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COMPARATIVE ANALYSIS OF DIGITAL INK-JET PRINTS, PERFORMED ON DIFFERENT TYPES OF PLASTICS

ABSTRACT: In the present paper, the problems connected with the printing technology in relation to manufacture of advertisement materials, including stands, i.e. the so-called product presenting packaging (POS marketing) on plastics have been discussed. The comparative analysis is based, first of all, upon colour aspects but other parameters concerning ready prints as well as their manufacturing process have been also considered.
On the grounds of the obtained data, diagrams were plotted and the respective calculations were carried out. After analysis of the results of the conducted measurements, it was concluded that in spite of using the same digital large-format machine, the same UV inks and identical technical arrangements, the overprints differed each other in respect of the quality; it was affected by the type of the employed plastic. The overprints made on a substrate from high-impact polystyrene were characterized by the best quality parameters. Polyvinyl chloride was only somewhat worse material which could be overprinted. On the other hand, acrylic glass was decisively interior in comparison to other plastics and may not satisfy the expectations of the most demanding producers.
Key words: digital printing, ink-jet, plastics, optical density, trapping, relative contrast, gamut

STRESZCZENIE: W niniejszym artykule poruszane są zagadnienia związane technologią drukowania w odniesieniu do produkcji materiałów reklamowych, w tym standów, czyli tzw. opakowań prezentujących produkt (POS marketing) na tworzywach sztucznych. Analiza porównawcza opiera się przede wszystkim na aspektach kolorystycznych, ale rozpatrywane są również inne parametry dotyczące gotowych wydruków, jak i procesu ich produkcji.
Na podstawie uzyskanych danych utworzono wykresy i dokonano odpowiednich obliczeń. Po analizie wyników pomiarów wywnioskowano, że mimo wykorzystania tej samej cyfrowej, wielkoformatowej maszyny, tych samych atramentów UV oraz identycznych ustawień technicznych, nadruki różnią się od siebie jakością, na co wpływ ma rodzaj wykorzystanego tworzywa sztucznego. Nadruki wykonane na podłożu z wysokoudarowego polistyrenu cechują się najlepszymi parametrami jakościowymi. Niewiele gorszym materiałem, który można zadrukować, okazał się polichlorek winylu. Natomiast szkło akrylowe zdecydowanie odstawało pod tym względem od pozostałych tworzyw sztucznych i może nie spełniać oczekiwań najbardziej wymagających producentów.
Słowa kluczowe: drukowanie cyfrowe, drukowanie natryskowe, tworzywa, gęstość optyczna, trapping, kontrast względny, obszar barw odtwarzalnych

INTRODUCTION

Digital technologies play greater and greater role in printing sector; they are constantly developed with the aim to create a real competition for analogue methods. At the beginning, due to the limitations connected with the performance of equipment and costs of inks, digital machines were employed only for printing of low and trial volumes.

Another problem, before which the discussed branch of printing industry was faced, concerned the direct contact of ink with the substrate, without printing mould. When the substrate was not sufficiently prepared, ink was absorbed too much by the structure of paper, causing defects of the print whereas in the case of too large quantity, of inaccurately dried layer, the print could become blurred.

The technology of ink-jet printing and UV ink-jet printing is responsible for the mentioned problems connected with the digital methods of printing. Its dynamic development satisfied all expectations of the customers, the problems connected with the mentioned above phenomena and the competition with the classical printing methods. To these ends, printing

heads which have been developed ensure the appropriate high quality of overprinting owing to the possibility of printing of image with 1200 dpi resolution, using the variable drop volume. The machines and inks have been improved and adjusted to the increase of the yield of printing by the ink-jet methods and the range of possible substrates to be used. The mentioned progress caused reduction of defects as compared to the analogue technology without loss of advantages which are characteristic of ink-jet printing.

The factors affecting quality of the print are widely differentiated and are dependent on many componential elements. In the case of ink, we have to pay attention to the composition, type of binder and the size of the individual particles of dye. The substrate is evaluated in respect of the structure and preparation of the surface to be overprinted. To obtain a high quality of overprint, the equipment (machine) must be appropriately calibrated and the supplied file must be well prepared. The mentioned earlier heads are discussed in respect of such parameters as their types, maximum resolution, performance and volume of the sprayed drops and the possibility of changing their size.

