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A MODEL FOR IMPROVING THE FLEXOGRAPHIC PRINTING PLATE MAKING PROCESS

Dragoljub Novaković, Sandra Dedijer, Sanja Mahović Poljaček

Original scientific paper

Thermal development process of photopolymer printing plates is one of the newest technologies in the flexographic reproduction process. It is solely based on mechanical process and thus enables the elimination of the chemical processing and drying phase from the plate making process. Taking into account that chemical processing is one of the critical problems in standardization of the plate making process, thermal development process should ensure greater quality and stability in the plate making process. This paper evaluates the specific conditions in the plate making procedure based on thermal development. Testing of the back and main exposure duration of the photopolymer plates, as well as duration of the thermal development, were the objects of this research. The thickness and hardness, as well as SEM analysis of the printing plates were performed. Characterization of the produced plates was made and new model for improving the production line of the observed flexographic plates was defined.

Keywords: *flexographic printing plates, quality, thermal development process*

Model poboljšanja izrade fleksotiskarskih tiskovnih formi

Izvorni znanstveni članak

Proces termalne obrade fotopolimernih tiskovnih formi za fleksotisak novost je u grafičkom reprodukcijskom procesu. Proces je baziran na mehaničkoj obradi tiskovnih formi čime se eliminira proces kemijskog razvijanja i sušenja iz postupaka izrade tiskovnih formi. S obzirom da je kemijsko razvijanje jedno od najnestabilnijih procesa u izradi tiskovnih formi te time otežava standardizaciju postupka izrade tiskovnih formi, proces termalne obrade bi trebao unaprijediti kvalitetu i stabilnost promatranog procesa. U ovom radu su praćene sve faze u izradi tiskovnih formi baziranih na termalnoj obradi. Mjerena je debljina i tvrdoća uzoraka, te je provedena i SEM analiza. Karakterizacija uzoraka je provedena, te je predložen model za poboljšanje uvjeta izrade fleksotiskarskih tiskovnih formi.

Ključne riječi: *fleksotiskarske tiskovne forme, kvaliteta, proces termalne obrade*

1 Introduction
Uvod

Flexography is a printing technology generally used in packaging. It is a relief printing process meaning that the image areas on the printing plate are raised above the non-image areas. During the reproduction process, image areas receive the printing ink which is transferred directly to the print substrate when the substrate is pressed with support of the impression cylinder against the printing plate. The pressure between the anilox roll (carrier of the printing ink) and the printing plate, and then between the printing plate and the substrate, must be carefully adjusted to give a uniform print with no areas of over impression. The printing process requires only a slight contact pressure to enable reliable ink transfer from printing plate to substrate. Soft, flexible printing plates facilitate quality imprints even with a low and gentle contact pressure within the printing plate and printing substrate [1-4]. Printing process is characterized by flexible printing plates and low viscosity printing inks. It is possible to print at almost every substrate [5], i.e. on very thin, flexible, and solid materials, virtually all papers, thick cardboard, rough-surfaced packaging materials and fabrics. Flexographic plates vary in their hardness and thickness which has to be adapted to the particular substrate and specific process characteristics. They are mainly made of rubber or photopolymers. Basically, they consist of elastomeric vehicles, unsaturated monomers and UV photo-initiators which are soluble in water or in organic solvents.

Flexographic printing plates can be produced by photographic/chemical processes or by one of the digital laser-based computer to plate (CtP) technologies [4, 6]. There are different imaging systems available for CtP in flexographic printing. One of the processes used for producing photopolymer plates includes laser imaging of the surface in which the base, photopolymer, receives a black, sensitive coating. By computer controlled system, laser beam causes ablation of the black coating in accordance with the computer image (information). The remaining part of this coating forms a mask for the subsequent main exposure of the photopolymer coating with UV light. Main exposure causes the cross linking reaction in the printing plate which has to be, after the exposure, washed off by chemical processing method, dried, post-exposed and post-processed.

Nowadays, for high quality requirements, especially in the area of packaging printing, digital photopolymer wash-off plates are commonly in use. New, thermal technology patented by DuPont, Cyrel, USA eliminates the solvents and aqueous solutions from the plate making process, i.e. washing-off process. Taking into account that chemical processing is one of the critical problems for standardization of the plate making process, thermal development process, which does not use chemicals, should ensure greater stability of the printing plates. This process is environmentally friendlier than the others which use the wash-off processes. In addition, it ensures greater productivity by approximately five times, that is quite significant in the production workflow [7]. Expansion and development in the area of flexography is welcome, but it is confronted with one main problem: the absence of standards for producing the printing plates of high quality and stability. Lack of standards has caused inability to predict results and necessity to adjust the plate making process to the current production conditions. In majority of processes, requirements for the printing plate procedure are addressed to the manufacture recommendations which often define technological tolerances in which the plate making process can be optimally obtained.

