WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.1.2640
e-ISSN 2729-8906
67(1): 2022 26-40 pp.

EFFECT OF SMOOTHING IN CALENDER AND HOT STAMPING MACHINE ON THE PROPERTIES OF COATED PAPERBOARDS FOR PRINTED ELECTRONICS

JURAJ GIGAC, MÁRIA FIŠEROVÁ
PULP AND PAPER RESEARCH INSTITUTE
SLOVAK REPUBLIC

(RECEIVED JULY 2021)

ABSTRACT

The methods of coated paperboards smoothing with a hot stamping machine using a smooth metal die and a conventional calender were compared. The printing roughness required for printing electrical and electronic components was achieved by both smoothing methods. The printing roughness of the coated paperboards decreased after hot stamping by 18 to 42% and after calendering by 22 to 41% depending on the grade of coated paperboard. The stiffness of coated paperboards decreased after hot stamping by only 4 to 21%, while by up to 38 to 51% after calendering. The ratio of specific stiffness and printing roughness of coated paperboards after hot stamping ranged from 2.5 to 8.1 $mN \cdot \mu m^{-2}$ and after calendering from 2.0 to 6.7 $mN \cdot \mu m^{-2}$. The stiffness of the coated paperboards decreased less after hot stamping, and that only in the printed electronics area, while after calendering the stiffness decreased significantly more in the whole profile. It can be assumed that packaging made from coated paperboards smoothed by hot stamping will have a lower weight and thus lower costs than packaging from calendered coated paperboards.

KEYWORDS: Coated paperboard, calendering, hot stamping, printing roughness, stiffness, surface free energy.

INTRODUCTION

Packaging is a big part of everyday life of people all around the world. According to a market survey carried out by Smithers Pira, in the next decade, the global packaging market will grow by almost 3% annually and will exceed $1.2 trillion by 2030. The global packaging market has increased by 6.8% over the past 5 years. In addition, one of Unesco's Sustainable Development Goals for 2030 is the significant reduction of single-use plastics. Currently, trends such as e-commerce and the digitization of packaging are emerging as the big challengers over the next 10 years; and while these trends are not new, the COVID-19 pandemic has accelerated their adoption. The market for paper packaging is seen as ready for the use of digital printing technology https://www.elempaque.com/temas/The-packaging-and-conversion-industry-in-2030-challenges-and-opportunities).

Paperboards are currently one of the most commonly used packaging materials. Paperboards are layered products, which are made from primary or recycled fibres. Paperboards from primary fibres use different types of pulps in different parts of the layered structure. Outer layer consists of bleached chemical pulps and the middle ply consist of any type of mechanical pulp like TMP or CTMP, so that the final product has the necessary stiffness and bulk. Paperboards made from recycled fibres use deinked pulps from different types of waste paper in different part of the layered structure. Higher quality types of recycled fibres form the top layers, while the middle layers are made of lower quality recycled fibres. Stiffness of paperboards is important, because it correlates well with stacking strength of the final package, their purity is also important. Typical tests include internal bonding strength Scott Bond and surface strength IGT (Kiviranta 2000, Häggblom-Ahnger and Komulainen 2003).

Printed electronics has a great potential to offer biodegradable and recyclable solutions, which is a way forward to minimize the electronic waste caused by the ever-increasing number of disposable electronic devices (Tan et al. 2016, Zeng et al. 2017). Printed electronics are manufactured in a process of registering thin functional material (ink) layer combinations on a low-cost substrate that may be recycled and/or naturally degraded in the environment. Manufacture of electrical and electronic components by conventional and the state-of-the-art printing methods makes it possible to reduce the amount of waste materials as well as the fact that it is not necessary to use etching and masking (Maddipatla et al. 2020). Correspondingly, the manufacturing process is composed of three complementary stages: material selection, printing and post-printing (Wiklund et al. 2021).

Recently, the popularity of radio frequency identification has increased significantly, especially in connection with the printing of antennas on paper labels. Low-cost and recyclable paper substrates are being considered for various novel, value-added printed applications. This opens up the possibility of using RFID tags, for example, as part of packaging and other applications, for which the device has short life expectancy and is ultimately disposed. Literature on this subject has shown that manufacturing of RFID tags is not limited to a specific printing technology and gravure, screen, flexographic, inkjet, thermal-transfer and hot stamping printing technologies have been effectively used (Salmerón et al. 2014, Fernández-Salmerón et al. 2015, Voigt et al. 2010, Kavčič et al. 2014, Bollström 2013, Xiao et al. 2018, Gigac et al. 2021a,b, Lyashenko et al. 2012).

Hot stamping is the process of using heat and pressure to apply metallic ribbon or holograms to materials such as papers, paperboard, laminated board, plastics and corrugated board. A stamping ribbon includes a carrier film, a release layer, a layer of vacuum deposited metal such as aluminum or gold, silver, copper and chromium (Kipphan 2001), and a layer of heat activated adhesive. The layers are activated by heat and pressure by a die which causes the layers to delaminate from the carrier film and adhere to a surface of a substrate in a predetermined electrically conductive pattern (Agca and Tasdemir 2016).

Different printed electronic devices require different substrate properties such as flexibility, high light transmittance, low surface roughness, light weight, low thermal expansion, stiffness, heat resistance, low cost and low thickness (Suganuma 2014). The print quality is affected by the surface roughness and porosity of the substrate (Morfa et al. 2016, Agate et al. 2018, Bollström et al. 2014).