The technology of UV ink-jet printing is distinguished by the highest number of printable substrates. Apart from the traditional paper of cardboard carriers, we may mention textiles and plastic films or large-format panels made from glass or plastic such as PMMA, PET-G or PVC. Such comprehensive application makes that the discussed technology is an ideal competition for screen printing in the case of internal and external advertisement prints due to its high resistance to atmospheric conditions [1-3].

THE PURPOSE OF THE STUDIES

At the beginning, the quality of digital overprint, including that one made by inkjet technology, was comparable to the copies, performed by classical printing methods. It did not however solve the problems in the areas, requiring attention and parameterization. The established quality parameters have been recorded in standard ISO/IEC TS 24790:2012 and may be divided into two groups.

FIG. 1. GROUPS OF PARAMETERS USED IN EVALUATION OF THE DIGITAL OVERPRINT QUALITY IN ACCORDANCE WITH STANDARD ISO 15311

Groups of quality parameters	Criteria of quality evaluation	Typical method of evaluation
Reproduction of colour (precision of mapping the colour)	– Total coverage of area – Colorimetric and densitometric deviations – Curves of printing – Colour gamut (spectrum of colours) – Consistence of uniform colour of background (apla) and increase of raster halftone value and values indicated in ISO12647-2	– Measurement of colour and determination of difference in colours on colourful bands (fields) and test tables
Sharpness of details	– Resolution – Range of tonal reproduction – increase in raster tonal value – No matching: “image-to image” , “image –to-edge”, “obverse –to-reverse’	– Siemens star (visually) – Control band (visually) – Markers of cut (visually and measurements) – Blurriness and raggedness of line
Uniformity of overprint	– Uniformity of overprint on surface of printing sheet – Uniformity during printing a volume, – Uniformity of overprint on large areas of image (banding)	– Profiles of optical density – Nine-point measurement of overprint uniformity on a sheet in accordance with ISO 12647-7 – measurement of M-score in accordance with ISO 15311-1

The first group concerns the correct evaluation of the quality of the overprints in form of uniform colour background (in Polish: "apla"), raster and non-printed surface. We may distinguish such parameters as background haze and extraneous marks of the non-printed area, graininess and mottle of overprint, optical density (darkness) and voids (non-printed fields) in the case of large-format overprints.

The second group of parameters is connected with the evaluation of overprint line and font; it includes blurriness and raggedness of edges, optical density and width of the line, extraneous marks and background haze in the area of font, contrast and filling.

Apart from the discussed above classification, according to the mentioned standard, there is also another standard – ISO 15311, indicating another possibility of parameterization and evaluation of the quality of prints without classification into the techniques of printing. It has been presented in the form of fig. 1.

The choice of plastic materials in advertisement sector is dependent on the site and conditions in which a final product will be exposed: whether it will be a flat plate, or a packaging made from it and presenting a promoted product. The quality of overprint is not a condition, determining the mentioned choice, so, nobody performs the comparison of the discussed quality between different types of plastic materials. Within the frames of the experiment, the selected quality parameters of the overprints, performed in UV inkjet technology were tested, valuated and compared; the experiment was carried out in one machine on the plates (panels), made from different types of plastics.

PLASTIC PANELS

In the studies, the plates made from three different plastic materials in standard white colour were used.

HIPS – is polystyrene with the addition of rubber with the aim to increase its impact strength, i.e. resistance to tensile stress at a room and lower temperature. Owing to this fact, the fragility of common polystyrene is eliminated and one meaningful defect is a very quick yellowing and ageing of material as affected by sun light what eliminates the product as an element of external advertisement. Its advantages include good dielectric and plastic properties and a very high resistance of the effect of chemical and organic substances.

PPMA, being commonly called Plexiglas or acrylic glass, is most widely used plastic from those three ones used in the experiment. It is characterized by a high resistance to UV radiation, high resistance to chemical substances and by transparency. Additionally, it is easily subjected to recycling process.

PVC, i.e. polyvinyl chloride, can be distinguished by a perfect resistance to effect of chemical agents and by dielectric properties. It is a very light material, with a high elasticity module but also, a high rigidity. In advertisement sector, it is popular due to the great resistance to external conditions such as temperature fluctuations, humidity or natural light [5-8].