The aim of this study was to evaluate the specific conditions of the processes in the plate making procedure based on thermal development according to the parameters defined in manufacturer's recommendations. Furthermore, the object of this study was to find the optimum duration of all processes in the plate making procedure in order to accelerate the productivity and to ensure the high quality and functionality of the printing plates as well.

2
Thermal technology
Termalna tehnologija

Thermal development process is one of the newest technologies in the field of flexography. It is the process which allows the removal of untreated (unexposed) polymer through a strictly mechanical process, without using any solvents. It has many advantages in regard to other digital technologies used in the flexographic plate making process. It is environmentally friendly with no solvents and aqueous solutions to handle, store or recycle workflow [7]. It is designed to meet the needs of high quality imprints with fine halftones, lineworks and solids.

The structure of the CtP flexographic untreated plate for digital image transfer by CtP systems is shown in Fig. 1. It consists of protective layer on the top of the plate, followed by laser energy absorbent layer, photopolymer relief layer and base material.

CtP flexographic plate making process, based on thermal development, consists of a series of successive, mutually dependent stages presented in Fig. 2: back exposure, laser imaging, main exposure, thermal development process, post exposure and light finishing processes (UVA and UVC).

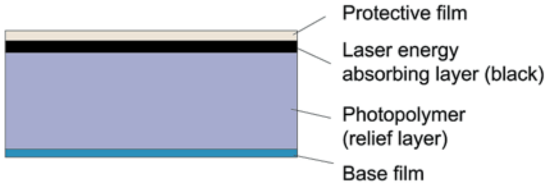


Figure 1 *Structure of the CtP flexographic plate*
Slika 1. *Struktura CtP fleksotiskarske tiskovne forme*

In the first stage, back exposure (Fig. 2a), photopolymer is treated with UV-A light, to form relief depth and to support the anchoring of fine details. Duration of the back exposure varies according to the depth of required relief. In the next phase (Fig. 2b), absorbing layer (Laser Ablatable Mask (LAM) layer) is revealed on removal of the protective film. It has to be ablated to create the image with computer controlled laser beam. In this process the laser beam ablate the black, energy-absorbent layer and creates the reverse image in the layer.

Black layer has a function of a mask in the next exposure phase – main exposure (Fig. 2c). Main exposure is carried out with UV-A light in order to form future image areas in the polymer. In the next, thermal processing unit, the printing plates are firstly treated by the IR heater, whose task is to melt untreated (unexposed) monomer (Fig. 2d). Further, the printing plate has to be put in contact with processing cylinder by means of a heated cylinder.

Furthermore, the untreated polymer is removed mechanically by transferring the untreated polymer on the processing cylinder (carrier of fabric) which is in the contact with the printing plate cylinder.

Depending on the relief depth and thickness of the printing plates, the rotation has to be repeated 10 to 12 times in order to completely remove melted material [8].

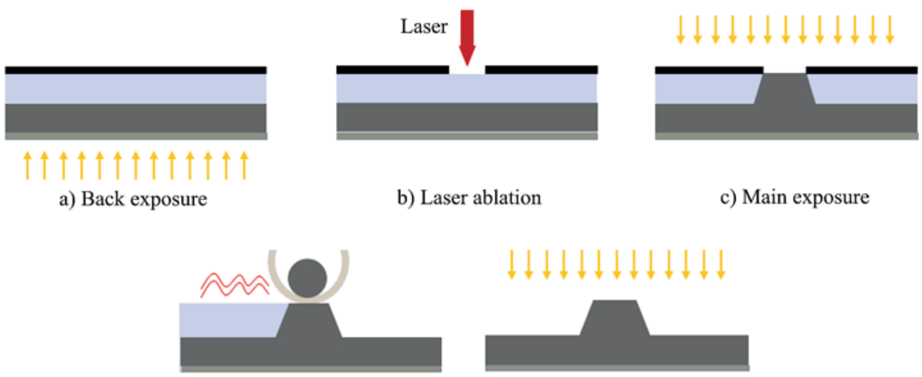


Figure 2 *Imaging and thermal development of photopolymer plates*
Slika 2. *Osvjetljavanje i termalna obrada fotopolimernih tiskovnih formi*

Thermal development process is rather specific while quality of the processed plate is defined through a number of drum rotations (Fig. 3). The rotations speed cannot be changed and it is defined by the manufacturer; one rotation lasts 1,12 minutes [8].

During thermal development, the drum has to be water cooled in order to avoid self overheating as well as overheating of the photopolymer plate. In the next stage, post exposure and light finishing (Fig. 2e) are carried out with UV-A and UV-C light in order to eliminate stickiness of the plate and to provide complete curing of polymers.

