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The change of the 3D printing product mechanical properties in the function of different post-treatment

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Abstract. Rapid prototyping (RP) has changed the method of product design and manufacturing. With the help of RP technologies a physical model can be created within couple of hours from any complex CAD model. RP technologies in contrast with conventional subtractive manufacturing technologies produce the end product by adding material layer-by-layer. 3D printing is one of the most widespread technologies in the industry. Because of the porous structure and bad mechanical properties of the models further post treatment is needed. Post treatment always means infiltration of the models, in case of gypsum and cellulose epoxy resin is mostly used. In our work the effect of post treatment method was examined on the mechanical properties of the pieces. The investigated pieces were prepared with four different setting of a printer.

Introduction

In today's fastened world, it is essential to shorten product development time, and lower development costs. The conventional, sequential product development has been exchanged to simultaneous product engineering. This means that two or more phases of the development are running simultaneously, but intermediary control and communication between developers is necessary [1-5]. Rapid prototyping technologies give essential help for this type of product development.

RP technologies make it possible for designers to produce complex physical models, without the need of considering the constraints of conventional manufacturing technologies. Prototypes are made basically for three main purposes. In the first case only the geometry is important for visualization (visual model). In the second case functional models might be needed, in this case the model can contain moving parts or it should have similar material properties as the final part. Finally prototypes are also used as negative models for rapid tooling applications [6-8].

3D printing was developed by MIT (Massachusetts Institute of Technology). Several companies have purchased the license, and developed the technology further for commercial use. The most successful is Z Corporation, which introduced a 24-bit color printer in 2004. With this development it became possible to print full color 3D models, allowing the user to print out the model with the result of stress analysis or differentiating material or functions of a part by color.

With 3D printing it is possible to manufacture any given shape, from a wide variety of materials. The main criteria for the material is that it should be available as powder, with small enough grain size, and adequate water soluble binder should be available. Z-Corporation offers cellulose, gypsum and ceramic powders with suitable binder. Before starting the printing process, 30-40 layer of powder were layed down to guarantee the flat surface. During the production process the print head prints the binder material on the powder in the given cross section of the model. After printing the build piston lowers vertically one layer thickness distance, and the next powder layer is spread from the base material with the help of the leveling roller. These two steps repeat until the final geometry of the model is ready (Fig. 1).

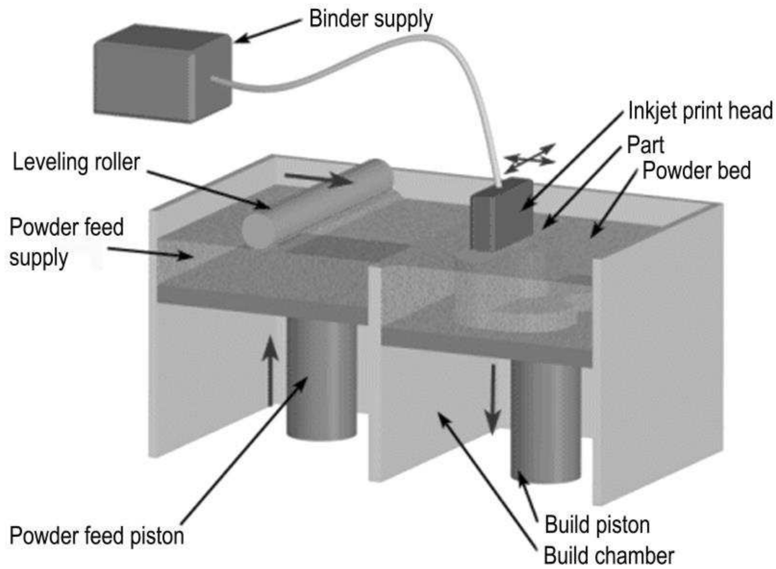

Fig. 1. The principle of spatial printing [9]

After printing the model, it can be removed from the powder bed. During production the models are prepared with a core – shell structure where the saturation level of the shell is twice as that of the core (Fig. 2). This procedure is fast, simple, relatively cheap and reliable. Since the product is in a powder bed, no additional support material is needed. The technology is also suitable for manufacturing ceramic mould for metal casting. Main disadvantages of technology are that it needs post treatment, accuracy is affected by the grain size of the material used and inner surface of the parts are hard to access [2, 8].

