3D Printing as a Function of 2D Printing

Branka Lozo, Maja Stanić, Sonja Jamnicki; University of Zagreb – Faculty of Graphic Arts; Croatia; Tadeja Muck; University of Ljubljana – Faculty of Natural Science and Technology; Slovenia

Abstract

The application of 3D printing in conventional printing technology was studied. Two methods of using of 3D prints in function of 2D printing were considered. Physical and mechanical characteristics of printed 3D material were determined in order to verify the use of 3D prints in conventional flexography printing process. 3D prints can be used as flexographic printing plate directly and as a negative matrix for conventional photopolymer flexographic printing plate production. Current material 3D prints are brittle and porous; therefore the finishing is required before further use. Liquid epoxy resin was considered as an appropriate agent as well as some other infiltrates, such as cyanoacrylate and polyurethane infiltrants. It is important that the applied infiltrant penetrates completely into the 3D print without any influence to its dimensions. The digital test form of the flexographic printing plate is required for the 3D printing. It can be constructed either by computer program or by scanning. 3D scanner is appropriate if the conventional flexographic printing plate exists and the 3D technology is used to produce the copy. The attempt of producing the 3D digital test form of the flexographic printing plate by means of computer programming was done.

Introduction

3D printing process is a novel and propulsive way of digital fabrication. By employing the well developed technique of ink-jetting one type of material onto the other type and thus binding them together, it enables the fast and accurate production of complex three-dimensional objects. Although this process is called printing, strong links between 3D printing and the 2D printing techniques, used for transferring the information usually onto a kind of printing substrate, do not exist. Considering existing research and patents which deal with more complicated methods of producing the standard printing plate with the Ink Jet process technology [1] [2], the possible use of 3D prints in production of a printing plate for a conventional 2D printing process was chosen and investigated as a possible link between the two printing technologies. Flexography printing is the main process used in printing on corrugated containers transport packaging. This application is not too demanding on print quality since, basically, there is no halftone or screening process involved.

Both methods of utilizing the 3D prints in printing plate production for flexography, one being direct printing and other being negative matrix printing, were investigated. For a negative matrix printing method, more widely used combination of plaster-based powder and water-based binder with the addition of an appropriate infiltrant, was considered as a material. After evaluation of both methods, it was decided to continue with the attempt of producing the printing plate via 3D printing of the negative matrix in which a conventional polymer, UV curable, would be poured, cured and later removed.

3D Printing Process Overview

3D printing technique is a type of rapid prototyping (RP) process. It is classified as an additive RP process, using the powder material which is fused by ink jetting the binder [3]. 3DP^{TM} process has been developed by the Massachusetts Institute of Technology (MIT) and licensed to various companies in diverse fields of use. The process technology itself is based on Ink Jet printing; it employs a similar method of jetting the binder material in a form of controlled droplets which join the powder particles together. In a 3D color printer, the color inks are a part of the binder solution. 3D printing process functions by building parts in layers, which have been sliced by computer algorithms from the CAD model of the desired object. For the each layer production, the powder particles are evenly distributed over the printing surface and selectively joined by employing a binder material. The support piston is then lowered and the next layer of powder is applied, followed by the binder material. This process is repeated until the desired object is finished. It is then raised out of the unbound powder and usually finished with the appropriate agent.

The 3D printing is currently the fastest rapid prototyping technology available. Other than that, it is capable of adapting to newly developed materials and compositions. This is due to its flexibility in material handling and the fact that it uses different print heads for different materials, makes it able to locally tailor material composition. Furthermore, it has no limitations in terms of geometry of the designed part [4]. Nowadays, 3D printing is used in various fields and areas, such as architecture, engineering, GIS, medicine, product development, concept modeling, direct casting, art and etc. 3D printing is considered one of the emerging application fields of standard Ink Jet printing [5], and having in mind the technological progress both in printing technology and material research, it is one of the most propulsive RP processes.