3
Experimental part
Eksperimentalni dio

3.1
Materials and methods
Materijali i metode

In the study DuPont TM Cyrel ® DFH 45 printing plates were tested. The experimental part of the work was performed in standardized production conditions [9]. Printing plates were stored under the prescribed

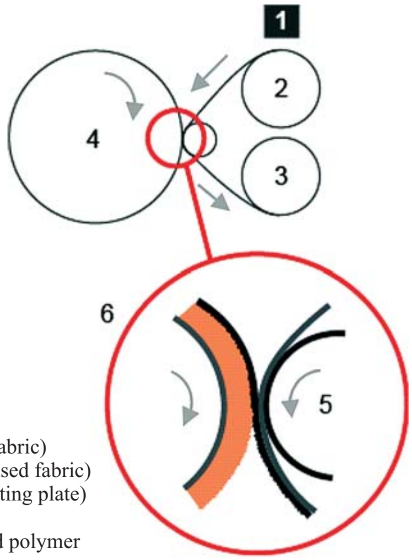


Figure 3 *Thermal development unit*
Slika 3. *Termalna jedinica*

requirements - in the original package and protective foil in a flat position, in defined atmospheric conditions, away from heat sources. During the study, plates were not exposed to direct daylight or UV light (working lab had protective yellow light). The tests were done in air-conditioned room (26-30 °C).

Imaging of the printing plates was made by CDI Spark 4835 Esco Expoze device (imager with external drum and one laser beam) with amplitude raster, 48 l/cm. Back exposure, main exposure, post exposure and light finishing were made by DuPont™ Cyrel 1000 ECLF device. Thermal development process was made by DuPont™ Cyrel ® FAST 1000 TD device.

Characteristics of the printing plates addressed in the work were the thickness and hardness of the flexographic printing plates. Thickness of the printing plates was measured with AB Lorentzen and Weltre (type 556 G) micrometer (precision of 0,001 mm). Hardness of the printing plates was measured with Zwik analog hardness tester. Standard DIN 53505 Sh A prescribed a method for measuring the hardness of flexible materials [10].

The radiation intensity of UV lamps (80 W) used for imaging of the printing plates was measured by Kühnast UV-meter. The results showed that the lamps had appropriate intensity; mean intensity per unit area was 20,2 mW/cm^2. Microscopic recordings of selected areas of the printing plates were taken with scanning electron microscope (SEM) JEOL JSM 6460 LV.

3.2
Designing the digital test form
Oblikovanje digitalne testne forme

Special digital test form was designed for this research (Fig. 4). It consists of specially defined fields in order to provide adequate monitoring and quality control of printing plate during the platemaking process. The elements of the digital test form and their significance:

1) Halftone patches from 1 to 100 % of coverage - ensure a clear reproduction of halftone dots in all tone value ranges in the highlights and shadows;
2) Positive and reverse text in the 1, 2, 3, 4, 5, 6, 8, 10 and 12 pt of sizes;
3) Groups of positive and reverse lines from 0,03 to 1 mm of thickness (0,01 mm step) and from 1 to 5 mm (step 1 mm) of thickness;
4) Positive and reverse cross lines from 0,002 mm to 2 mm of thickness;
5) Patches with positive and reverse solid tons;
6) Positive and reverse microelements in the diameter of 0,1 to 0,5 mm.

3.3
Back exposure test
Test donje ekspozicije

In order to define the impact of exposure time on relief depth, different duration of back exposure was tested. Appropriate back exposure has to be defined because