The paper substrates have a rougher surface compared to the plastic film. The irregular surfaces and structural properties of conventional paper substrates allow their use only for electronic components with lower resolution requirements or printing quality. The surface of paper substrates can be modified by coating and smoothing. The smoothness of the surface depends on composition of coatings, the amount and layers of the coating, and the final surface finish. Depending on the composition of the coatings, properties such as smoothness, porosity, permeability and surface energy as well as optical properties (brightness and opacity) can be varied. The properties of the paper substrate can be adjusted to achieve also simultaneously functional properties such as water, oil and grease resistance, low vapor and gas permeability and flame retardation.

Coated paper substrates do not have a sufficient surface smoothness for good quality printed electronics, so it is necessary to reduce surface roughness and tighten the holes, which is conventionally achieved by calendering (Gullichsen and Paulapuro 1999). Surface smoothness of the paper substrate is achieved by exposing the fibre structure of the paper substrate to high pressure and temperature by heating the hard calender rolls and by pressing the rolls against one another such that a high nip pressure is obtained in the nip between the rolls. Due to these forces the fibres forming the web reach their glass transition temperature, and the deformation caused by the nip load is permanent. The gliding of the web surface against the roll surfaces may also give rise to alterations in fibre shape, thus enhancing the smoothing effect.

The longer nip dwell time and the reduction of the nip load during calendering can essentially reduce the structural changes in the paper web so that it is possible to reach a good surface quality at the same time. Long nip calendering resulted in a better volume and improved flexural resistance together with good surface properties compared with the common hard nip or soft nip calendering (Leinonen et al. 2001). The calender, which is also called a shoe calender, uses the same shoe roller technology as the press section of the paper machine. The long nip is formed between a heated hard roller and a soft belt of the shoe roller. The nip dwell time is not determined by the nip load when using a long nip calender but the needed dwell time is reached by the choice of a suitable shoe rail length.

Hot stamping (without ribbon) with smooth die can be used for smoothing surface of paper substrates before printing of electrical and electronics components. The smoothing effect of paper substrates depends on input parameters of hot stamping such as pressure time, pressure, temperature and surface roughness of the die.

The aim of the study of smoothing methods was to improve the printing roughness of coated paperboards to the level required for printed electronics and to compare hot stamping and calendering methods.

MATERIAL AND METHODS

Materials

Coated paperboard A is a single-sided white light folding boxboard (FBB2), which contains chemical thermo-mechanical pulp while the top layer consists of chemical pulp and the bottom side has a hint of yellow. *Coated paperboard B* is a single-sided coated white lined chipboard (WLC2) made from recycled fibres, the top layer is white, the inner layer and the bottom side are both gray. Its bulk was 1.43 $cm^3 \cdot g^{-1}$.

Coated paperboards C, D, E are single-sided coated white lined chipboards (WLC3) made from recycled fibres, the top layer is white, the inner layer and the bottom side are both gray. Their bulk were 1.12-1.29 $cm^3 \cdot g^{-1}$.

Methods

Calendering

The smoothing in the two-roll calender FUS 80 (Kleinewefers GmbH, Germany) was performed by one or two coated paperboard passes between a paper and a metal roller with a temperature of 80°C, a surface roughness Ra of 0.5 μm and a dwell time in pressure zone of 0.12 s at a pressure of 52 MPa. The coated side was in contact with the heated metal roller (Gigac et al. 2021a,b).

Hot stamping

The smoothing of coated paperboard in the HX-358 stamping machine (Ruian Hongxing Machinery Co., Ltd., China) was performed with a metal die with dimensions (l x w x h) 110 x 70 x 10 mm, surface roughness Ra 0.7 μm, temperature 95°C and a dwell time 3 s at a pressure of 2.6 MPa.

Stiffness

Stiffness is defined as the paperboard's resistance to bending caused by a given applied force. Stiffness was determined as bending resistance (mN) by the two-point method, at a 15° bending angle, 38 mm wide strip, 10 mm distance of clamp and blade distance according to the standard ISO 2493-1 method on L&W Bending tester, app. 16 0, type 10-1 (Lorentzen & Wettre GmbH, Germany). The ratio of specific stiffness and printing roughness values ($mN \cdot \mu m^{-2}$), determined 48 hours after smoothing, was used to compare the effect of smoothing methods on the properties of coated paperboard. The specific stiffness ($mN \cdot \mu m^{-1}$) was calculated from the ratio of bending resistance and a thickness of coated paperboard.

Printing roughness

Printing roughness PPS (Parker Print-Surf) was calculated from the measured values of the average surface roughness OVS (Optical Variability of Surface) using the Eq. 1:

$$PPS = 0.103\ OVS + 0.192 \qquad (1)$$

The surface roughness OVS of coated paperboards was evaluated by the photoclinometric method as optical variability of surface (Kasajová and Gigac 2013). Photoclinometry in the visible range of electromagnetic radiation is a promising method that may be used for on-line measurement of paper roughness. It describes the process of transformation of a 2D surface image into a map of various height levels. Incident light creates shadows (different gray levels). Paper is an anisotropic material, therefore it is necessary to obtain surface images from at least two directions: machine direction (MD) and cross direction (CD). The paperboards surface was scanned using charge-coupled device (CCD) Nikon Coolpix E4500 camera (Nikon Corporation, Japan) by inclined illumination at 10° from MD and CD. Optical variability of surface was calculated from image analysis using the program ImageJ.

Surface free energy

Initial and dynamic contact angle (CA), surface tension (γ) of liquids, as well as surface free energy (SFE) of coated paperboards were measured using the OCA 35 optical tensiometer (Dataphysics Instruments GmbH, Germany). Contact angle was measured by sessile drop method. Wetting time was recorded by a CCD camera at the sequence 20 frames$\cdot s^{-1}$ from the first contact of the liquid drop with the paperboards surface from 0.05 to 5 s. Contact angle was calculated as the average of 10 parallel measurements (Gigac et al. 2014a,b). Three testing liquids (diiodomethane, ethylene glycol, thiodiglycol) with different surface tensions were used to determine SFE of paperboards. SFE (ISO 19403-2: 2017), as well as its dispersive and polar components (ISO 19403-5: 2017), was calculated by the OWRK (Owens-Wendt-Rabel and Kaelble) method using values of initial CA.