Its drawbacks are mainly concentrated on the characteristics of the produced objects. Printing resolution is still considerately lower than of the standard Ink Jet printing, printed objects are relatively rough and somewhat heavily textured and their mechanical properties are weak.

Conventional Flexographic Printing Plate

Flexography is a direct printing process that derives from the conventional letterpress printing technique. It employs a flexible and resilient printing plate, whose thickness is in the range of millimeters. Flexible printing plate, in conjunction with the low printing pressure needed for producing an imprint and low viscosity inks, result in flexography being the only printing process capable of printing on various and very differing substrates, including thin films, thick cardboard, rough surfaced packaging materials, like corrugated containers and various quality grades printing papers. General quality capabilities of flexography printing are still not in range of high quality offset printing, but flexography is mostly used for packaging printing and its quality level is satisfactory for most of its area of usage. Other than that, computer to plate platemaking systems have tremendously improved quality in flexography.

Currently, printing plates for flexography are made from rubber or polymer material. Printing plates are made by molding a matrix, by photographic/chemical process or by laser engraving. Rubber printing plates are mostly made by molding an embossed casting mold with natural rubber or by direct ablation of printing plate by laser engraving the non-printing areas. Photopolymer printing plates are most commonly used flexographic printing plates and are currently produced by photographic/chemical process or by some of the computer to plate processes employing laser. Photopolymers for flexographic printing are water or solvent soluble when untreated, but when exposed to UV light they become cross-linked. Cured photopolymers are not longer soluble, which makes the current platemaking process able to produce printing plates. The platemaking process generally consists of the following: full surface back exposure; main exposure though the negative film in order to cure the printing elements; washing off of the unexposed material; post exposure and drying. In computer to plate process, laser beam ablates the carbon black layer which serves as a negative film and the process from this point on is almost identical to photographic/chemical one.

Unlike in other conventional printing processes, printing plates for flexography printing vary in hardness and thickness, and are chosen in accordance with the specific process characteristics. Printing plates may be flat and later fastened onto the plate cylinder or already be produced in a cylindrical form. Their thickness varies from about 0.015 inch up to as much as 0.250 inch, with the relief depth from about 0.008 to 0.120 inches. The hardness of flexographic printing plates is most often expressed in Shore A scale units, and is usually in range of 20-80 Shore A points. Having in mind various substrates and final uses of flexography prints, a wide variety of inks are used. It is important that the printing plate material must be inert when in contact with the ink, e.g. it must not swell in contact with ink or be etched by the ink [6].

Materials and Methods

Testing of 3D Materials Properties

The first step in assessing the 3D prints usage in 2D printing plate production was to characterize some of the properties of the current powder type material and water-based binder material combination in 3D prints. The combination of plaster-based powder and water-based binder was chosen and testing of mechanical properties was performed. In addition to testing of "raw" printed samples, three infiltrant agents were used. Properties of finished samples were determined.

The standard sized samples needed for testing were printed on the Z510/Cx printer. It is a color printer, with resolution of 600 x 450 pixels, build size 10 x 14 x 8 inches, build speed of 2-4 layers per minute, user selectable layer thickness between 0.0035-0.008 inches (0.089-0.203 mm). Material options are high performance composite, elastomeric and direct casting materials. Its printing head system comprises of four printheads (C, M, Y color binders and clear binder) with 1216 jets total. The prints were made with the ZP130 high performance composite material and ZB58 binder, with the layer thickness set to 0.0035 inch.

Powder ZP130 components [7]

	App. % by weight
Plaster	50-95%
Crystalline Silica	<1%
Vinyl Polymer	2-20%
Sulfate Salt	0.5%

Binder ZB58 components [8]

	App. % by weight
Glycerol	1-10%
Sorbic Acid Salt	0-2%
Surfactant	<1%
Pigment	<20%
Water	85-95%

Printed samples were divided into four groups and handled in the following manner: first group samples were untreated, second group samples were finished by the Z-Bond 101 CyanoAcrylate infiltrant (Beta-Methoxyethyl cyanoacrylate), third group samples finished by the Z-Max Epoxy infiltrant (one component epoxy resin and other component piperazine derivative) and fourth group samples finished by the Protektin polyurethane infiltrant (acrylic resin and organic solvent). Additionally, three more subgroups of samples for the tensile properties test were made; one printed in x-y direction of printing, one printed in additive synthesis black color (table of abbreviations) and one baked at approximately 140 degrees Fahrenheit for 30 minutes. All three subgroups were later finished with the Z-Bond infiltrant and tested.