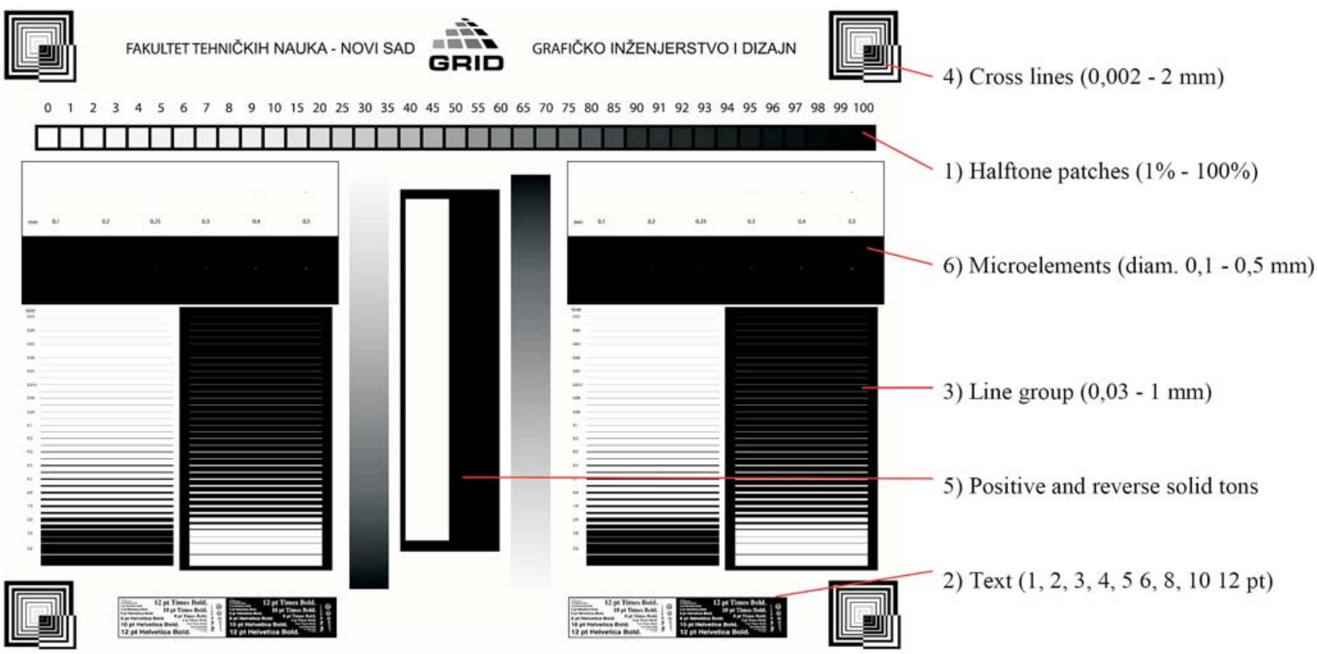


Figure 4 *Digital test form*
Slika 4. *Digitalna testna forma*

it has one of the major influences on the printing plate's quality and stability during the reproduction process. Testing the back exposure was made on printing plates 300 × 600 mm dimensions in steps of 10 seconds. Eight covering tiles were set on the printing plate and last covering tile was not moved throughout the test. The exposure started with removing of the first tile from the plate surface with 10 seconds duration. Second exposure lasted 10 seconds as well, and was made by removing the second tile from the printing plate surface. The procedure was repeated by selective removing of all the tiles and by identical duration of the exposures. The last covering tile was not removed. For this testing the main exposure was not performed. After back exposure, the thermal development of printing plate sample was performed by 10 rotations of the drum (manufacturer recommendation).

Measurements of the thickness of each field were conducted three times. The calculated mean value was subtracted from the value of plate thickness in order to determine the relief depth obtained with different duration of back exposure.

3.4 Main exposure and thermal development test
Test glavne ekspozicije i termalne obrade

Testing of the main exposure was made in accordance with the optimal back exposure, defined in the previous testing stage. In this phase, the influence of drum rotations number (thermal development of printing plate sample) was observed in relation to the main exposure. The test was carried out with 8, 10, 12 and 14 minutes of main exposure and 8 and 10 rotations of the drum. The post exposure (UVA) and light finishing (UVC) was conducted for 7 min [8]. Optimum duration of the main exposure could be controlled on the finished printing plates by observing the halftone patches of 1 and 97 % of surface coverage and by observing the sharpness of the positive lines of 0,05 mm, positive and reverse cross lines from 0,03 mm to 0,04 mm. SEM analysis was performed on those selected areas.

3.5 Characterization of the thickness and hardness of the printing plates
Karakterizacija debljine i tvrdoće tiskovnih formi

According to the recommendations, the thickness of flexo plate should not deviate more than ± 0,010 to 0,015 mm from its nominal value [11]. The same tolerant area is recommended for the plate thickness within the package box, while the thickness of the plates between two packages should not differ more than ± 0,025 mm.

Regarding the hardness of the flexographic printing plates it is possible to measure two different values. The first one is the hardness of the raw plate and the second one is the hardness of the printing plate after processing. The hardness of the raw printing plate is usually not controlled, because this information generally is not useful for plate functionality. This is the reason why printing plate hardness must be considered after processing because it has the direct influence on transferring the printing ink from the plate to the printing substrate. Suppliers indicate that printing plate of 1,14 mm of thickness should have hardness of 75 Sh A with possible tolerances of ± 2 Sh A.

4 Results and discussion
Rezultati i rasprava

4.1 Defining the back exposure – optimal relief depth
Određivanje donje ekspozicije – optimalne dubine reljefa

Results of back exposure test are presented graphically in Fig. 5.

Based on the results the corresponding dependence between back exposure and relief depth can be expressed as follows: longer duration of the back exposure results in shallower relief. Shorter back exposure (10 s) resulted in cross linking process in the surface areas of photopolymer and caused the relief depth of 0,721 mm. Longer back exposure (80 s) resulted in shallower relief of 0,04 mm. Based on the results adequate duration of back exposure was defined on 50 seconds.

