Developments in the Field of Rapid Prototype Production

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Developments in the Field of Rapid Prototype Production

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Abstract. Characteristics of 3D printed specimens are porous structure and low mechanical strength. Due to porous structure post treatment is possible, and in most cases infiltration with an epoxy resin, wax or cyanoacrylate material takes place. As a result of post treatment, the mechanical strength can be increased by 100%, although this is strongly influenced by the infiltration depth that depends on the porous structure and the resin viscosity. In the framework of the common research of the Department of Polymer Engineering, BME and Varinex Zrt. the applicability of a 3D printer is examined in the field of direct tool making. As the first step, the resin uptake ability of specimens prepared with a Z810 3D printer is examined.

Introduction

The development time of different products and the time until they enter the market decreased significantly in the last years. The reason for this is the ever increasing market needs and the rapidly developing technology [1, 2]. Computer aided design (CAD) and manufacturing (CAM) and the appearance of different integrated systems lead the product development into new ways. The conventional, subsequent design and production processes are replaced by simultaneous product design [3, 4]. Intermediate checking and the efficient communication of those taking part in the design process play a great role in this process. Rapid prototyping (RPT) unites all these aspects well. In some phases of design prototypes produced by the means of RPT help find a compromise among the technical, ergonomic and design aims and also assist in expressing the requirements of the products. Although they can differ significantly concerning technical realization – since there are 30-40 different RPT technologies all over the world – the principle of operation is the same in all cases: the models are prepared by adding material layer by layer [5, 6, 7, 8, 9]. The technology of 3D printing was developed at MIT in 1989. This is a technique in which the base material is in powder form and bonding material is added. During production firstly 30-40 layers of powder is spread on the work table, and this way it can be guaranteed that a totally flat surface is formed in the workspace. The production process itself during which the printer heads bind the powder particles together in a given cross section of the model can start only afterwards. Then the work table lowers with one layer thickness distance, and the next powder layer is spread from the base material tank with the help of the spreading cylinder. The periodic repeating of bonding material uptake and powder layer spreading (Fig. 1) continues until the model is finished. Afterwards the model is relaxed in the powder bath for 2 hours before it can be removed. The powder without binder can only be removed then, since it serves as a support for the model to be constructed [6, 10, 11, 12, 13, 14].

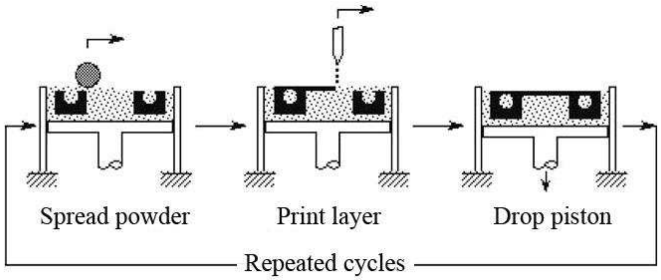

Fig. 1 Layer by layer building process of 3D printing [6]

The post treatment of the model can start after removal. This usually refers to infiltration with a kind of epoxy resin, or there is also a possibility to use wax or cyanoacrylate. As a result of infiltration the mechanical properties improve significantly and this improvement depends on the infiltration depth influenced by the porous structure and the viscosity of the resin [6].

Experimental

The resin uptake of specimens prepared with 3D printing was examined during our work. Two specimens of different geometry were used for the examinations, and both were produced on the 3D printer type Z810 in the laboratory of the Department of Polymer Engineering (Table 1).

Table 1 Geometrical data of applied specimens

Cylindrical specimen		Sheet specimens		
Diameter [mm]	Height [mm]	Width [mm]	Length [mm]	Thickness [mm]
12	30	100	100	1
		100	100	2
		100	100	3

The base material for the production of specimens was Z102 gypsum powder and Zb53 binder, while the applied layer thickness was 0.1 mm. A characteristic of the technology is the core - shell structure formed during production. It is revealed in a way that the saturation of the binder in the outer layer, i.e. the shell is larger (Fig. 2) [6].

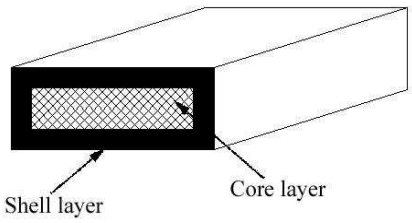

Fig. 2 Illustration of the core-shell structure of a product manufactured with a 3DP device

Two different methods were used for the examination of resin uptake capability. In the first case cylindrical, while in the second one sheet type specimens were dipped into the resin bath. All the specimens were dried at 60°C for 2 hours.