RESULTS AND DISCUSSION

Printing, converting and finishing processes are used to increase the added value and improve the overall quality of paperboards packaging, which depend on the properties of the paperboards, in particular basis weight, thickness, stiffness, printing roughness and free surface energy.

Characteristics of coated paperboards

Coated paperboards A, B, C, D and E were selected to study the effects of smoothing with a calender and stamping machine. The basis weight of the coated paperboards ranged from 179 to 352 $g\cdot m^{-2}$, the thickness from 201 to 455 µm and the bulk from 1.12 to 1.68 $cm^3\cdot g^{-1}$ (Tab. 1).

Besides basis weight and thickness, stiffness is especially important when choosing the right paperboard grade for packaging applications. Because paperboard is an anisotropic material, which means that the properties have a direction caused by the alignment of fibres in the machine direction (MD), it was necessary to make measurements of stiffness both in this direction and in the cross direction (CD).

The stiffness of coated paperboards in the MD direction ranged from 779 to 4510 mN and in the CD direction from 375 to 1937 mN (Tab. 1). As a result of this directional effect, the stiffness was approximately 55% higher in the MD direction than in the CD direction. From the stiffness values in the MD and CD directions, the arithmetic mean stiffness value was calculated, which ranged from 577 to 3224 mN for the tested coated paperboards. Higher stiffness values were obtained for coated paperboards E and A with greater thickness (455 and 402 µm). In addition to thickness, the modulus of elasticity in the outer layers also affects the stiffness of the coated paperboard. Thickness affects stiffness more significantly as compared to modulus of elasticity.

Tab. 1: Properties of coated paperboards.

Sample	Grade	Basis weight	Thickness	Stiffness			Side	Printing roughness	Surface energy		
				MD	CD	Average		PPS	SFE	SE disp	SE polar
		$g\ m^{-2}$	µm	mN	mN	mN		µm	$mJ\ m^{-2}$	$mJ\ m^{-2}$	$mJ\ m^{-2}$
A	FBB2	239	402	2815	1665	2240	top	0.80	20.40	20.06	0.34
							bottom	4.80	27.39	27.20	0.19
B	WLC2	252	361	2238	1016	1627	top	1.17	37.21	36.40	0.80
							bottom	4.15	29.21	29.11	0.10
C	WLC3	179	201	779	375	577	top	1.21	28.62	28.50	0.12
							bottom	3.80	33.89	30.17	3.72
D	WLC3	228	264	1325	630	978	top	1.28	37.18	36.50	0.68
							bottom	4.05	34.12	32.10	2.02
E	WLC3	352	455	4510	1937	3224	top	1.63	36.33	35.85	0.48
							bottom	4.15	65.97	63.51	2.46

Long fibres from chemical pulp make it possible to have a good bonding and hence a high modulus of elasticity, and are most efficiently utilised in the outer plies of the paperboard. The type of fibre also influences thickness, for example mechanical fibre creates higher bulk when used in the centre plies. The various layers of fibres have to be well bonded together for optimum utilisation of the fibre characteristics.

Printing roughness and surface energy of paper substrates are important in terms of print quality. Each paper has a unique structure in terms of surface roughness, porosity, and surface energy that are the result of manufacturing technology (Gigac et al. 2014a). In Tab. 1, the printing roughness of the coated paperboards are presented, which range from 0.80 to 1.63 µm on the top side and from 3.80 to 4.80 µm on the bottom side. The coated paperboard A had the lowest printing roughness on the top side of 0.80 µm, while the coated paperboard C had the lowest printing roughness on the bottom side of 3.80 µm.

The surface properties of printing substrates and inks determine the success of all printing processes, whether they are conventional or digital printing technologies, because wetting and spreading of printing inks on the surface and good adhesion of the printed layer are determined by these properties. The free surface energy of substrates and inks determines their cohesive and adhesive energy. The difference between the adhesive and cohesive energies is expressed by the Harkinson spreading coefficient, which determines whether (or not) the ink wets the surface of the substrate (Kaplanová et al. 2009). Low surface dispersive energy of papers negatively influences wetting and spreading inkjet inks on surface, print density and colour gamut (Gigac et al. 2014b). Techniques such as corona, UV ozone, sintering, plasma, and laser treatments are employed to modify the surface energy of the substrates (Ali et al. 2018, Gerhard et al. 2012). In printed electronics, it is always desirable to have the surface energy of the substrate at least above 7-10 $mJ\cdot m^{-2}$ compared to surface tension of the ink to get good wetting and adhesion characteristics (Turkani et al. 2018).

While variations in printed layers are relevant for graphic papers only if they can be perceived by the human eye, for printed electronics papers, detailed reproduction of structural elements is essential for the reproducibility and reliability of electrical properties of the printed layers (Fugmann et al. 2006).

