THE INFLUENCE OF HUMIDITY AND TEMPERATURE ON THE PROPERTIES OF PHOTOPOLYMER MATERIALS MADE BY POLYJET TECHNOLOGY

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The paper is focused on the study of environmental changes and their impact on selected mechanical properties of parts made of photopolymer materials used by the PolyJet technology. Discussion deals with changes in material properties of parts exposed to increased temperature and humidity. Different layer orientations during 3D printing of parts was another evaluating aspect that influenced the final mechanical properties. All analysed materials were graded according to the hardness in order to observe changes in mechanical properties of the widest possible range of materials that can be processed by this technology.

KEYWORDS

PolyJet, photopolymers, 3D Print, mechanical properties

1 INTRODUCTION

The technology of 3D printing is an advanced progressive technology employed in many technical disciplines. Today we can use several materials for printing final products and use various techniques. What is the common and important factor for various materials? The mechanical properties, but not for typical environment, but for differing environment (different humidity or temperatures). As a consequence, the influence of various mechanical load types and long-term exposition to the environment must be taken into account when considering the application requirements. This article deals with photopolymers which can be processed with the use of PolyJet technology. Photopolymers or photo curable materials (resins) can represent many different compositions, from flexible to rigid, transparent to opaque [Pandey 2014]. Photopolymers are light sensitive polymer materials which change their properties when exposed to UV light. They can change their state from liquid like substance to solid like substance. Only the area exposed to UV-light hardens, whereas unexposed parts remain still in a liquid state, which means that photopolymers are only curable with light sources (UV laser, lamp, sunlight etc.). The light from these sources initiate chemical reactions (photo-polymerization) which change their structure and modify their chemical and mechanical properties [Fouassier 2012]. Light initiated reactions used in photopolymer technology are divided into categories based on the utilized physical and chemical process [Crivello 2014, Pandey 2014]. In general, photopolymers may contain several components including binders, photo initiators, additives, chemical agents, plasticizers and colorants. However, the three main components which build the photopolymers are binders, monomers and photo-initiators.

PolyJet is one of two 3D printing technologies to print different colours or different material directly into the part and this technology is the only one capable of printing multiple materials simultaneously, offering gradations from stiff to flexible in one part [Hsieh 2017]. In this work, the influence of environmental conditioning and layers orientation on mechanical properties of photopolymers is studied.

PolyJet 3D printing works similarly to inkjet printing. Instead of jetting drops of ink on the paper, PolyJet 3D printers use fine printing head nozzles to deposit droplets of photocurable liquid material onto a build tray in layers as fine as 14 or 16 microns to form 3D parts. The thickness of each layer can be adjusted by moving a roller across the build tray immediately after printing, whereupon curing is induced using UV light [Ibrahim 2009]. The repeated application and solidification of photopolymer layers gradually results in the formation of a solid 3D model. PolyJet prints the thinnest layers of any 3D printing processes and that means less visible contours of individual layers thereby very for smooth product surfaces. PolyJet parts require support structures to build overhanging features and holes. Without support structures the product shape can warp, which results in inaccurate walls, features, etc. The support material is laid on at the same time as the material used in the model and has specific composition for easy release from the part when jetted off or dissolved with water. Products can be used instantly after printing which does not necessarily need post curing process [Ibrahim 2009, Udriu 2017].

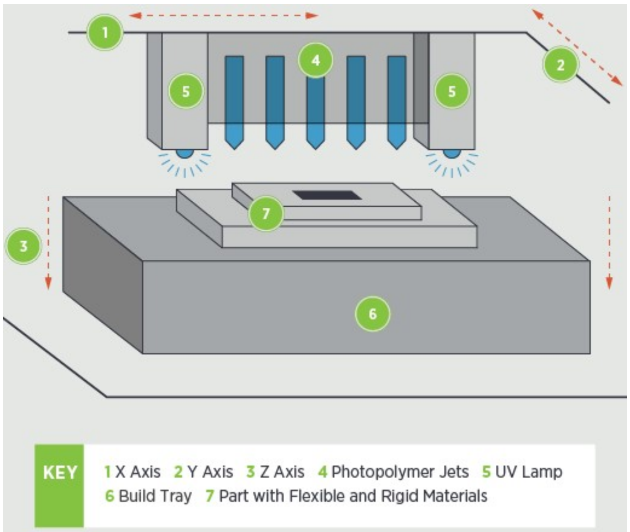

Figure 1. The principle of PolyJet technology [Prolabs 2018]