The examination of cylindrical specimens started with weighing the initial mass, then placing it into the resin bath for different time intervals. During the measurement, it should be provided that the specimens spend the same time in the bath, and the specimens (5 pieces) that belong to the same measurement point (time) are taken out at the same time. This aim was achieved with the help of a

frame prepared by us. After taking out the specimens from the bath, the surplus material was removed from their surface and they were weighed. This way the mass before and after infiltration were known, and the extent of resin uptake could be calculated in a simple way using the Eq. (1) below.

$$w = \frac{m_{gy} - m_0}{m_0}, \qquad (1)$$

where w is the absorbed relative resin mass [-], m_{gy} is the mass after infiltration [g] and m_0 is the initial mass (before infiltration) [g].

The sheet specimens were examined in a cyclic resin uptake test [15-17]. The measurement was carried out on a tensile tester type Zwick Z005. The set-up of the measurement is shown in Fig. 3.

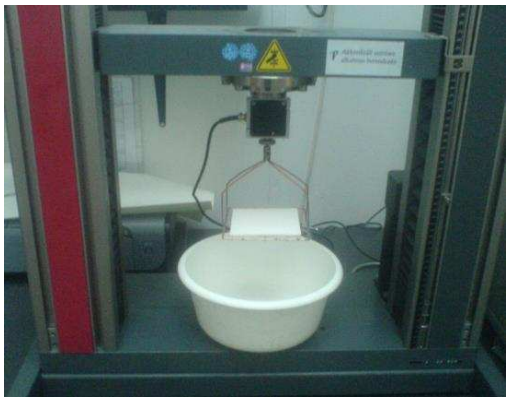

Fig. 3 Set up of the resin absorption measurement system

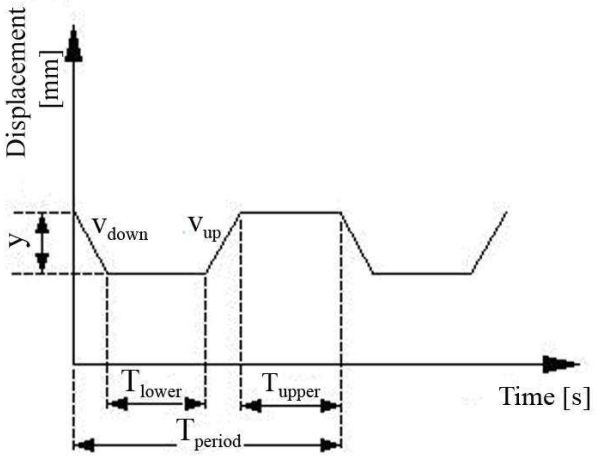

Fig. 4 Resin absorption process – cross head movements in the function of time

The measurement is based on lowering and lifting the frame that holds the specimen, and this cycle can be programmed exactly on the tensile tester (Fig. 4). The major parameters of the cycle are the vertical displacement (y=100 mm) and the velocity (v_{down}=v_{up}=25 mm/s) of the cross head, as well as the time spent in the lower and the higher dead points (T_{lower}=T_{upper}=0.2 s) (Fig. 4). The specimens were infiltrated with epoxy resin obtained from "P+M Polimerkémia Kft".

Results and discussion

During the examination of cylindrical specimens the experience was that the initial part can be characterized well but this method is not adequate for the examination of the total uptake process (Fig. 5). A further problem is the relatively high deviation value experienced at the measurements (Fig. 6).

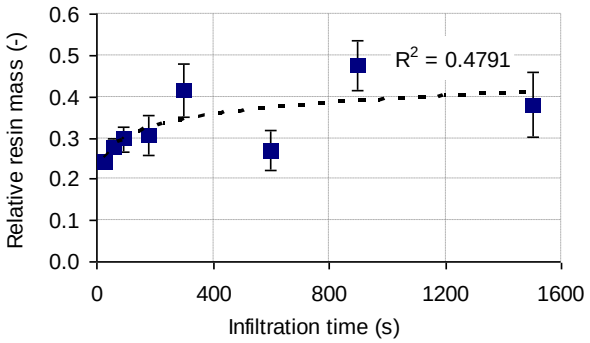

Fig. 5 Resin absorption process – the relative resin mass absorption in the function of the infiltration time