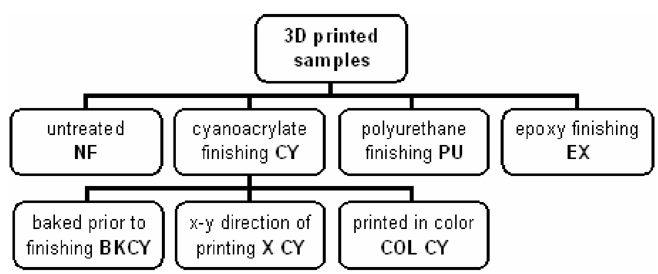

***Figure 1**. Workflow of the material mechanical testing procedure*

Considering infiltrant manufactures, Z-Bond and Z-Max are manufactured by Z Corporation and Protektin by a local Slovenian manufacturer. All infiltrant agents were applied onto the samples by dipping them into the infiltrant fluid for the following amount of time: 2 seconds in the case of cyanoacrylate agent, 2.5 minutes in the case of epoxy agent and 2 minutes in the case of polyurethane agent. The amount of infiltrant was quantified gravimetrically.

In order to test physical and mechanical characteristics of non-finished 3D prints, as well as those finished by the infiltrants, the selected test were conducted. Tensile properties were tested in accordance with the ISO 527-1:1996 and the ISO 527-2:1996 standards, and were expresses as ultimate tensile stress in the moment of material breakage. The measurement scale of machine was set to 0-950 N, with the load speed of 7 mm/min. Impact strength was tested on the unnotched standard sized sample, in accordance with ISO 179-1:2000 (E) (Charpy) standard. Hardness of materials was tested by the ball indentation method, in accordance with ISO 2039-1:2001 (E) standard. The hardness measurements were done by the ball of 5 mm in diameter and with the pressure of 5 kP (NF, CY, PU samples) and 13.5 kP (EX sample), and are shown for t = 30 seconds. All material testing was done under the uniform conditions, with the relative humidity at 65% and temperature at 71.6 degrees Fahrenheit.

Flexographic Printing Form Production

The second step of employing 3D prints in platemaking production was to produce a 3D printed matrix and infiltrate it with the appropriate agent. It would be then filled with the liquid photopolymer material, which would be UV cured and thus producing the printing plate for the flexographic printing (Figure 2).

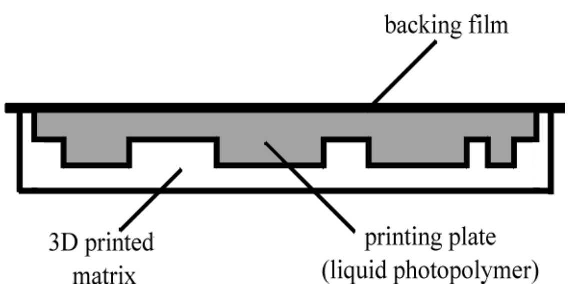

***Figure 2**. Scheme of utilizing 3D print as a negative matrix in photopolymer printing plate production*

The design of digital test form consisted of various graphical and typography elements in various line widths and sizes (Figure 3).