ARIZONA 350 GT BY CANON

Plastic panels were overprinted using large-format digital machine Arizona 350 GT by Canon company. It employs ink-jet technology with the preservation of inks by UV radiation. VariaDot technology enables obtaining almost photographic quality of overprint with resolution of 1440 dpi and using the set of only four basic colours. The variable volume of drop within the limits of 6-42 picoliters allows a precise reproduction of font of 6 pt as gradients or total passages as well as obtaining uniform, saturated colours. Additionally, it has the possibility of printing with white colour which – as the remaining dyes – is found n easily replaceable bags. The maximum area of overprinting the flat surfaces is 1.26 m x 2.51 m, with the possible bleed, from edge to edge. Manufacturing speed is 22.2 m^2 of good copy per hour and in the case of additional use of white colour, the mentioned value oscillates within 7.6 m^2 [4].

VISUAL EVALUATION

The selected elements from the first page of control test, using the mentioned three substrates were subjected to visual evaluation. The results of the observations were compared each other with the aim to find out the differences between the overprints performed on different plastic materials. The following elements were evaluated and compared:

TAB. 1. OPTICAL DENSITY ON HIPS PANEL

Colour	Series of measurements					Mean
	1	2	3	4	5	of measurements
C	1.00	1.00	1.02	1.00	1.02	1.01
M	1.25	1.19	1.25	1.18	1.21	1.22
Y	0.97	0.96	0.97	0.96	0.96	0.96
K	1.92	1.93	1.88	1.89	1.91	1.91

TAB. 2. OPTICAL DENSITY ON PMMA PANEL

Colour	Series of measurements					Mean
	1	2	3	4	5	of measurements
C	1.70	1.70	1.69	1.69	1.70	1.70
M	1.85	1.84	1.85	1.84	1.84	1.84
Y	1.15	1.14	1.15	1.15	1.15	1.15
K	2.11	2.10	2.10	2.10	2.10	2.10

TAB. 3. OPTICAL DENSITY ON PVC PANEL

Colour	Series of measurements					Mean
	1	2	3	4	5	of measurements
C	1.48	1.50	1.50	1.51	1.49	1.50
M	1.63	1.64	1.66	1.63	1.65	1.64
Y	1.02	1.02	1.02	1.03	1.02	1.02
K	2.01	2.04	2.03	2.06	2.04	2.04

– illustrations – food, nature, human skin and details in darker surrounding;
– line and geometric figures; and
– two types of typeface, serif and sans serif.

The images overprinted on HIPS panels are best reproduced; those made on PVC are little worse. The colours are distinct, the details on the food and nature-containing images as well as the details on the darker background are reproduced in a good quality. Unfortunately, the illustrations overprinted on PMMA panel are distinctly of worse quality, the colours are more weathered. The details in the shadow are invisible and generally, the images are less contrastive in comparison to the earlier compared ones.

Triangles and circles with the inscribed line are similar on all substrates, irrespectively of the type of used plastic. Shapes and lines are distinctly visible even at thickness of 0.01 mm with only small deformations.

Inscriptions made with the use of Arial and Times New Roman font are also reproduced on a similar level on all substrates. The texts in opposition to background (white letters on dark background) can be read without greater problems at 5p and black inscriptions on a white background at 4 p are readable in the case of sans serif as well as serif fonts.

STABILITY OF COLOURS

To evaluate the stability of colours, field no 1 from the first age of control test, i.e. bands of CMYK colours, was used. Five measurements of optical density of each colour of uniform background ("apla"), being printed on each plastic material, were performed. The results are given in tables 1, 2 and 3.

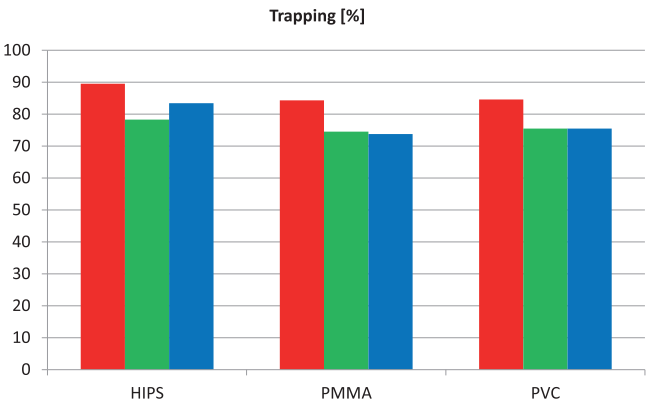

FIG. 1. TRAPPING ON DIFFERENT PLASTIC PANELS; R, G, B

CONCLUSIONS FOLLOWING FROM THE MEASUREMENTS OF COLOURS' STABILITY

Optical densities of all colours on all plastic materials are stable, mostly on PMMA panel. It may be stated that physical properties of plastic materials did not affect negatively any of the overprinted colours.