Surface free energy, dispersive and polar component of surface energy of coated paperboards are given in Tab. 1. The surface free energy (SFE) of the coated paperboards ranged from 20.4 to 37.2 $mJ\cdot m^{-2}$ for the top side and from 27.4 to 66.0 $mJ\cdot m^{-2}$ for the bottom side. The coated paperboards B and D had the highest surface free energy of the top side, while the coated paperboard E had the highest surface free energy of the bottom side. The dispersive component of surface energy of the coated paperboards ranged from 20.1 to 36.5 $mJ\cdot m^{-2}$ for the top side and from 27.2 to 63.5 $mJ\cdot m^{-2}$ for the bottom side. The coated paperboard D had the highest dispersive component of surface energy of the top side, while the coated paperboard E had the highest dispersive component of surface energy of the bottom side. The polar components of the surface energy of the coated paperboards ranged from 0.13 to 0.80 $mJ\cdot m^{-2}$ for the top side and from 0.10 to 3.72 $mJ\cdot m^{-2}$ for the bottom side (Tab. 1). The coated paperboard B had the highest polar component of surface energy of the top side, while the coated paperboard E had the highest polar component of surface energy of the bottom side.

The effect of calendering and hot stamping on coated paperboards properties

The quality of printed electrical and electronic components is affected mostly by printing roughness of the paper substrate. Smoothing the coated paperboard in a calender commonly used in the paper industry to reduce printing roughness was compared with smoothing in a stamping machine.

Changes in printing roughness, thickness and stiffness of coated paperboards (Tab. 1) after smoothing by calendering (C1 or C2) and hot stamping (HS) methods are shown in Figs. 1-5. Procedures C1 or C2 indicate 1 or 2 passes of coated paperboard in a nip between calender rollers. There are three graphs in each figure. The graphical representation of the relationship between print roughness and thickness is located at the top left of each figure, the relationship between average stiffness and thickness at the top right, and the relationship between printing roughness and average stiffness in the center at the bottom. The measurements of the evaluated properties in Figs. 1-5 were performed 2 and 24 hours after smoothing.

Coated paperboard A with a thickness of 402 µm, an average stiffness of 2025 mN and a printing roughness of 0.80 µm was smoothed in a calender using procedures C1 and C2 and in a hot stamping machine HS (Fig. 1). After smoothing in a calender by the C2 procedure, the original coated paperboard A thickness was reduced to 268 µm, the average stiffness to 1125 mN and the printing roughness to 0.63 µm. After hot stamping, the thickness of the original coated paperboard A was reduced to 297 µm, the average stiffness to 1535 mN and the printing roughness to 0.64 µm. A comparison of the properties after 24 hours shows that after calendering the thickness decreased by 34%, the average stiffness decreased by 44% and the printing roughness by 22% and after hot stamping the thickness decreased by 26%, the average stiffness decreased by 24% and the printing roughness by 21%.

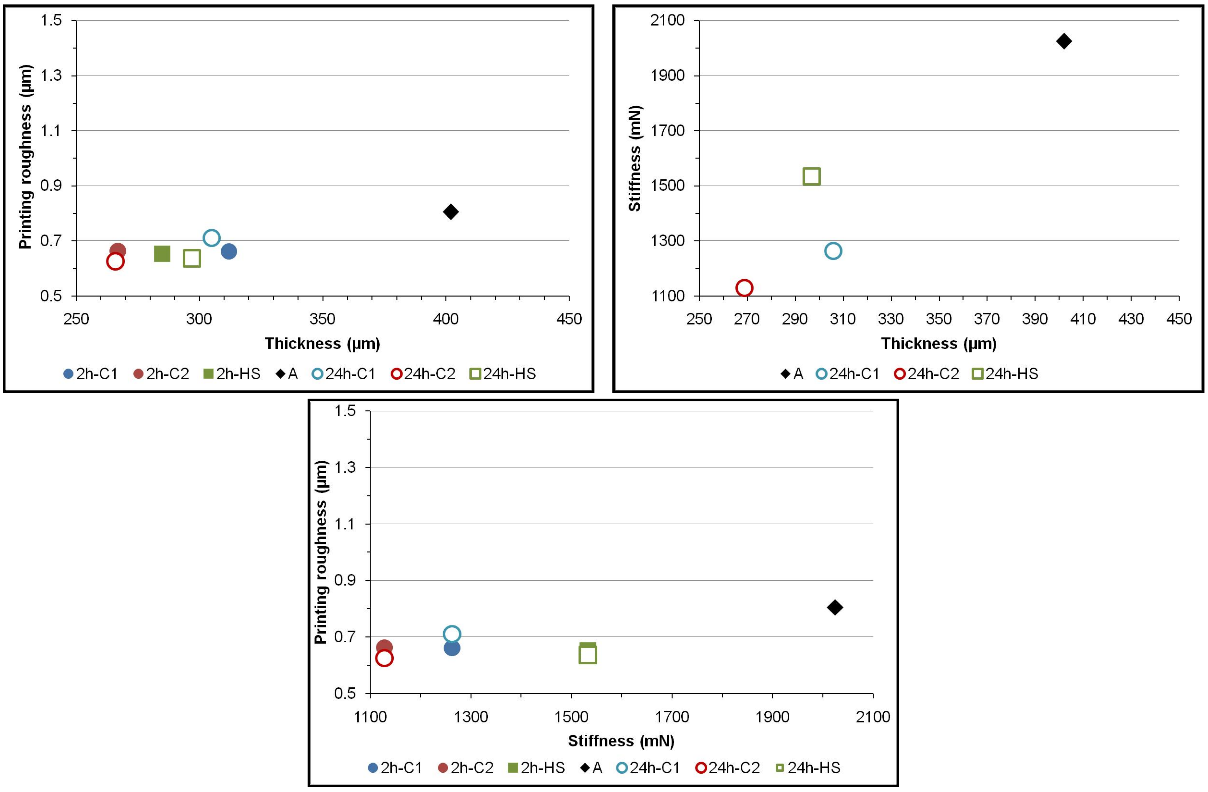


Fig. 1: The effect of smoothing by calendering and hot stamping on the relationships between thickness, printing roughness and stiffness of coated paperboard A.