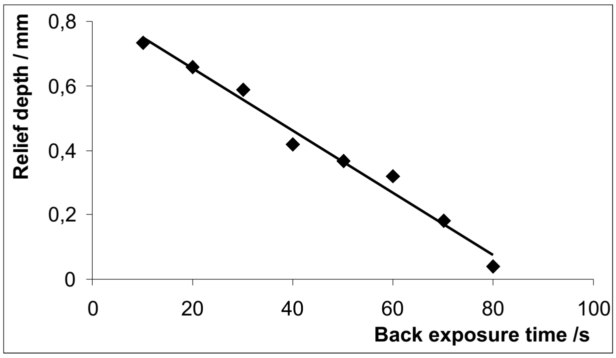


***Figure 5** Back exposure test – dependence of relief depth on back exposure duration*
***Slika 5.** Test donje ekspozicije – ovisnost dubine reljefa o trajanju ekspozicije*

4.2 Defining the main exposure and thermal development
Određivanje glavne ekspozicije i termalne obrade

The main exposure test was conducted through monitoring further parameters: sharpness of halftone dots of 1 to 98 % of coverage, clearness in reproductions of 0,03 and 0,04 mm positive lines, sharpness of the positive and reverse line ratios and relief depth.

The main exposure test was conducted in relation to the thermal development conditions. According to the manufacturer thermal development should be repeated by 10 to 12 rotations of the drum to remove all the melted material and the main exposure can vary from 10 min to 15 min. In order to observe shorter duration of thermal development, it was carried out with 8 and 10 rotations of the carrying drum. Testing was made for the main exposure of 8, 10, 12 and 14 minutes for both thermal processing conditions. After thermal development, each plate was treated with UVA and UVC light for a period of 7 minutes (manufacturer's recommendations). As defined in previous test back exposure was 50 seconds.

Measuring of the relief depth has been carried out in the same way as the back exposure test and the results are displayed graphically in Fig. 6. It can be seen that increasing of main exposure from 8 to 14 min causes the decreasing of relief depth from 0,383 to 0,31 mm for 8 rotations of the drum, i.e. from 0,4 mm to 0,31 mm for 10 rotations of the drum. It can be seen that the observed number of drum

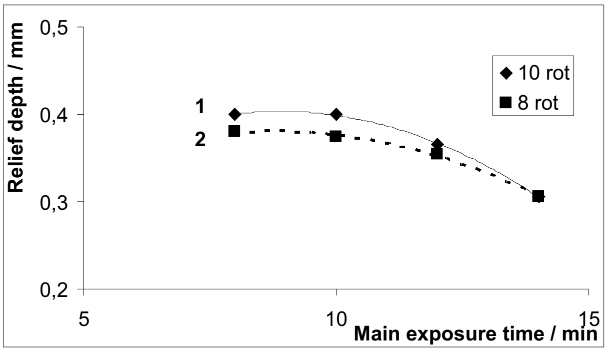


Figure 6 *Dependence of relief depth on main exposure for thermal development of 8 and 10 rotations of the drum*
Slika 6. *Ovisnost dubine reljefa o trajanju glavne ekspozicije za termalnu obradu od 8 i 10 okretaja*

rotations has a minor influence on the relief depth. According to these results, optimal main exposure has been defined on 12 min because in both cases this main exposure resulted with relief depth of 0,361 mm and 0,367 mm, respectively.

4.3 SEM analysis
SEM analiza

SEM micrographs of the characteristic elements on a reproduced test form have been made. Fig. 7 shows SEM images of 1 % of coverage obtained with main exposure of 12 minutes and processed with 8 and 10 rotations of the drum. One can see uniformly distributed, stable dots (image areas) at 1 % of coverage processed with 8 rotations of the drum (Fig. 7a). Every dot has a clearly formed body shape and fully cured polymer along the entire polymer plate surface. From these images it is possible to see that shaped dots have been formed correctly in exposed photopolymer areas. Longer thermal processing (10 rotations of the drum) presented in Fig. 7b indicates that dot of 1 % of coverage has similar quality and characteristics, and furthermore, through both processing conditions, untreated polymer has been completely removed. Impurities visible on the SEM images are probably particles of dust.

SEM images of 98 % of surface coverage exposed with 12 minutes and processed with 8 and 10 rotations of the drum are presented in Fig. 8. It is possible to see that thermal development of 8 and 10 rotations of the drum cause the forming of uniformly distributed relatively sharp and pure surface coverage (image areas) with no significant irregularity. Impurities visible on the SEM images are probably particles of dust.

SEM micrographs of positive and reverse cross lines of 0,03 mm and 0,04 mm are presented in Figure 9. The micrographs were taken for printing plate samples obtained with main exposure of 12 minutes and thermal development of 8 and 10 rotations of the drum. One can see that in both rotations conditions lines have been correctly formed, sharp and straight, without any significant irregularity.