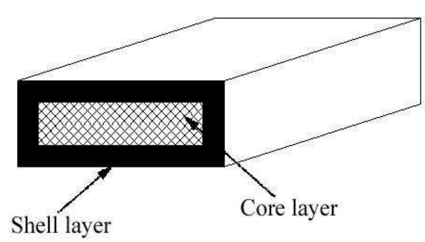

Fig. 2. Illustration of the core-shell structure of a product manufactured with a 3DP device

The aim of our work was to determine the optimal saturation level, and post treatment method in function of compressive strength and modulus of compression. In this work the effects of saturation level (porosity) and different post treatment methods were studied on the mechanical properties of 3D printed specimens. Test specimens with four different saturation levels were manufactured in three different building directions (x-y-z axis) (Fig. 3). The test specimens were infiltrated with epoxy resin with two different methods, and after curing they were submitted to compression tests.

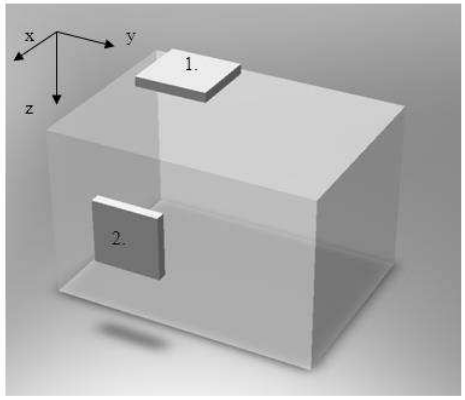

Fig. 3. Printing layout - The different build direction

Experimental

The testing samples were prepared at the Department of Polymer Engineering in the Budapest University of Technology and Economics on a Z810 3D printer. For the production of the test specimens Z102 gypsum powder and Zb53 binder were used.

Previous research [10] showed that the core – shell structure reduces the possible infiltration level of the specimens, thereby lowering their mechanical properties. To eliminate this effect the system setup of the 3D printer has been reset and constant saturation was used throughout the whole part. The four different saturation levels for the test specimens were 21.29, 30.16, 35.48 and 40.8%. 150x150x4 mm test specimens were produced in two directions, parallel and perpendicular to the building plane (Fig 3).

After printing the samples they were removed from the powder bed, and dried for 2 hour on 60°C (raw specimens). After drying the specimens they were infiltrated with epoxy resin. Two different methods were used for infiltration. In the first method the samples were impregnated by hand lay-up, and only capillary forces were responsible for the infiltration level. The other method was vacuum assisted resin transfer molding (VARTM), where not only the capillary forces but vacuum was also responsible for the infiltration level. After resin infiltration the samples were left on room temperature (20°C) for 24 hours, after that they were put into a heated chamber for 2 hours and 80°C for post curing. After curing the samples they were cut into 6 mm wide and 100 mm long specimens for compression tests according to ASTMD – 3035–A. The layout of the compression test apparatus can be seen on Fig. 4.

Fig. 4. Layout of compression test

Results and discussion

Compressive strength and modulus of compression were compared in the function of the saturation and the method of post treatment in every build up direction (x-y-z). The results hand lay-up method are shown on Fig. 5-6. Fig. 7-8 show the result of the VARTM method.

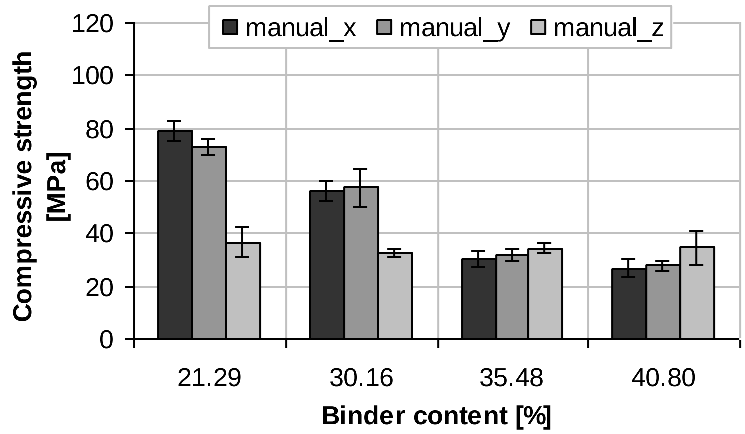

Fig. 5. Change of the compression strength as a function of binder content in the case of manual laminated