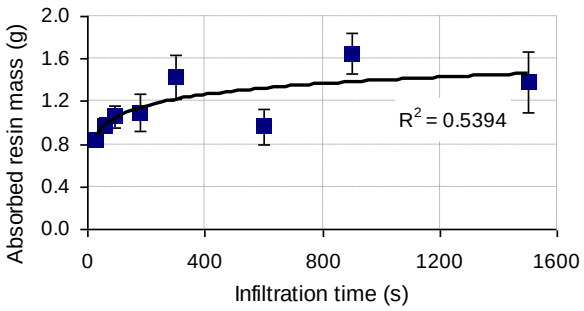

Fig. 6 Resin mass absorbed by the cylindrical specimen in the function of the infiltration time

As a summary of this examination series, it can be concluded that the deviation of the measurement results of the experiments carried out so far can be traced back to the bad reproducibility of the post treatment process although the frames provide the simultaneous entering and removal of the samples. This measurement method does not allow the examination of a total infiltration process of one specimen. Since not one specimen is infiltrated totally but several specimens are treated for different times and the resin uptake curve is determined in this way, the slight differences in the structure can also result in deviations in the measurements. Infiltration was always carried out with the same method so that the results can be compared. The frames built by us provided the simultaneous removal of the specimens but in case of entering the resin some specimens floated to the surface of the resin and this way giving false results. The investigations revealed that the frames should also keep the specimens under the resin.

In case of the sheet specimens of different thickness in each cycle the correspondent force-time value pairs were subtracted from the force-time curve registered with the tensile tester. Using these data, the saturation curve of the specimens can be determined. Due to the changing specimen thickness, the relative resin mass applied before gives results that are difficult to handle (Fig. 7). Resin uptake does not start when the specimen is totally under the resin level but when the first surface of the specimen reaches the resin bath. The data of absorbed resin mass gives better results and is easier to interpret than the relative resin mass applied before (Fig. 8). The measurement results reveal clearly that as a function of thickness increase, the saturation limit value grows, as well.

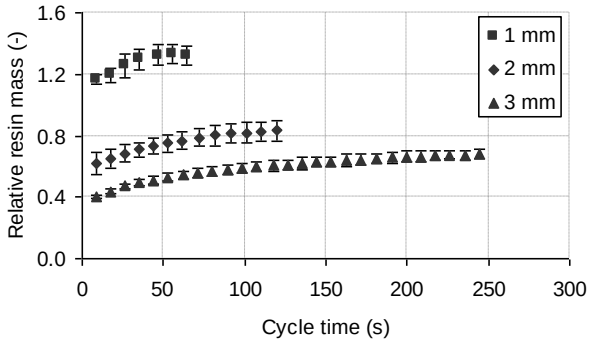

Fig. 7 Resin absorption process as a function of time during cyclic testing

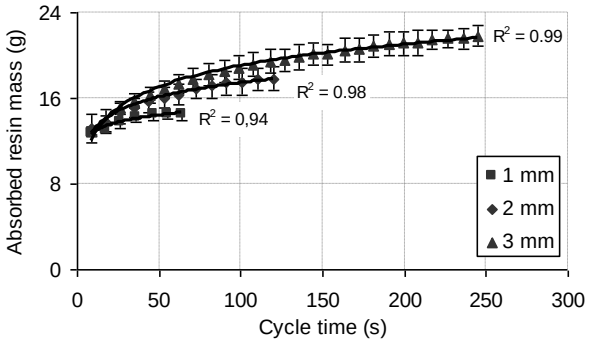

Fig. 8 Absorbed resin mass as a function of time

Cyclic testing allows a resin uptake process that is easier to follow in case of cylindrical specimens, and the saturation curve can be determined in an adequate way. If the parameters of the cycle are set better, the stage of the measurement that is close to saturation can be improved. Since in this case

the specimens sank into the resin surface due to the too fast cross head movement, there was already resin not only on the lower but also on the upper surface of the specimen.

Summary

Resin uptake capability of cylindrical specimens produced by 3D printing was examined in this work with different methods. The experience revealed that the dipping method applied in case of the examination of cylindrical specimens has a high deviation among the results due to the measurement method. This method is also not capable of the examination of the total infiltration process of the specimens. In case of the sheet specimens it was concluded that the saturation curve can be determined but the relatively high cross head speed results in measurement uncertainty, hence set measurement parameters have to be used. Our investigation proved that the method can be used for checking the infiltration process of products prepared in 3D printing products and also for determining the maximal absorbable resin amount.

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