Coated paperboard B with a thickness of 356 μm, an average stiffness of 1595 mN and a printing roughness of 1.17 μm was smoothed in a calender using procedures C1 and C2 and in a hot stamping machine HS (Fig. 2). After smoothing in a calender by the C2 procedure, the thickness of the original coated paperboard B was reduced to 241 μm, the average stiffness to 775 mN and the printing roughness to 0.85 μm. After hot stamping, the thickness of the original coated paperboard B decreased to 306 μm, the average stiffness to 1260 mN and the printing roughness to 0.94 μm. A comparison of the properties after 24 hours shows that after calendering the thickness decreased by 33%, the average stiffness decreased by 51% and the printing roughness by 28% and after hot stamping the thickness decreased by 14%, the average stiffness decreased by 21% and the printing roughness by 18%.

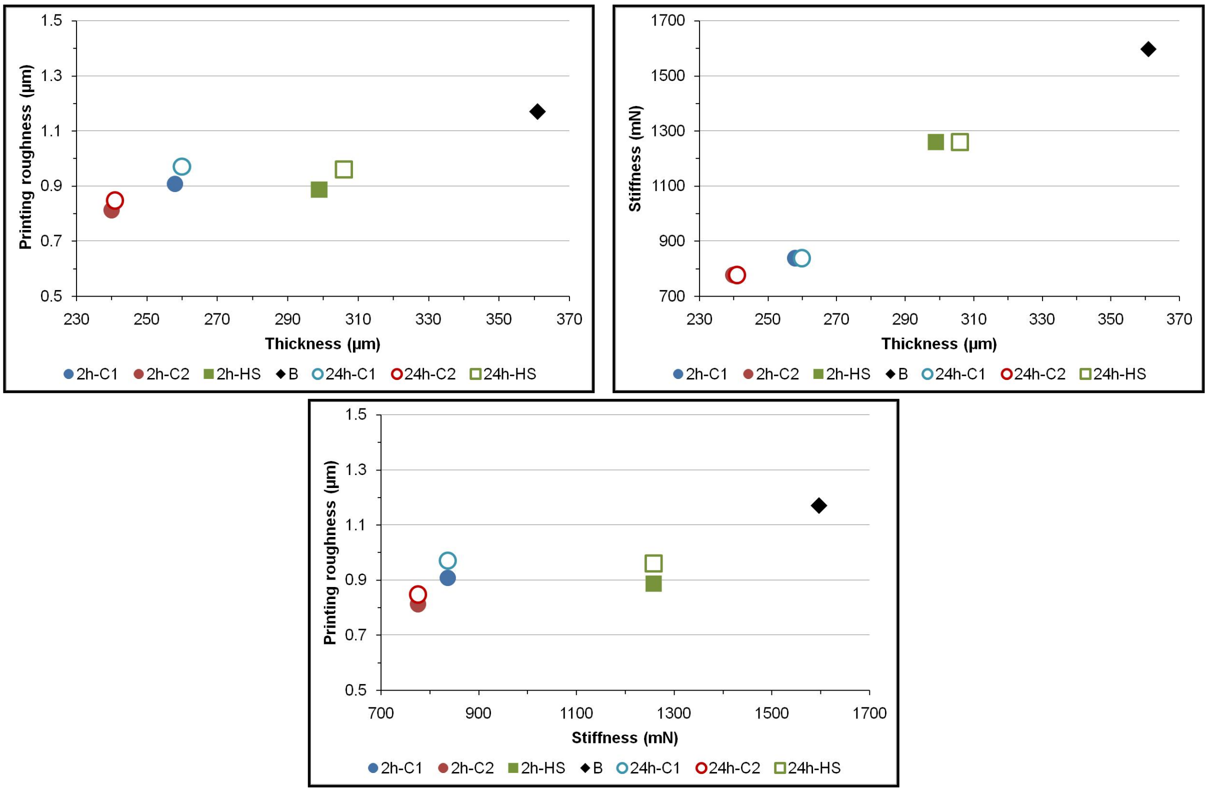
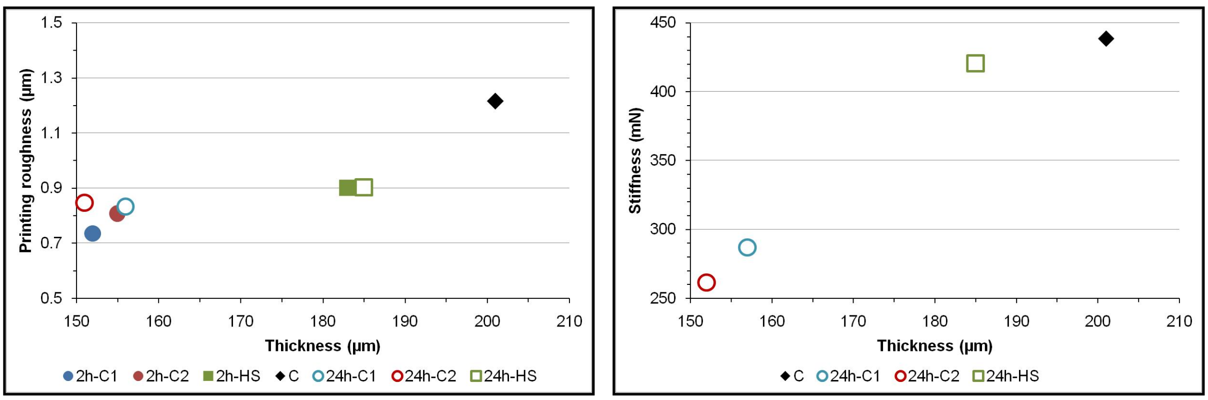


Fig. 2: The effect of smoothing by calendering and hot stamping on the relationships between thickness, printing roughness and stiffness of coated paperboard B.

