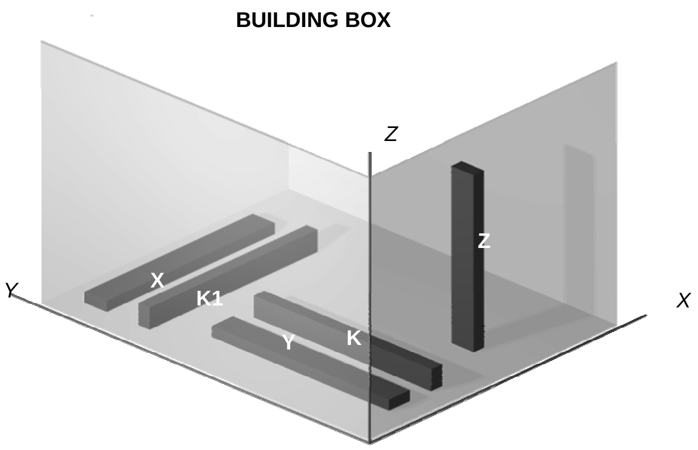

Figure 2.1 Considered model orientations in printer building box

Table 2.1 Considered model orientations legend

Label	Main model orientation	Main dimensions building plane	Note
X	*X*	*XY*	Along the gantry direction of travel
Y	*Y*	*XY*	Along the binder cartridge direction of travel
Z	*Z*	*YZ*	Along the layer building direction
K	*Y*	*YZ*	Transversally to the binder cartridge direction of travel
K1	*X*	*XZ*	Transversally to the gantry direction of travel

Binder ratio was set regarding layer thickness and basic material according to recommendation from printer software manual [2]. Because used binder type zb58 is directly determined by selection of basic material, it is therefore considered as research constraint. In most cases, binder ratio is determined automatically by algorithm implemented in software and it is higher for higher layer thickness.

Considered post-processing parameters - variations of infiltration material and oven drying as heat treatment - are determined by selection of the base material, so their choice also has to be considered as research constraint. Post-processing parameters variations in experiment were: green model without post-processing (label **Z**), heat treated green model (**T**), infiltration with ZBond i.e. cyanoakrylate (**B**), infiltration with wax (**V**), heat treated and ZBond infiltration (**BT**), heat treated and wax infiltration (**VT**), heat treated and wax followed by ZBond infiltration (**MT**).

After determination of the research framework, we build up the experiment plan and summarized it in table for easier tracking (Table 2.2).

Table 2.2 Factors and variations

Factor	Variation labels
Layer thickness	D1, D2
Model orientation	X, Y, Z, K, K1
Post-processing	Z, T, B, V, BT, VT, MT

3. EXPERIMENT

Printing and post-processing of test pieces was done at the Faculty of Mechanical Engineering in

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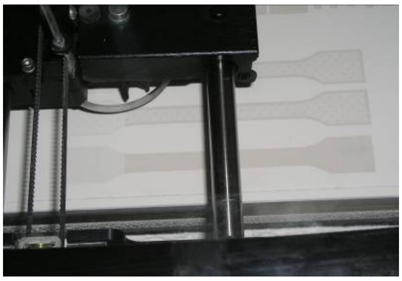
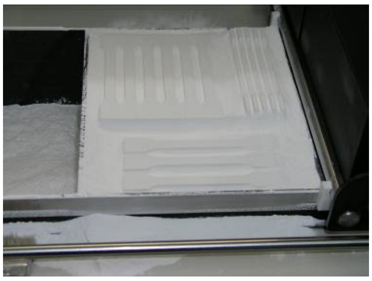
Tuzla, Bosnia and Herzegovina. Activities in preparation of test pieces for hardness measuring are illustrated with sequel of photos (***Figure 3.1***).



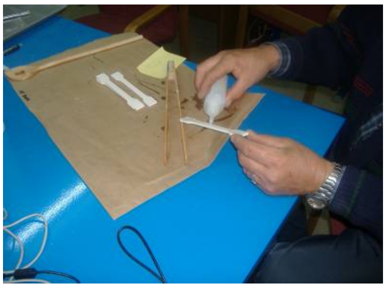
a)



b)

c)

d)



e)

f)

Figure 3.1 Preparation of test pieces: a) printing; b) various model orientation; c) sorted by layer thickness and model orientation; d) wax infiltration; e) cyanoakrylate infiltration; f) sorted and labeled

Hardness test of printed model is performed using Shore durometer (***Figure 3.2***). Shore hardness test is suitable for rubber, polymers and generally softer materials. Since printed models are mixture of materials and Shore hardness test gave us the most usable results on the first pieces, we selected it between several available tests (Brinell, Rockwell, etc.).