2 EXPERIMENTAL PROCEDURE

Material analysis of PolyJet parts were performed on test bodies 1BA according to ISO 527 and on test bodies of type 1 with the shape of rectangular prism according to ISO 179-1 and ISO 178. The test bodies were made of commercially available acrylate-based photopolymers (Stratasys Ltd.) VeroWhitePlus (Shore D = 85), RGD8560-DM (Shore D = 80) and FLX2195-DM (Shore A = 43). Materials RGD8560-DM and FLX2195-DM are manufactured by combining materials VeroWhitePlus and TangoBlackPlus (Shore A = 27) in proportion (82:18) for material RGD8560-DM and (36:64) for FLX2195-DM.

Parts were printed using the J700 (Stratasys Ltd.), the material temperature within the print head was (75 ÷ 78) °C. Parts with a layer thickness of 0.033 mm were printed with layers' orientation to the printing area under the angle of 0° and 90°. An example of output from 3D printing is shown in the Figure 2. After removing the test bodies from the printer, the support material was removed by water jet. Because of high tendency of the photopolymers to water absorption, the samples were placed in the drying chamber for 24 hours to ensure the same starting conditions for all tested materials.

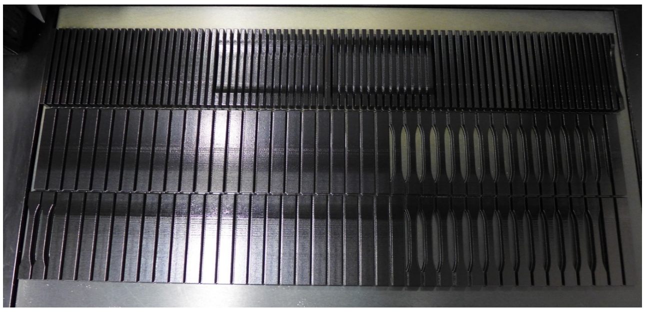

Figure 2. Specimens after print.

2.1 *Exposure of parts to the environments with increased humidity and temperature*

The mechanical properties of the photopolymers were evaluated on the parts conditioned in the standard 23/50 environment (23 ° C and 50% relative humidity), in the environment with increased relative humidity 80% at 30 ° C (for two weeks) and on the parts exposed to thermal loading according to the temperature program shown in Fig. 3. The thermal loading of photopolymer-based 3D printing parts (see Fig. 3) is recommended to ensure the dimensional and shape stability of the samples at elevated temperatures.

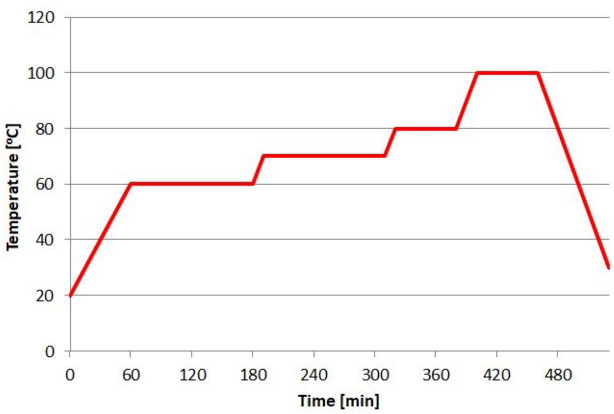

Figure 3. The temperature profile during part conditioning

The moisture content of parts prior to the assessment of their strength characteristics after conditioning in a standard environment and in an environment with increased humidity is shown in the Table 1. Moisture was measured using thermogravimetric analysis on the Mettler Toledo HX204 halogen moisture analyser. The basic principle of thermogravimetric moisture determination is the observation of weight changes in the moisture content of material at a precisely defined heating. To determine moisture a 7g weighing was used, which was dried at the temperature of 130 °C until a mean loss of weight per unit of time, which was less than 1 mg per 140 sec, was achieved. All samples were measured three times and average values of the moisture content are listed in the Table 1.