According to the SEM analysis one can conclude that with main exposure of 12 min and thermal development with 8 and 10 rotations of the drum, relief depth varies insignificantly, 0,06 mm. Previous analysis of the SEM images leads to the conclusion that the same result is gained in both cases. One can say that printing plates with optimum quality can be performed with 8 rotations of the drum and, according to that, production workflow can be improved for time period of 2 rotations, i.e. 2,24 min.

SEM images of halftone fields of 50 % are presented in Figure 10 to confirm the fact that thermal development with 8 rotations of the drum can be applied for this kind of photopolymer plates. One can see that thermal development of 8 rotations of the drum causes forming of uniformly distributed, sharp formed surface coverage (image areas).

4.4 Control of the thickness and hardness of the printing plates
Kontrola debljine i tvrdoće tiskovnih formi

Characterisation of the thickness and hardness of the printing plates was made in order to control the observed

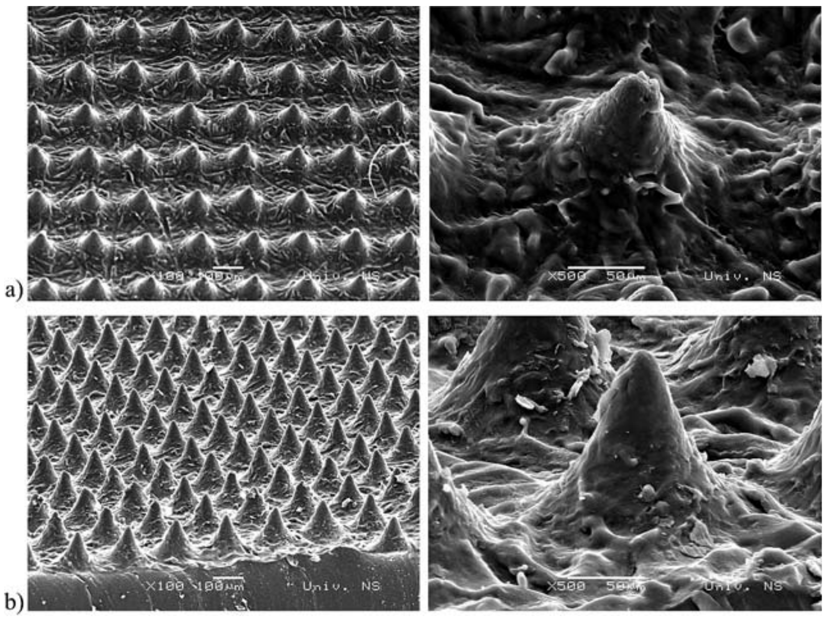
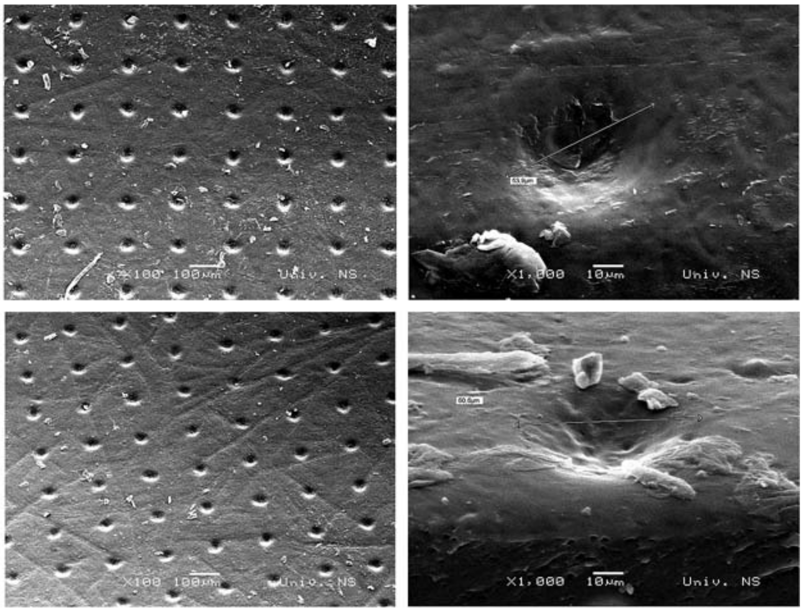
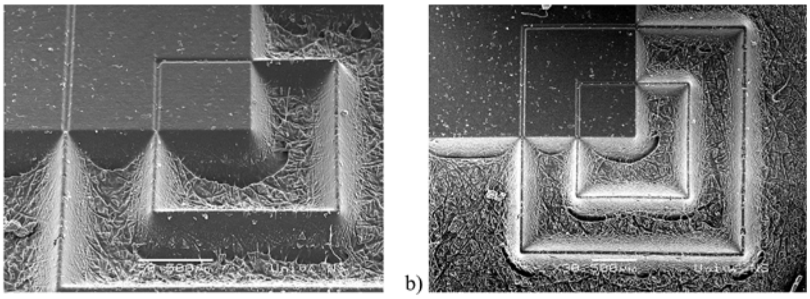