Figure 3.2 Shore hardness test

Shore hardness test is quick, simple, and cheap and, what is the most important, non-destructive. Since test is non-destructive, test pieces could be used in other purposes after experiment is done. According to ISO 838 standard, test pieces should be at least 6.4 mm thick [4] and it is allowed to put several test pieces on stack to achieve prescribed thickness as we did (***Figure 3.2***).

4. RESULTS

Results of the Shore hardness test are presented in three charts: for green models (***Figure 4.1***); for layer thickness D1 (***Figure 4.2***) and for layer thickness D2 (***Figure 4.3***).

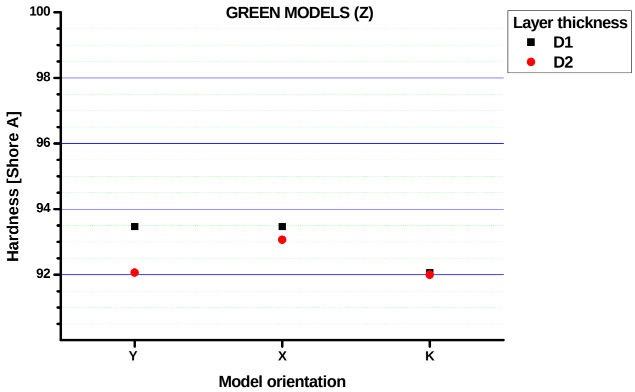


Figure 4.1 Hardness of green models

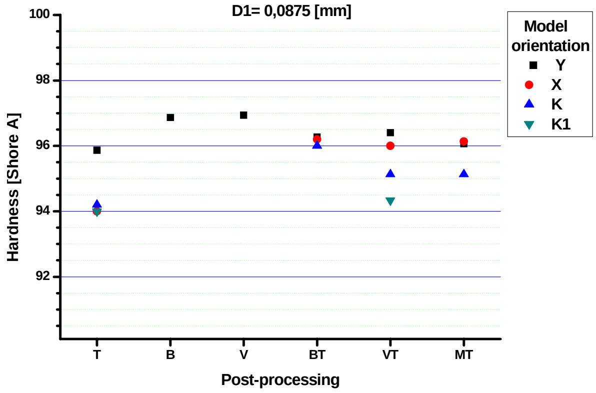


Figure 4.2 Hardness for layer thickness D1

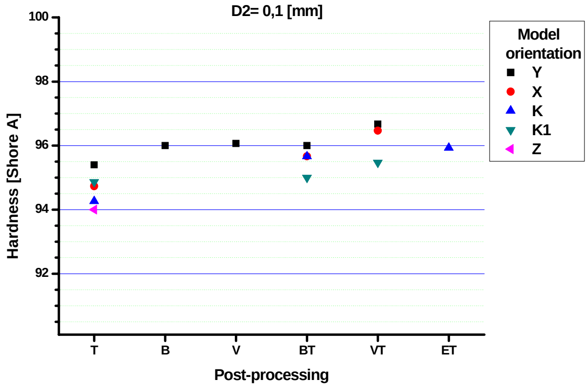


Figure 4.3 Hardness for layer thickness D1

5. CONCLUSION

Hardness test results for the green models clearly shows that variations of processing parameters could not significantly affect hardness of the green models. Consequently, hardness of the green models is determined only by the base material and it is around value of 93 on a Shore A scale.

From the results of post-processed models (***Figure 4.2*** and ***Figure 4.3***) it can be concluded that post-processing increases overall hardness of the 3DP models. Average post-processing gain on hardness is 3%.

Models oriented along the binder cartridge direction of travel (label Y) acquired the greatest hardness comparing to other model orientations.

Layer thickness variations did not result in any significant differences in the hardness of the models.

Finally, we can conclude that the variations of the considered parameters do not have any significant influence on the hardness of the three-dimensional printed models.

6. LITERATURE

[1] Fajić A., Tiro D., Galeta T., Topčić A.: Research of 3D Printing Process Characteristics, The 5th International Research/Expert Conference, “Quality 2007”, Neum, 2007.
[2] ZPrint Software User Manual, Version 7.3, Z Corporation
[3] Steve Upcraft, Richard Fletcher: “The rapid prototyping technologies”, Assembly Automation; Volume: 23 Issue: 4; 2003. Research paper
[4] ISO 838 standard (ASTM D2240, DIN 5305)