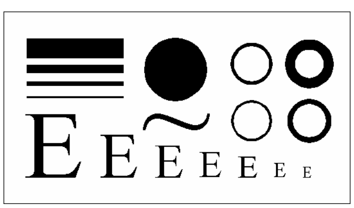

***Figure 3**. Digital test form design elements*

The matrix was printed on the Z510/Cx printer, from the ZP130 powder and ZB58 binder, with the layer thickness set to 0.0035 inch. The printed matrix was finished with the chosen infiltrants. The optimal infiltrant for the finishing of the matrix has to have appropriate mechanical properties to ensure proper behavior during the printing plate production and in addition, must not change matrix dimensions and should ensure smooth surface finish. Infiltrants used for the finishing of the matrix were the cyanoacrylate agent and the polyurethane agent as it was observed that they both meet the demands. The obtained matrix was filled with the liquid photopolymer material (photosensitive polyurethane elastomer, VE 108 W 55) regularly used in the laboratory for production of rubber stamps and flexographic printing plates. The photopolymer was poured into the matrix and the thin polyester foil was placed on the top, in order to serve as a backing film for the support and easy handling of finished printing plate. The matrix was then placed into the platemaker apparatus (AZ 1500 N3) which employs an UV lamp (UV-A light emitting source) in order to cure the photopolymer material. When observed to be fully cured, the printing plate was peeled out of the matrix. Laboratory prints were done using water-based flexo ink.

Results and Discussion

Testing of 3D Materials Properties

Abbreviations

NF	Raw, non-finished
CY	Cyanoacrylate finishing
EX	Epoxy finishing
PU	Polyurethane finishing
COL CY	Color (R 0 G 0 B 0)
X CY	x-y direction of printing
BK CY	Baked prior to finishing, for 30 minutes at 140 degrees F

Gravimetric measurements of samples show that the weight increased for 21% after being finished by the epoxy agent, 12% by the cyanoacrylate agent and 7% by the polyurethane agent. This can be explained if penetration depth of infiltrants is taken into account. Epoxy infiltrant penetrates up to 10 mm in depth and cyanoacrylate infiltrant only up to 3 mm [9], thus the amount of epoxy agent absorbed is higher then of other two agents. It is also observed that the samples finished with the epoxy infiltrant vary the most in weight and that the amount of the infiltrant absorbed rises with the weight of the initial sample.

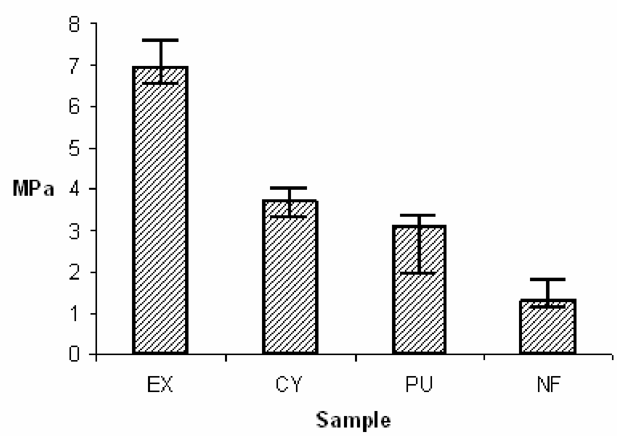

***Figure 4**. Tensile Strength plot*

Figure 4 shows that the EX sample endures the highest force before breaking into two pieces, followed with the CY sample, PU sample and NF sample respectively. When comparing NF sample with the according finished samples, finishing by epoxy agents improves tensile strength 5.23 times, by the cyanoacrylate agent 2.77 times and by the polyurethane agent 2.32 times.