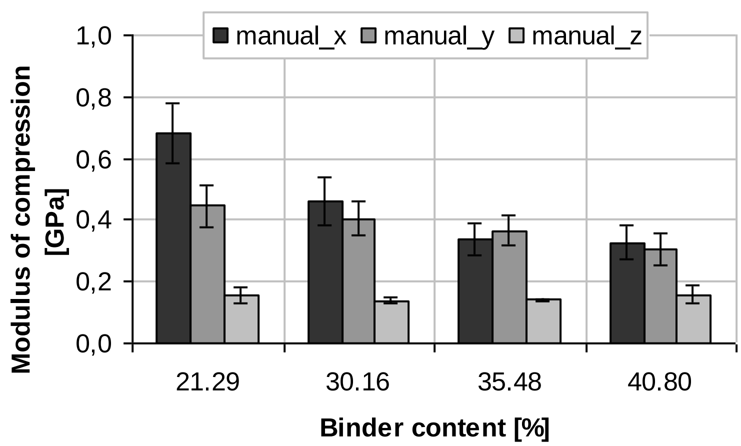

Fig. 6. Change of the modulus of compression as a function of binder content in the case of manual laminated

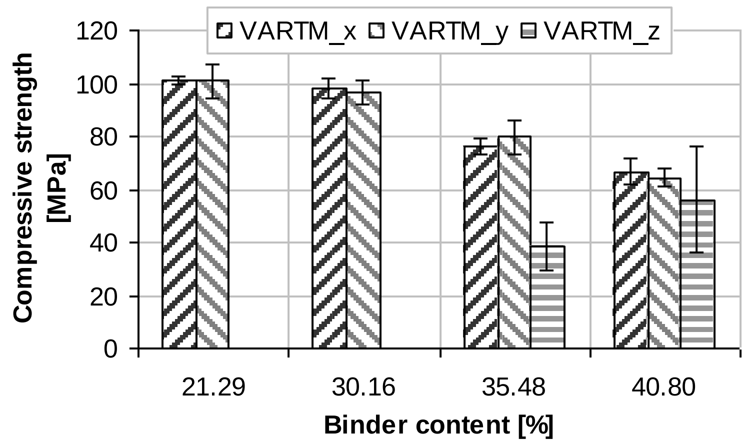

Fig. 7. Change of the compression strength as a function of binder content in the case of injected

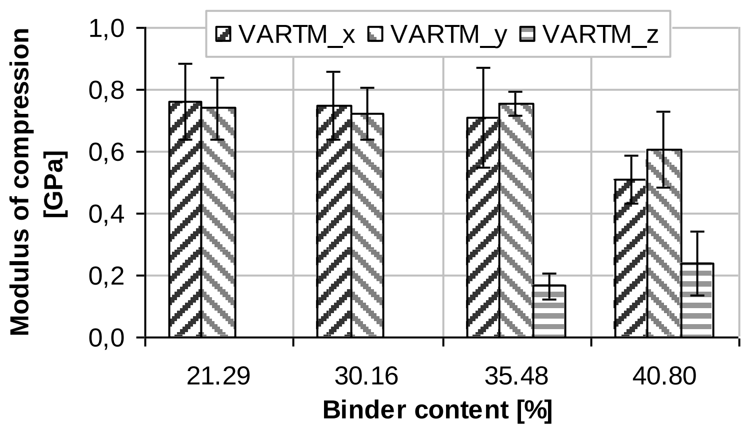

Fig. 8. Change of the modulus of compression as a function of binder content in the case of injected