Table 1. Humidity of photopolymers depending on their conditioning

Material	Conditions 23°C/%50	Conditions 30°C/80%
VeroWhitePlus	0,50 %	1,70 %
RGD8560-DM	0,91 %	2,23 %
FLX2195-DM	1,05 %	2,60 %

2.2 *Charpy notched impact strength of photopolymers*

The impact properties of the parts, depending on the conditioning process, were evaluated on the basis of Charpy impact strength results, which were determined in a standard 23/50 environment on the Resil Ceast S.p.A. by ISO 179-1 / 1eA. The measured values are shown in Figures 4, 5 and 6.

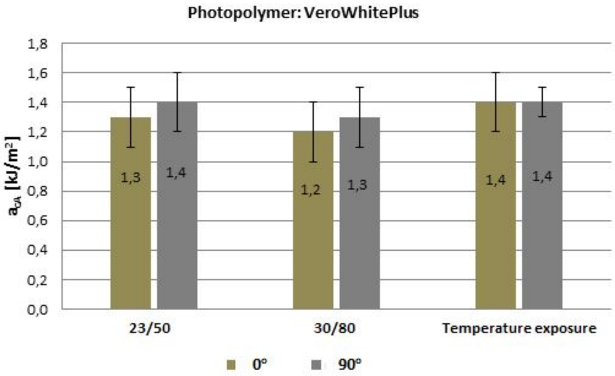

Figure 4. Charpy notched impact strength of VeroWhitePlus

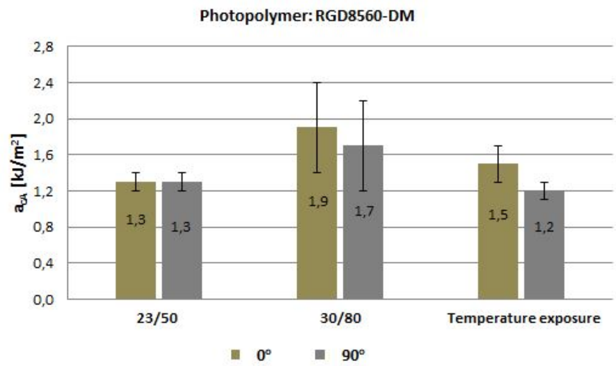

Figure 5. Charpy notched impact strength of RGD8560-DM

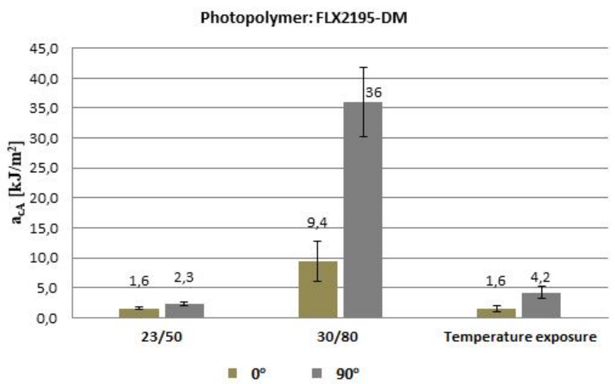

Figure 6. Charpy notched impact strength of FLX2195-DM

Photopolymers are highly water-absorbing materials. Moisturization increases their impact strength. Whereas, for VeroWhitePlus photopolymer the impact strength (with respect to the scattering of the measured values) is independent on the degree of wetting, RGD8560-DM and FLX2195-DM materials increase their impact strength after exposure to the environment with increased humidity, especially FLX2195-DM, which consists of a VeroWhitePlus photopolymer and a TangoBlackPlus photopolymer (rubber like material) in a ratio of (36:64). In the case of the layers' orientation under the angle of 0° the notched impact strength was increased 5-times and with the layers' orientation under the angle of 90° the notched impact strength increased almost 15-times, see Figure 6. Observed differences can be attributed to the fact, that mechanical construction of the notch of the test body with the orientation (90°) results in the disturbance of only a few layers and the remaining intact layers are able to absorb the impact stress than samples with the layers' orientation (0°) where all layers were negatively affected by the created notch and thereby the final cohesiveness was reduced. For VeroWhitePlus and RGD8560-DM materials, the influence of increased humidity and thermal exposure on their impact properties was not observed with respect to the variance of the measured values. Similarly, significant influence of the layers' orientation on the final impact properties of the parts was not found when analysing these materials.