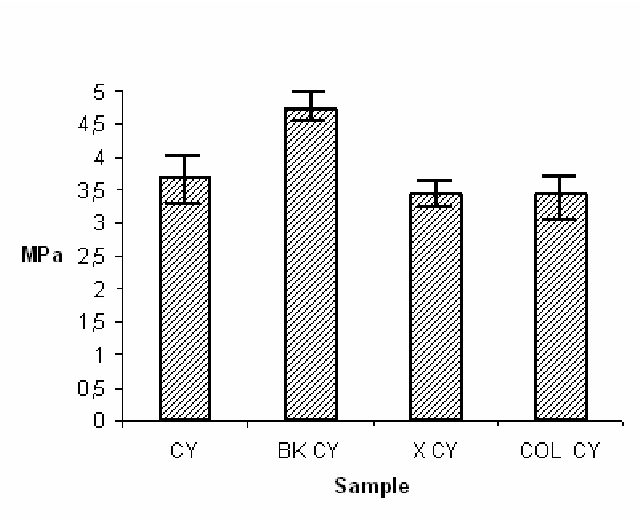

***Figure 5**. Tensile Strength plot for CY group of samples*

It is presumed that the various printing preferences such as color or direction of printing (x-y or y-x direction) may have effect on the finished sample tensile characteristics. The CY samples were divided in four groups of samples, according to different printing and finishing preferences. The CY sample which was baked as it was prescribed by the manufacturer of the material and then finished by the agent show the highest tensile strength among the CY group of samples (Figure 5).

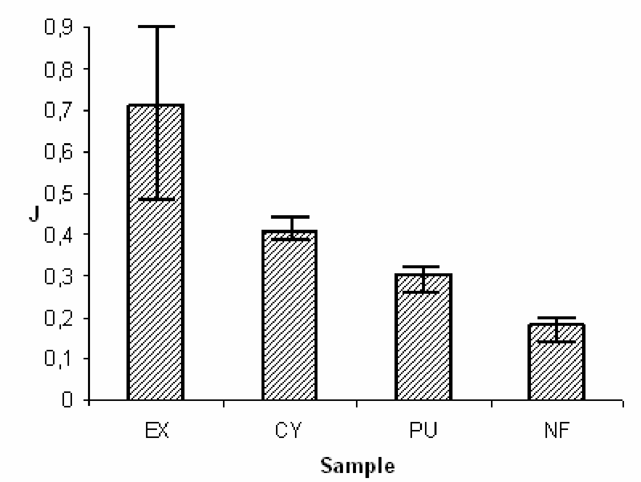

***Figure 6**. Impact Strength plot*

The improvement in strength is 1.28 times when comparing BK CY and CY sample. The samples COL CY (printed in additive synthesis black color, table of abbreviations) and X CY (printed in the axis x-y direction) can be compared with the CY sample (printed in axis y-x direction) since they were all finished with the same agent. X CY sample compared to CY sample (x-y versus y-x direction) show a small degradation in tensile properties as it has only 5.98% lower measurements results. The COL CY, on the other hand, was printed in y-x direction of printing, as CY sample was, but its measurement result showed 6.52% degradation. This is due to the sample being printed in color.

The plot of the results for impact properties of samples is shown in Figure 6. Again, EX samples showed the highest impact strength and were followed with the CY samples, PU samples and NF samples respectively. The finishing by the epoxy agent increases impact strength 3.86 times, by the cyanoacrylate agent 2.22 times and by polyurethane agent 1.65 times when compared to NF sample measurement result.

Figure 7 shows the plot for the results of Brinell Hardness measurements. The EX sample shows the highest hardness, followed by PU, CY and NF sample in descending order. When comparing the hardness measurements of the NF sample with the finished samples, the finishing of the original sample by the epoxy agent improved hardness 5.2 times, by the polyurethane agent 2.06 times and by the cyanoacrylate agent 1.86 times. The hardness measurement is the only mechanical property tested in which the PU sample shows higher measurement result then CY sample.