Results showed that there is no significant difference between results of X-Y axis building directions, since the results are within variance. It can be also concluded that higher binder content lowers compressive strength and modulus of compression, although the effect on compressive strength is higher than on modulus of compression. Results also show that at higher binder content the investigated mechanical properties can be 60-80% lower in the Z-axis building direction than in X or Y axis directions. The difference in the building directions caused the raw specimens with 21.29 and 30.16% saturation, with Z-axis building direction to break under the vacuum infiltration. This difference is caused by the different resolution of the machine in the different directions. While the droplets of the binder material are 0,01 mm apart from each other on the X-Y plane, the same distance is at least 0,1 mm in the Z direction because of the mean powder grain size (100 μm according to manufacturer). In these two cases the binder content in the Z-axis building direction was not sufficient to secure the structural integrity of the samples under vacuum.

The comparison of the different post treatment method can be seen on Fig. 9-10. Results show a growing difference between the compressive strength and modulus of compression in function of the post treatment method. The difference is caused by the different processes responsible for the resin infiltration. During hand lay up resin only infiltrates the structure because of the capillary action, in contrast to VARTM when the forces caused by the pressure difference are responsible for the resin infiltration. From these results in can be concluded that if the post treatment of a 3D printed part will be hand lay up a lower saturation level for the model is better for the final parts compressive mechanical properties. If VARTM as post treatment method is available for the part produced with 3D printing, than build up direction of the product must be considered also before lowering saturation level. If critical cross sections of a part have Z-axis building direction, saturation should be kept above 35%.

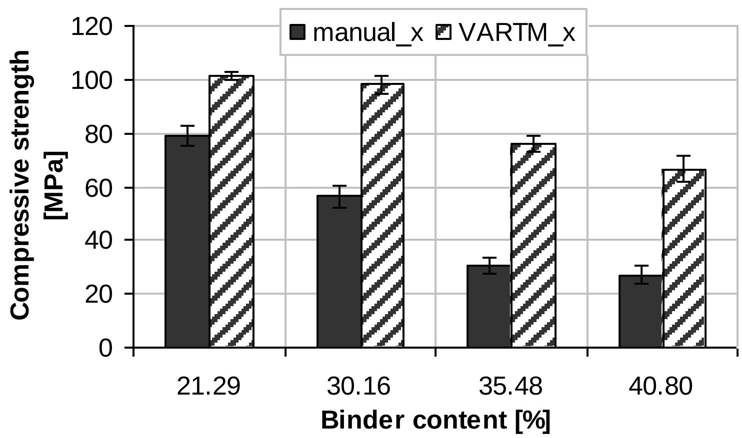

Fig. 9. The conformation of compressive strength as a function of different post treatment

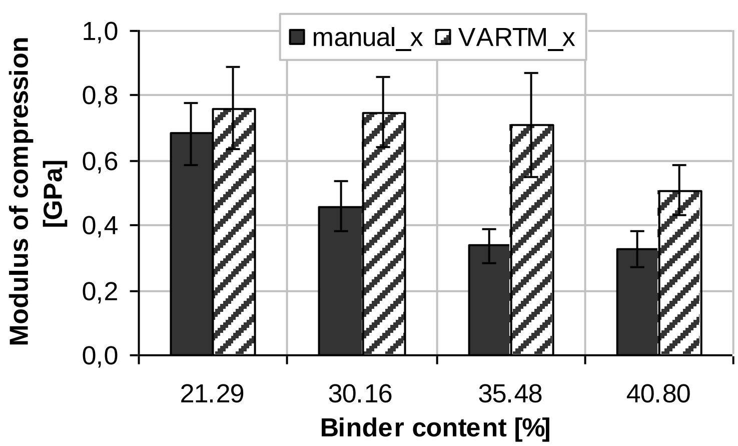

Fig. 10. The conformation of modulus of compression as a function of different post treatment

Summary

In this work two different methods of post treatment for 3D printing were compared. Compressive strength and modulus of compression were measured in order to examine the effect of saturation on post treatment method. From the results it was concluded that by knowing the post treatment method used on the printed parts, the saturation level of the parts can optimized. Lower binder content will cause higher porosity of the raw specimen and resin infiltration will be more effective.

Acknowledgement

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