Coated paperboard C with a thickness of 201 µm, an average stiffness of 440 mN and a printing roughness of 1.21 µm was smoothed in a calender using procedures C1 and C2 and in a hot stamping machine HS (Fig. 3). After smoothing in a calender by the C2 procedure, the thickness of the original coated paperboard C was reduced to 151 µm, the average stiffness to 260 mN and the printing roughness to 0.85 µm. After hot stamping, the thickness of the original coated paperboard C was reduced to 183 µm, the average stiffness to 420 mN and the printing roughness to 0.90 µm. It follows that after calendering, the thickness decreased by 25%, the average stiffness decreased by 40% and the printing roughness by 30%, and after hot stamping, the thickness decreased by 8%, the stiffness decreased by 4% and the printing roughness by 26%.



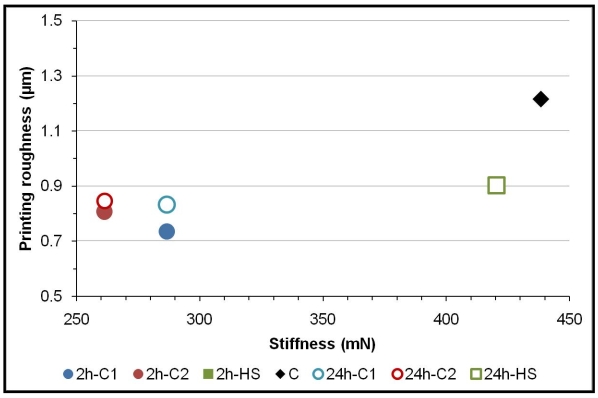


Fig. 3: The effect of smoothing by calendering and hot stamping on the relationships between thickness, printing roughness and stiffness of coated paperboard C.

Coated paperboard D with a thickness of 264 µm, an average stiffness of 835 mN and a printing roughness of 1.28 µm was smoothed in a calender using procedures C1 and C2 and in a hot machine HS (Fig. 4). After smoothing in a calender by the C2 procedure, the thickness was reduced to 191 µm, the average stiffness to 515 mN and the printing roughness to 0.84 µm. After hot stamping, the thickness of the original coated paperboard D was reduced to 240 µm, the average stiffness to 795 mN and the printing roughness to 0.75 µm. It follows that after calendering, the thickness decreased by 28%, the average stiffness decreased by 38% and the printing roughness by 35%, and after hot stamping the thickness decreased by 9%, the average stiffness decreased by 5% and the printing roughness by 42%.

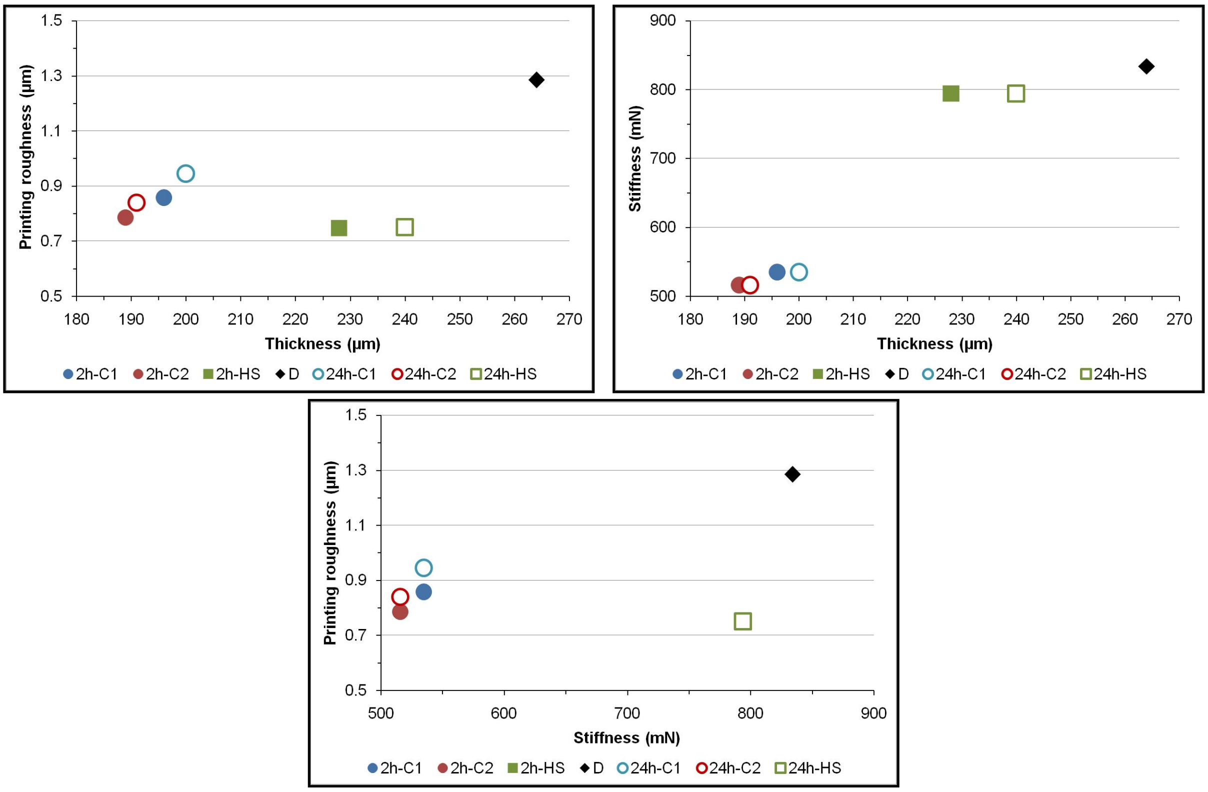


Fig. 4: The effect of smoothing by calendering and hot stamping on the relationships between thickness, printing roughness and stiffness of coated paperboard D.