***Figure** 7 SEM images of 1 % of coverage (a) main exposure 12 minutes; thermal processing carried out with the 8 rotations of the drum and (b) main exposure 12 minutes; thermal processing carried out with the 10 rotations of the drum (magnification 100 and 500×, respectively)*
Slika 7. *SEM slike za 1 % pokrivenosti površine (a) glavna ekspozicija 12 min; termalna obrada sa 8 okretaja bubnja (b) glavna ekspozicija 12 min; termalna obrada sa 10 okretaja bubnja (povećanje 100 i 500×, redom)*



a) b)

Figure 8 *SEM images of 98 % of coverage (a) main exposure 12 minutes; thermal processing carried out with the 8 rotations of the drum and (b) main exposure 12 minutes; thermal processing carried out with the 10 rotations of the drum (magnification 100 and 500×, respectively)*
Slika 8. *SEM slike za 98 % pokrivenosti površine (a) glavna ekspozicija 12 min; termalna obrada sa 8 okretaja bubnja (b) glavna ekspozicija 12 min; termalna obrada sa 10 okretaja bubnja (povećanje 100 i 500×, redom)*



a) b)

Figure 9 *SEM micrographs of the positive and reverse cross lines of 0,03 and 0,04 mm. Main exposure 12 minutes; thermal development: (a) 8 and (b) 10 rotations of the drum (magnification 500×)*
Figure 9. *SEM slike pozitivskih i križnih linija debljine 0,03 i 0,04 mm. Glavna ekspozicija 12 min; termalna obrada: (a) 8 and (b) 10 okretaja bubnja (povećanje 500×)*

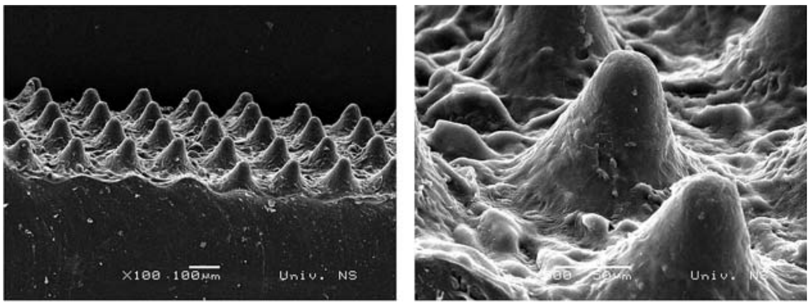


Figure 10 *SEM images of halftone fields (50 % coverage), main exposure 12 min; development 8 rotations of the drum (magnification 100 and 500× respectively)*
Figure 10. *SEM slike polja (50 % pokrivenosti površine), glavna ekspozicija 12 min; termalna obrada 8 okretaja bubnja (povećanje 100 i 500×, redom)*

characteristics of the produced printing plate samples. Deviations of those parameters could decrease the printing plates' functionality. The higher values of the printing plate thickness result in increasing of half tone values in reproduction [12].

The thickness of the samples was measured on the three printing plates from two different packages. Measuring was made after thermal development and light finishing phase. Measurements were performed for printing plates with the main exposure of 12 minutes and the thermal development of 8 and 10 rotations of the drum. Each plate was measured four times in different places, and then the mean value for each plate was calculated. The mean value of thickness of the printing plates from the same box was calculated as well, in order to see whether the thickness of the plates is within the tolerance limits. Taking into account that the measured sample should be at least 10 mm thick and that the measuring area should be 30 mm in diameter, 10 samples of 40×40 mm were placed one over another and then measured.

Measured values of printing plate thickness (Tab. 1) show that mean values of thickness do not deviate more than 0,002 mm. This result confirms that observed photopolymer plates show consistency in thickness of individual plate as