2.3 *Tensile strength of photopolymers*

Tensile strength (σ_m) was determined in a standard 23/50 environment by ISO 527 / 1BA / 50. Measurements were made on TiraTest 2300. The measured values are shown in the Figures 7, 8 and 9.

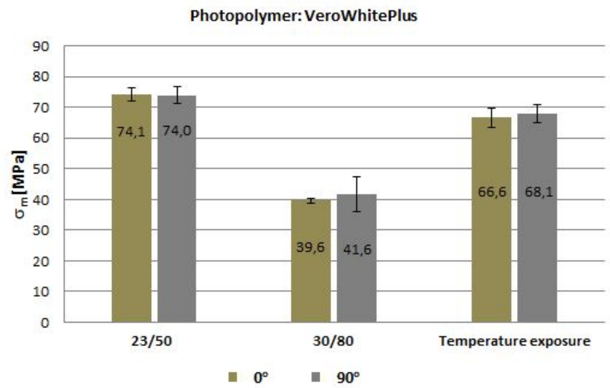

Figure 7. Tensile strength of VeroWhitePlus

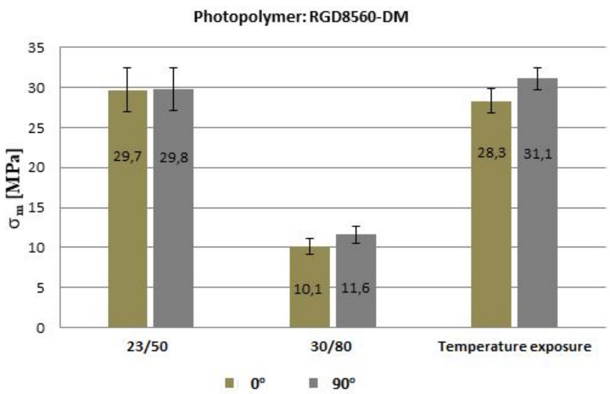

Figure 8. Tensile strength of RGD8560-DM

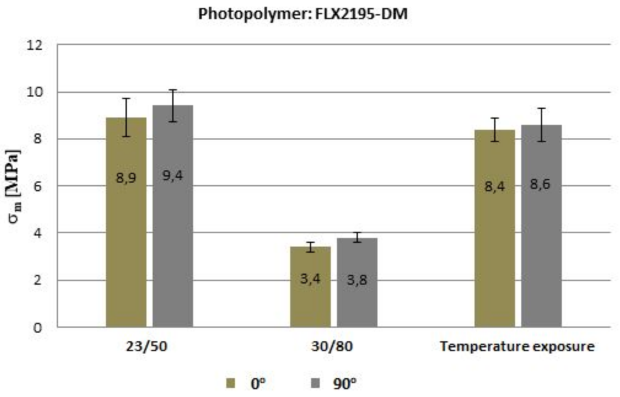

Figure 9. Tensile strength of FLX2195

As a result of wetting, VeroWhitePlus photopolymer showed the drop in tensile strength by 47% and RGD8560-DM and FLX2195-DM photopolymers by (62÷64)%. Concerning the influence of the thermal exposure, VeroWhitePlus performed tensile strength lower by 10% comparing to data reached after conditioning under 23°C/50% air humidity. This divergence is at the limit of statistical significance and is attributed to the micro-cracks that occurred on the parts during their heating and subsequent cooling (see Figure 10). The tensile strength of photopolymers with a higher content of TangoBlackPlus component did not markedly change due to temperature exposure, see Figures 8 and 9. The influence of studied layer orientation on the strength of photopolymer-based parts can be neglected.

Figure 10. Microscopic image of VeroWhitePlus photopolymer after thermal loading

2.4 *Flexural properties of specimens*

Flexural characteristics, particularly flexural strength (σ_{fM}) and flexural modulus (E_f), were determined in a standard 23/50 environment on Honsfield H10kT at a loading speed of 2 mm / min according to ISO 178. The measured values are shown in Figures 11, 12, 13 and 14.