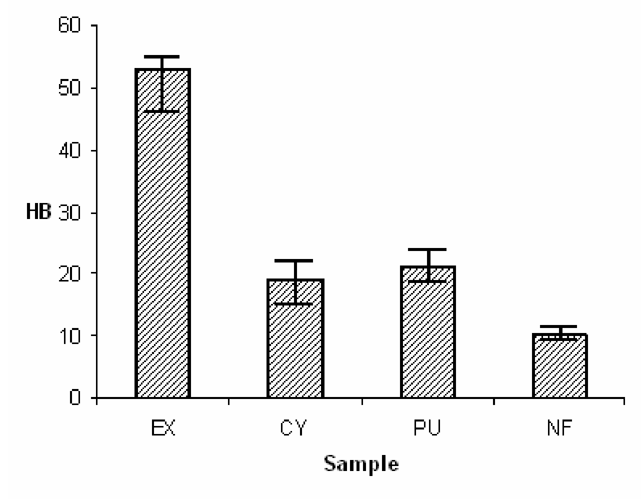

***Figure 7**. Brinell Hardness plot*

Besides testing of the mechanical properties, all samples have been observed in order to check the visual appearance of their surface. Visual observation of the finished samples shows that the epoxy finished samples have, in some cases, traces of the leftover epoxy agent on their surface. A small amount of infiltrant does not penetrate completely but hardness on the surface, thus slightly increasing the dimensions of the samples and making them uneven in the relief.

The results of the mechanical properties testing, combined with the detailed visual inspections, serves as a decisive element for the choice of the infiltrant to be used in production of matrix for the printing plate. It is decided that the appropriate infiltrant agent has to secure easy handling of finished matrix (good mechanical properties), can not change dimensions of 3D prints and has to offer smooth surface finish but should not block fine details by filling the small cavities. Other than being the factor for the choice of the infiltrant agent, the results obtained show some of the effects of infiltrant agent type onto the selected mechanical properties. They can also serve as guidance for some future uses of 3D prints in platemaking, which would utilize them for direct printing.

Flexographic Printing Form Production

For finishing of the printed matrix all three above tested infiltrant agents were considerate. Epoxy agent, although having the best mechanical characteristics, was discarded as it was established that the small amount of it sometimes stays on the surface and changes the surface dimensions and uniformity. Polyurethane finished samples have similarly rough surface as the samples finished by cyanoacrylate agent. They also have slightly lowered tensile and impact strength, and their hardness measurement result was only slightly higher then the polyurethane finished samples. Considering these small differences, two matrixes were used and infiltrated, by the cyanoacrylate and polyurethane agents respectively, in order to see the effect of the finishing agent choice on the visual appearance of obtained printing plates. Laboratory prints were done using both printing plates.

The dimension of the object that can be printed on the existing 3D printers are limited, which in current practice is solved by printing the object in sections and later joining them together. This characteristic of 3D printers is not of vital importance for discussed printing plate production as flexography occasionally uses printing plates of small dimension for printing e.g. logos and safety signs on corrugated containers transport packaging. This also correlates with the low quality and resolution limitations of the current 3D technology, as high quality is neither expected nor needed for this area of application.

New materials for rapid prototyping processes, including 3D printing, are extensively researched. This is of vital importance for the second suggested method for utilizing 3D prints in conventional printing technology, the direct printing of the printing plate. This method of producing the printing plate for flexography would have to use rubber or elastomere materials in order to achieve the criteria needed for practical usage of printing plates produced in this manner.

When discussing the parameters of new materials for 3D printing that could be used for direct printing of flexographic printing plates, the materials will have to fulfill number of criteria important to printing plates when used in printing process, such as abrasion resistance, durometer hardness, resilience and solvent resistance (reaction of the plate material with the ink compounds) [10]. The method discussed in this work, the 3D printing of mold/matrix, can also benefit form new materials being researched, since the aim is to produce the material which will have the desired mechanical properties without the need for finishing and, in the same time, would produce objects with excellent dimensional accuracy (resolution) and smooth surface which will not require post treatment. Pfister et al. recently presented a material of similar characteristics which was actually used on a 3D printer [11].

Conclusions

Having in mind the results of materials tested mechanical properties, as well as 3D printed flexographic printing plate matrix production, it can be concluded that the choice of infiltrant agent for the finishing of 3D printed matrix needs to focus on finding the optimum combination of the mechanical properties and surface roughness of the material.