TRAPPING

The measurements conducted with the use of spectrophotometer of test fields, being found under number 9 at page 3 of the control test allow examination of the capabilities of absorbing ink by another ink, i.e. trapping. The data and the results for each plastic have been illustrated in the tables and diagram, being given below, respectively.

CONCLUSIONS RESULTING FROM TRAPPING MEASUREMENTS:

It has been assumed that value of trapping must be no less than 80% in order to obtain good quality of printing in offset technology.

TAB. 4. VALUES OF TRAPPING FOR HIPS PANEL

Optical density				Trapping [%]		
C	M	Y	K	YM (R)	YC (G)	MC (B)
0.87	1.13	0.88	1.78	89.5	78.3	83.4

TAB. 5. VALUES OF TRAPPING FOR PMMA PANEL

Optical density				Trapping [%]		
C	M	Y	K	YM (R)	YC (G)	MC (B)
1.25	1.43	0.81	1.70	84.3	74.5	73.8

TAB. 6. VALUES OF TRAPPING FOR PVC PANEL

Optical density				Trapping [%]		
C	M	Y	K	YM (R)	YC (G)	MC (B)
1.30	1.47	0.88	1.87	84.6	75.5	75.5

YM – acceptance of magenta colour by yellow ink YC – acceptance of cyan colour by yellow ink MC – acceptance of cyan colour by magenta ink

TAB. 7. PARAMETERS L*, A* AND B* FOR HIPS PANEL

Parameter	Colour						
	C	M	Y	K	R	G	B
L*	59.85	50.01	88.35	19.63	47.26	54.13	26.04
a*	-31.56	67.27	-5.97	3.36	63.69	-60.94	25.9
b*	-35.89	-8.7	89.29	-4.14	44	25.92	-50.31

TAB. 8. PARAMETERS L*, A* AND B* FOR PMMA PANEL

Parameter	Colour						
	C	M	Y	K	R	G	B
L*	59.85	50.01	88.35	19.63	47.26	54.13	26.04
a*	-31.56	67.27	-5.97	3.36	63.69	-60.94	25.9
b*	-35.89	-8.7	89.29	-4.14	44	25.92	-50.31

TAB. 9. PARAMETERS L*, A* AND B* FOR PVC PANEL

Parameter	Colour						
	C	M	Y	K	R	G	B
L*	59.85	50.01	88.35	19.63	47.26	54.13	26.04
a*	-31.56	67.27	-5.97	3.36	63.69	-60.94	25.9
b*	-35.89	-8.7	89.29	-4.14	44	25.92	-50.31

In the case of digital printing on the different plastic panels, only YM parameter exceeded the discussed limit value in all variants. The copies made on PMMA and PVC panels had similar although insufficient results. On the other hand, the overprint on HIPP substrate, with a small exception, met the adopted assumptions and it may be evaluated as being of good quality.

SPECTRUM OF COLOURS

On the grounds of field no 1 from page 3 of the control test, the data were collected; they are presented in the tables as given below. Parameters L*, a* and b* were measured using spectrophotometer for colours C, M, Y, K, R, G and B on three panels and allowed to plot the diagrams of the spectrum of colours, being otherwise called gamut, for all the examined plastic materials.