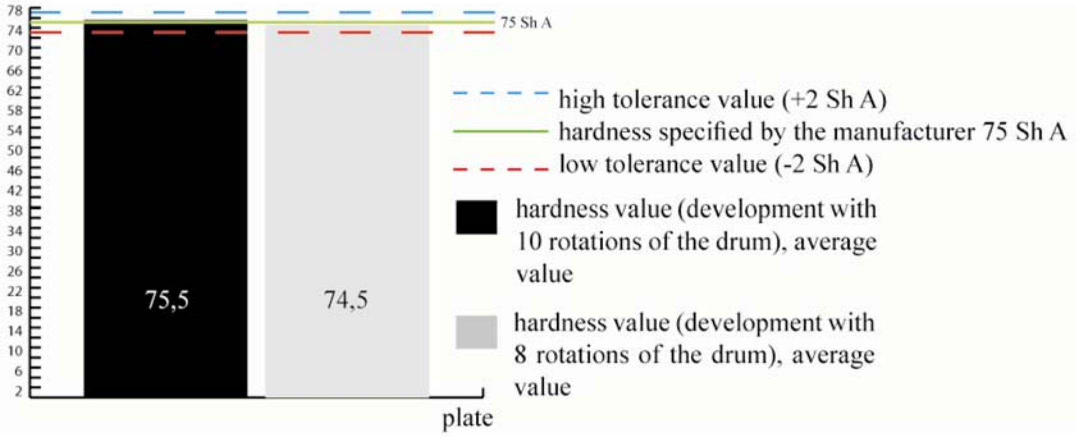


Figure 11 *Printing plate hardness, mean value*
Slika 11. *Tvrdoća tiskovne forme. srednja vrijednost*

Table 1 *Thickness of the printing plates*
Tablica 1. *Debljina tiskovnih formi*

Package	Printing plate	Thickness, mm	Mean value, mm
Box 1	Plate 1	1,145	1,142
	Plate 2	1,140	
	Plate 3	1,140	
Box 2	Plate 1	1,140	1,141
	Plate 2	1,145	
	Plate 3	1,145	

well as within different packages.

Hardness of the printing plates was measured on the samples obtained with main exposure of 12 minutes and development of 8 and 10 rotations of the drum. Each plate was measured 3 times and then the mean value was calculated. Printing plate of 1,14 mm of thickness should have hardness of 75 Sh A with possible tolerances of ± 2 Sh A. Lower hardness values could cause increasing of half tone values in the reproduction stage [12].

According to the results presented in Fig. 11, it can be seen that printing plate samples obtained with main exposure of 12 minutes and development of 8 rotations of the drum have hardness of 74,5 Sh A and that the other sample developed with 10 rotations has hardness of 75,5 Sh A. According to these results one can conclude that the printing plate hardness of samples is within the tolerance limits.

5 Conclusion
Zaključak

Photopolymer printing plates intended for thermal development have to be processed by a number of independent but strictly controlled and harmonized stages, i.e. back exposure, laser ablation, main exposure, thermal development, post exposure and light finishing. These production phases have to be in adequate balance for providing the printing plates of high quality. On the other hand, the manufacturers' recommendations are commonly given for characteristic parameters with certain tolerances which implies that every plate making stage must be individually defined according to the reproduction conditions. The aim of this paper was to define optimal duration of every processing stage with further improvement: decreasing of duration of certain stages in order to accelerate the plate making process with a goal to obtain the plates with optimal quality.

Testing of different duration of back exposure, main exposure and different duration of thermal development stage has shown interesting results: with back exposure of 50 seconds, main exposure of 12 minutes, development of 8 rotations of the drum and post exposure and light finishing time, it is possible to obtain the same results as recommended conditions.

The thickness of the printing plates was measured. Changes in the thickness of the printing plate have great importance in the reproduction process because the thickness irregularity influences the halftone values qualities. Measured values of printing plate thickness show that the mean values of thickness do not deviate more than 0,002 mm and do not exceed the given tolerances.

Hardness of the printing plates was tested. According to the results printing plate samples processed with the main exposure of 12 minutes and development of 8 rotations of the drum have hardness of 74,5 Sh A and that the other sample developed with 10 rotations has hardness of 75,5 Sh A. According to these results one can conclude that the printing plate hardness of samples is within the tolerance limits.

Obtained results indicate that it is possible to reduce the duration of back exposure, main exposure, and number of rotations of the drum during thermal development to obtain the high quality printing plates. SEM micrographs confirm the measurements: excellent tone reproduction of halftone values from 1 to 98 % surface coverage with sharp raster elements of adequate relief, and reproduction of lines in the positive and reverse of 0,03 and 0,04 mm. SEM images of halftone fields of 50 and 75 % coverage confirm the fact that thermal development with 8 rotations of the drum can be applied for this kind of photopolymer plates.

According to these results, one can say that reproduction workflow addressed to a photopolymer plates for flexographic printing technique can be accelerated. Since the research was related to a given printing plate thickness of 1,14 mm, the direction of future research should lead to the observation of printing plates of higher thickness.

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Authors' addresses
Adrese autora

Dragoljub Novaković, Prof.
Faculty of Technical Sciences
University of Novi Sad
Trg Dositeja Obradovića 6
21000 Novi Sad, Srbija
E-mail: novakd@uns.ac.rs

Sandra Dedijer, Assistant
Faculty of Technical Sciences
University of Novi Sad
Trg Dositeja Obradovića 6
21000 Novi Sad, Srbija
E-mail: dedijer@uns.ac.rs

Sanja Mahović Poljaček, Assistant Prof.
Faculty of Graphic Arts
University of Zagreb
Getaldićeva 2
10000 Zagreb, Croatia
E-mail: smahovic@grf.hr