The attempt of producing a 3D print of the printing plate matrix to serve as a mold for the UV curable photopolymer show that the available material and process serve as a good starting point for this method of producing printing plates. The printing plate obtained by the negative matrix production method achieves the required characteristics. Considering new materials being researched and technology improvements, 3D matrix printing method as well as the direct 3D printing of printing plate method, could prove to be optional solutions to current platemaking processes. The improvements can still be expected in the area of the 3D printing speed and resolution. The novel methods of printing plate production should improve the platemaking process energy efficiency and time-consumption.

References

[1] D. Gelbart, Creo Inc., Method for Making Printing Plate Using Inkjet, U.S. Patent 6520084 (2003).

[2] M. Figov, S. Dvoretzki, Creo IL Inc., Method for producing a flexographic printing plate formed by inkjetted fluid, U.S. Patent 7036430 (2006).

[3] http://web.mit.edu/afs/athena.mit.edu/org/t/tdp/www/whatis3dp.html

[4] J. Stampfl, R. Liska, "New Materials for Rapid Prototyping Applications" Macromol. Chem. Phys., 206, 1254 (2005).

[5] H. P. Le, "Progress and Trends in Ink-jet Printing Technology, Part 1" J. Imaging. Sci. and Technol., 42, 60 (1998).

[6] Helmut Kipphan, Handbook of Print Media (Springer-Verlag, Berlin Heidelberg, Germany, 2001) pg. 398.

[7] Z Corp. zpTM130 powder MSDS 8/04 revised 10/04, 4/05 (Z Corporation, Burlington, MA, 2005) pg. 1.

[8] Z Corp. zbTM58 binder MSDS 6/05 (Z Corporation, Burlington, MA, 2005) pg. 1.

[9] Z Corporation 3DP Consumables Catalog (Z Corporation, Burlington, MA, 2007) pg. 12.

[10] Mac Dermid Printing Solutions Tech Tips (Mac Dermid Printing Solutions, Atlanta, GA) pg. 1-4.

[11] J. Pfister, U. Walz, A. Laib, R. Mulhaupt, "Polymer Ionomers for Rapid Prototyping and Rapid Manufacturing by Means of 3D Printing" Macromol. Mater. Eng., 290, 99 (2005).

Acknowledgements

The authors wish to thank several persons for their help and support; 3D prints and finishing, Edo Sternad and Andrej Žužek from the Ib-Procadd, Ljubljana, Slovenia; polymer platemaking, Sanja Mahović Poljaček, Faculty of Graphic Arts, University of Zagreb, Croatia; material testing, Đurđica Španiček, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia.

Author Biography

Assistant professor Branka Lozo, PhD, received her Master of Science degree, as well as her PhD degree from the Faculty of Graphic Arts, University of Zagreb, Croatia. She works at the same Faculty as the assistant professor at the Department for Materials in Printing Technology. She is involved in the scientific research of paper properties and recycling processes under the European Science Foundation.

Maja Stanić, dipl. ing., graduated in Graphical Technology from the University of Zagreb, Faculty of Graphic Arts (2006) and is currently a PhD student in Graphical Engineering at the same University. Since the start of her doctoral study, she has focused her interests on novel printing techniques such as 3D printing, developments in non-impact printing techniques, print quality assessment and the use of image analysis techniques in paper and graphical technology.

Sonja Jamnicki, dipl. ing., graduated in 2004 in Graphical Technology from the University of Zagreb, Faculty of Graphic Arts and is *employed at he same Faculty as an assistant at the Department for Materials in Printing Technology. She is also a PhD student in Graphical Engineering at the same University. Her current occupation mainly involves laboratory testing of graphical materials properties.*

Assistant prof. Tadeja Muck, PhD, was born in Brežice on 5th May, 1971. She graduated in Chemical Technology at Faculty of Natural science and Technology Ljubljana in 1996, received PhD in Graphic Technology from the University at Ljubljana in 2002, Assist. Prof. in 2003. She is employed at the Faculty of Natural Sciences and Technology as assistant professor, where she gives lessons about Technology of Graphic Processes and Interactive Printing Technologies.