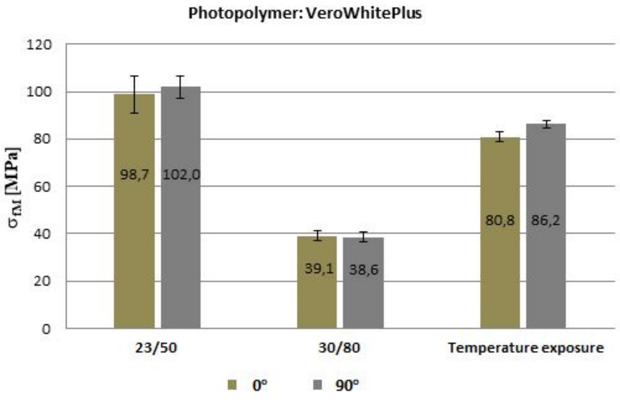

Figure 11. Flexural strength of VeroWhitePlus

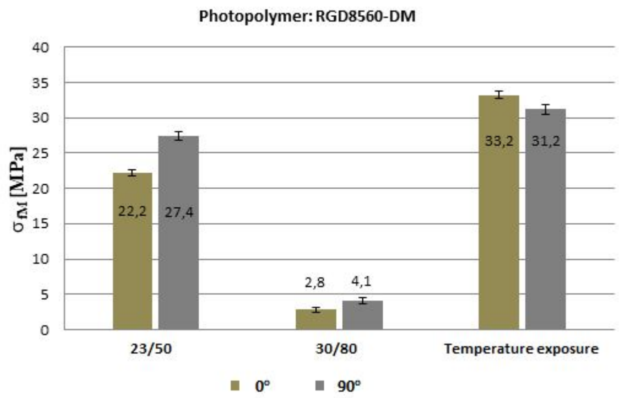

Figure 12. Flexural strength of RGD8560-DM

Higher moisture content reduced the flexural strength of VeroWhitePlus photopolymer by 62%, respectively by 88% fin the case of RGD8560-DM photopolymer. Similarly, the flexural modulus of VeroWhitePlus also was decreased by 54%, resp. by up to 93% when evaluating RGD8560-DM material. Flexural properties of FLX2195-DM (rubber like material), Shore A = 43) could not be determined.