Coated paperboard E with a thickness of 455 µm, an average stiffness of 3130 mN and a printing roughness of 1.63 µm was smoothed in a calender using procedures C1 and C2 and in a hot stamping machine HS (Fig. 5). After smoothing in a calender by the C2 procedure, the thickness of the original coated paperboard E was reduced to 336 µm, the average stiffness to 1805 mN and the printing roughness to 0.83 µm. After hot stamping, the thickness of the original coated paperboard E decreased to 407 µm, the average stiffness to 2825 mN and the printing roughness to 1.02 µm. It follows that after calendering, the thickness decreased by 26%, the average stiffness decreased by 42% and the printing roughness by 41%, and after hot stamping, the thickness decreased by 11%, the average stiffness decreased by 10% and the printing roughness by 28%.

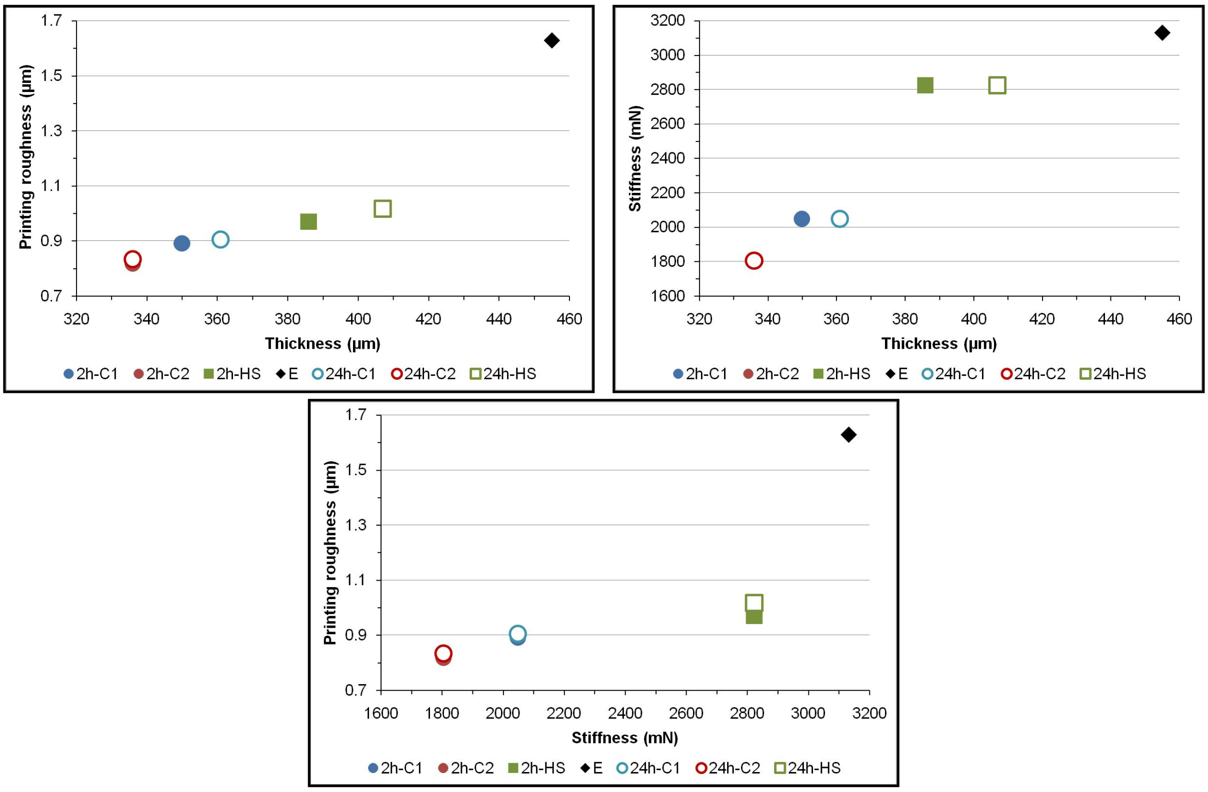


Fig. 5: The effect of smoothing by calendering and hot stamping on the relationships between thickness, printing roughness and stiffness of coated paperboard E.

Calendering of the original coated paperboards A, B, C, D and E was carried out at a temperature of 80°C and a dwell time in the pressure zone of 0.12 s at a pressure of 52 MPa, while the smoothing with a hot stamping machine took place at a temperature of 95°C and a dwell time in the pressure zone of 3 s at a pressure of 2.6 MPa. For comparison of the effect of both smoothing methods, carried out under different conditions, on the properties of the original coated paperboards, the specific stiffness per unit printing roughness parameter was used, calculated from the ratio of specific stiffness and printing roughness from values determined 48 hours after smoothing. A comparison of the procedures of smoothing C1 and C2 in the calender and in the hot stamping machine HS on the ratio of specific stiffness and printing roughness of original coated paperboards is shown in Fig. 6. Smoothing in the calender using the

C1 procedure did not significantly increase the ratio of specific stiffness and printing roughness, therefore the original coated paperboards were smoothed two times in the calender under the same conditions (C2 procedure). The hot stamping method reduces the printing roughness of the original coated paperboards while achieving a higher thickness and stiffness compared to the calendering method. For this reason, the highest values of the ratio of specific stiffness and printing roughness were achieved with smoothing with a hot stamping method of the original coated paperboards.