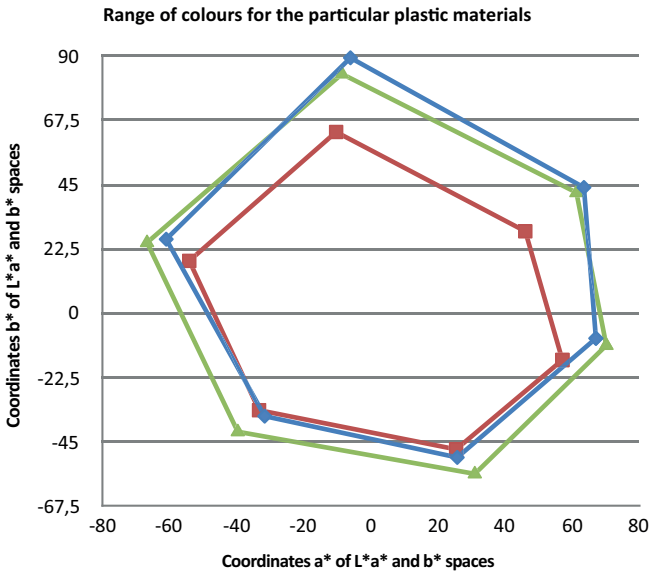

FIG. 2. RANGE OF COLOURS FOR PANELS MADE FROM DIFFERENT TYPES OF PLASTICS; PMMA, PVC, HIPS

CONCLUSIONS RESULTING FROM THE MEASUREMENTS OF GAMUT

After the illustration of the data obtained from all performed measurements, using spectrophotometer, we may conclude that the overprint on the substrate produced from PMMA differed from the two remaining materials in respect of the width of colour space. It is probably caused by a difference in physical properties of the discussed plastic materials, and especially, mainly due to the greater own transparency of Plexiglas as compared to the high-impact polystyrene of polyvinyl chloride.

RELATIVE CONTRAST

The relative contrast was determined by the measurement of the fields of element no. 8 at page 3 of the test and by the calculation according to the following formula:

$$Relative\ contrast = \frac{D_{100} - D_{75}}{D_{100}} * 100\ \%$$

D_{100} – optical density of field with 100% coverage

D_{75} – optical density of field with 75% coverage

Value of the discussed parameter should be equal to no less than 30% as to be recognized as a correct and satisfying the respective standards. The data obtained from the measurements using the spectrometer are found in the tables given below, together with the calculated parameters for the panel produced from each plastic material. The tables are accompanied by the diagram.

CONCLUSIONS, RESULTING FROM THE MEASUREMENTS OF RELATIVE CONTRAST:

The adopted approvable value of relative contrast cannot be less than 30%. The conducted studies showed that any

TAB. 10. RELATIVE CONTRAST FOR HIPS PANEL

Area coverage [%]	Optical density			
	C	M	Y	K
100	0.98	1.18	0.97	1.84
75	0.74	0.82	0.65	0.96
Relative contrast [%]	24.49	30.51	32.99	47.83

TAB.11. RELATIVE CONTRAST FOR PMMA PANEL

Area coverage [%]	Optical density			
	C	M	Y	K
100	1,61	1,77	1,14	2,04
75	1,3	1,3	0,93	1,48
Relative contrast [%]	19,25	26,55	18,42	27,45

TAB.12. RELATIVE CONTRAST FOR PVC PANEL

Area coverage [%]	Optical density			
	C	M	Y	K
100	1,45	1,61	1,02	2
75	1,1	1,13	0,77	1,26
Relative contrast [%]	24,14	29,81	24,51	37,00

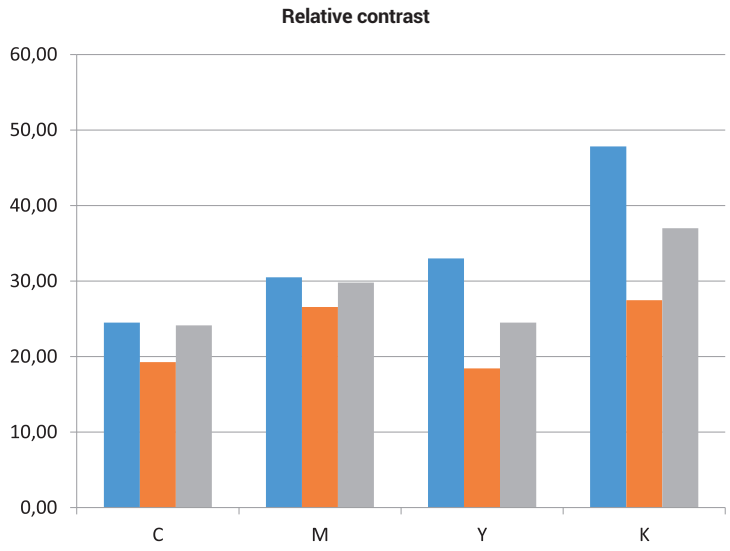

FIG. 3. RELATIVE CONTRAST FOR PARTICULAR MATERIALS; HIPS; PMMA, PVC

overprint, irrespectively of the substrate material, did not meet the mentioned condition in 100%. The overprint performed on HIPS panel was closest to obtaining a good result; however the value of relative contrast of cyan in all cases was found on a very low level, even below 20%. It shows that the details in dark areas may be very weakly reproduced and almost or even completely invisible for human eye.