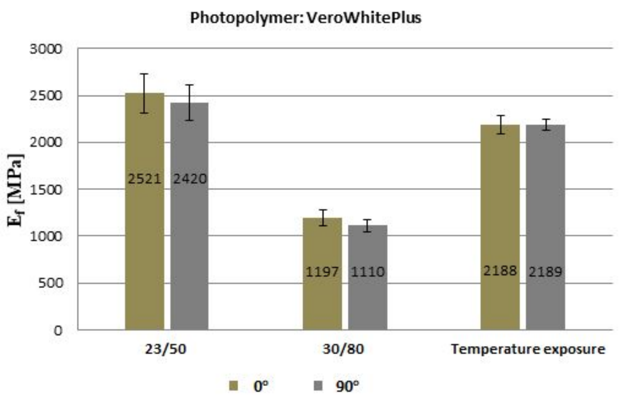

Figure 13. Flexural modulus of VeroWhitePlus

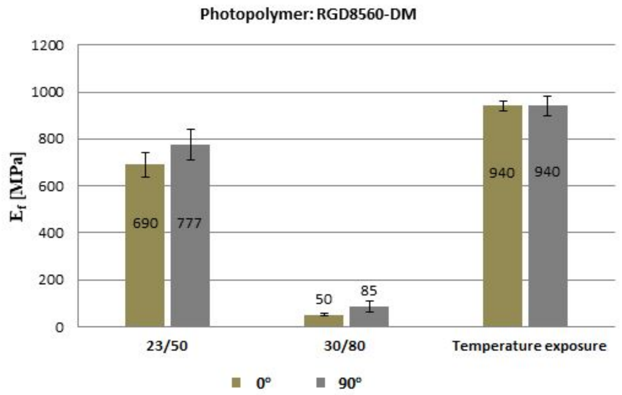

Figure 14. Flexural modulus of RGD8560-DM

After the thermal exposure of test bodies, VeroWhitePlus photopolymer performed flexural strength lower by up to 18% and flexural modulus was reduced by up to 13%, see Figures 11 and 13. Decrease in flexural properties after thermal exposure was induced by micro-cracks in the test bodies (see Figure 10), that occurred after their heating and cooling. Conversely, parts made of RGD8560-DM (photopolymer with lower hardness) exhibited increased flexural strength and flexural modulus when exposed to the heat. The scope of changes in flexural properties in this case were dependent also on the orientation of layers during 3D printing. With orientation of the layers (0°), the flexural strength of RGD8560-DM increased by about 50% and the flexural modulus by 36% as a result of structural changes. With the orientation of the layers (90°) the increase in flexural strength was only by 14 % and flexural modulus increased by 21%, see Figures 12 and 14.

When evaluating the influence of layer orientation during 3D printing, the fact can be stated that the only changes were observed when analysing the flexural characteristics of RGD8560-DM. Specimens with the orientation of layers (90 °) conditioned in a standard environment (23°C/50% a.h.) reached superior flexural strength by 23% compared to the orientation of the layers (0 °), and by up to 45% to bodies with higher humidity content. An exothermic reaction during simultaneous polymerization of the material by UV light was probably the cause of lower flexural strength with the layers' orientation (0°) where smaller surface for feat release is disposable.

CONCLUSIONS

From study of the influence of the environment on mechanical characteristics of photopolymer materials processed by PolyJet 3D printing technology the following results can be stated:

- Exposing parts to the elevated temperatures led to increased bending strength and flexural modulus for RGD8560-DM photopolymer (tensile strength did not change). These changes were not observed when analysing VeroWhitePlus photopolymer. On the contrary, specimens performed lower strength and stiffness due to micro-cracks initiated by their heating and subsequent cooling (in contrast to the VeroWhitePlus photopolymer).
- All studied photopolymers clearly demonstrated their susceptibility to moistening. The greatest effect of moistening was observed when analysing RGD8560-DM and FLX2195-DM photopolymers, which are made up of a mixture of VeroWhitePlus and TangoBlackPlus. The higher humidity exposure induced the decrease in tensile strength (by up to 64%), flexural strength and flexural modulus (by about 90%) for both photopolymer mixtures. With higher moisture content within the specimens the notched impact strength of the material increased, especially in the case of FLX2195-DM photopolymer (up to 15 times).

- The effect of various layers' orientation on final mechanical properties of 3D printed parts was demonstrated only by RGD8560-DM and FLX2195-DM photopolymers when measuring bending and impact properties. Higher bending and impact properties were achieved with the layers' orientation of 90°.

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REFERENCES

[Crivello 2014] Crivello, J. V., Reichmanis, E, Photopolymer materials and processes for Advanced Technologies. Chemistry of Materials, 26 (1), pp. 533-548, 2014. DOI: 10.1021/cm402262g.

[Fouassier 2012] Fouassier, J.-P., Lalevee, J. Photoinitiators for polymer synthesis: scope, reactivity and efficiency. Wiley-VCH, 2012.

[Hsieh 2017] Hsieh, Fan-Chun et al. Mechanical behavior of photopolymer for additive manufacturing applications. 2017 IEEE International Instrumentation and Measurement Technology Conference, 2017. DOI: 10.1109/I2MTC.2017.7969726.

[Ibrahim 2009] Ibrahim, D. et al. Dimensional error of selective laser sintering three-dimensional printing and PolyJet models in the reproduction of mandibular anatomy. Journal of craniomaxillo-facial surgery, 37, pp. 167-173, 2009.

[Pandey 2014] Pandey, R. Photopolymers in 3D printing applications. Degree thesis, Arcada, 2014.

[Prolabs 2018] ProLabs, 3D Engineering Solutions. PolyJet Matrix 3D Printing Services Process [online]. © 2013 [cit. 08-10-2018]. Available from: protolabs.co.uk

[Udriu 2017] Udroiu, R., Braga Ion Ch. Polyjet technology applications for rapid tooling. MATEC Web of Conferences 112:03011. DOI: 10.1051/matecconf/201711203011.

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