FINAL CONCLUSIONS

In final comparison of the overprints made on different types of plastic materials, using large-format digital ink-jet machine with UV ink, we should consider all the conducted tests, both visual and those ones, conducted with the use of measuring devices.

The purpose of the present study was to check and eventually, indicate the difference in the quality of the overprints, made on three plastic substrates: white HIPS, PMMA and PVC panels. It would allow the representatives of advertisement sector and the producers of POSM and POS marketing to consider not only physical and chemical properties, being important in location of the advertisement but also the quality aspect of the overprint when choosing the appropriate material.

Visual evaluation included subjective feeling concerning the quality of reproduction of the element of control test. The illustrations were expected to help in the recognition of the colour intensity, precision of details in lights and shadows and general contrast of images. Lines, geometrical shapes and font types printed normally and in the opposition facilitated observations of reproducing the small elements on the substrate. On visual examination, the overprint made on PMMA panel differed decisively from other ones, as it was characterized by image blurring and poor reproduction of colours and details. It was visible especially during the evaluation of illustrations with darks details and human skin. The study of colour stability did not reveal any defects in printing. Optical densities of each colour on all substrates were stable what was shown in measuring series, performed by spectrophotometer. It may be followed that different physical properties of the particular plastic materials do not have any negative effect on colour stability.

The measurements of trapping, i.e. capabilities of accepting one ink by another ink showed the satisfactory results only in the case of HIPS panel. The overprint which is aimed at having a good quality must be characterized by the discussed parameter art the level of at least 80%, at least in offset printing. Trapping of the print on PMMA and PVC substrates is considerably different than the mentioned minimal limit value; theoretically, it leads to the statement that the quality of the overprint made on the mentioned above substrates is of

a worse quality ac compared to the colours reproduced on high-impact polystyrene.

The evaluation of the spectrum of colours, i.e. gamut, indicated again the lower quality of overprint made on PMMA panel. The data obtained when using spectrophotometer and being utilised in plotting the diagram showed the small differences in respect of the width of colour space on HIPS and PVC substrates. On the other hand, the text printed on Plexiglas confirmed clearly the definitely smaller range of colours. It may be caused by a greater transparency of the discussed material.

The parameter of relative contrast was calculated using a formula and the data which were obtained with the utilization of spectrophotometer. The examination of the areas of CMYK colours with coverage of 100% and 75% highlighted the discussed problem with all plastic substrates. Any of the examined overprints has not exceeded the limit value of relative contrast at the level of 30%. The overprint made on HIPS panel occurred to be the best although still insufficiently good in this respect. Nevertheless, the value of relative contrast of cyan in all discussed cases is too low, sometimes even below 20%. It makes that the details in dark areas may be very poorly reproduced and perhaps even completely invisible for the observer.

Summing up: visual evaluation and the conducted tests revealed as follows: in spite of the utilization of the same digital large-format machine and the same UV inks and the identical technical parameters, the overprints were different in respect of quality as affected by the type of the employed plastic material. The overprints made on substrates made from high-impact polystyrene were characterized by the best quality parameters. Polyvinyl chloride occurred to be only somewhat worse material which may be overprinted. On the other hand, acrylic glass differed decisively from the remaining plastic materials in this respect and it may not satisfy the expectations of the most demanding producers and customers. It may also generate higher costs due to the necessity of performing more complicated treatment such as production of white sub-print, decreasing the transparency of the material.

The quality of printing is not, however, the most important criterion of the choice of the appropriate material as the substrate to be overprinted, for example, in advertisement sector. In spite of its worse overprinting quality, Plexiglas has many advantages, physical and chemical properties which make it one of the most popular plastics, employed all over the world in many sectors. On the other hand, as was revealed in the discussed study, we should pay also attention to differences in the quality of prints made on different plastic materials.

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