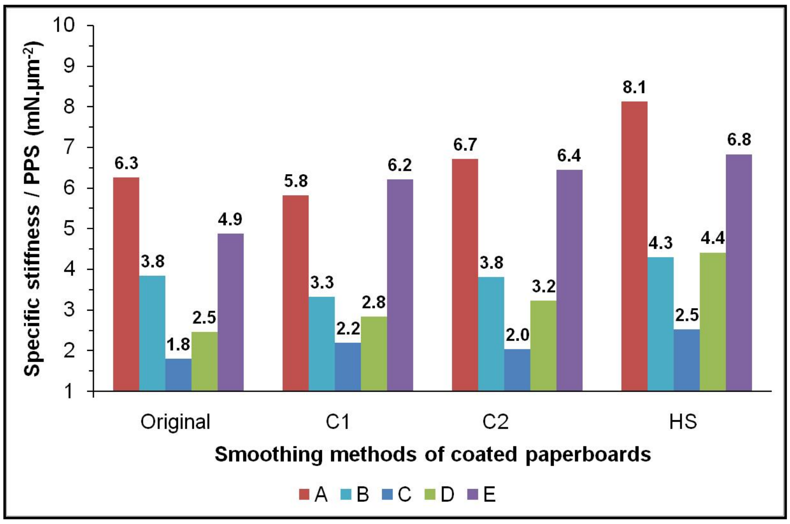


Fig. 6: The effect of smoothing methods of the original coated paperboards on the ratio of specific stiffness and printing roughness.

For the converter or end user, stiffness is a critical parameter which has a significant influence on conversion and packaging line efficiency. The maximum stiffness has to be achieved at the lowest possible grammage and thereby cost, whilst maintaining a consistent and uniform level.

When smoothing in a hot stamping machine, the thickness and stiffness of the coated paperboards were reduced only in place of a smooth metal die, while after smoothing with a calender in the whole profile. From the above it can be concluded that it will be possible to produce lighter packaging from coated cardboard smoothed by hot stamping.

CONCLUSIONS

The printing roughness of the coated paperboards to the level required for the printing of electrical and electronic components was achieved by smoothing in a calender and in a hot stamping machine. The advantage of the hot stamping machine compared to the calender was to achieve a higher stiffness of the smoothed coated paperboards with the same printing roughness.

Calendering reduces stiffness in the whole profile of the coated paperboards, while the hot stamping machine smoothed only a certain area, which is needed for printing electrical and electronic components. From the above it can be concluded that the coated paperboards smoothed by hot stamping have the same stiffness at a lower basis weight than those calendered.

Therefore, it will be possible to produce a packaging with a lower weight from coated paperboards smoothed by hot stamping.

In addition, calendering causes a reduction of the friction coefficient in the whole profile of the coated paperboards, which is often the cause of deteriorated stackability of packaging.

Direct printing of electrical and electronic components on coated paperboards smoothed by hot stamping can be an interesting alternative to the technology of gluing smart labels to packaging.

ACKNOWLEDGEMENTS

This work was supported by Slovak Research and Development Agency under contract No. APVV-19-0029.

REFERENCES

1. Agate, S., Joyce, M., Lucia, L., Pal, L., 2018: Cellulose and nanocellulose-based flexible-hybrid printed electronics and conductive composites. A review. Carbohydrate Polymers 198: 249-260.
2. Agca, M.A., Tasdemir, M., 2016: Investigation of hot stamping parameters in up/down machining on ABS materials under quality purposes of different stamping processes. ICAMS 2016 – 6th International Conference on Advanced Materials and Systems. Vol. 1.
3. Ali, S., Maddipatla, D., Narakathu, B.B., Chlaihawi, A.A., Emamian, S., Janabi, F., Bazuin, B.J., Atashbar, M.Z., 2018: Flexible capacitive pressure sensor based on pdms substrate and Ga–In liquid metal. IEEE Sensors Journals 19: 97-104.
4. Bollström, R., 2013: Paper for printed electronics and functionality. Ph.D. Thesis, Abo Akademi University, Turku, Finland, 100 pp.
5. Bollström, R., Pettersson, F., Dolietis, P., Preston, J., Österbacka, R., Toivakka, M., 2014: Impact of humidity on functionality of on-paper printed electronics. Nanotechnology 25(9): 094003.
6. Fernández-Salmerón, J., Rivadeneyra, A., Martínez-Martí, F., Capitán-Vallvey, L.F., Palma, A.J., Carvajal, M.A., 2015: Passive UHF RFID tag with multiple sensing capabilities. Sensors 15(10): 26769-26782.
7. Fugmann, U., Kempa, H., Preissler, K., Bartzsch, M., Zillger, T., Fischer, T., Schmidt, G., Brandt, N., Hahn, U., Huebler, A.C., 2006: Printed electronics is leaving the laboratory. MST News (2): 13-16.
8. Gerhard, C., Roux, S., Brückner, S., Wieneke, S., Viol, W., 2012: Low-temperature atmospheric pressure argon plasma treatment and hybrid laser-plasma ablation of barite crown and heavy flint glass. Applied Optics 51: 3847-3852.
9. Gigac, J., Kasajová, M., Stankovská, M., 2014a: The influence of paper surface energy on multicolor offset print mottling. Tappi Journal 13(2): 55-64.
10. Gigac, J., Stankovská, M., Letko, M., Opálená, E., 2014b: Effect of base paper properties on inkjet print quality. Wood Research 59(4): 717-730.

11. Gigac, J., Fišerová, M., Hegyi, S., 2021a: Comparison of thermal transfer and inkjet Printing of UHF RFID tag antennas on paper substrate. Wood Research 66(1): 71-84.
12. Gigac, J., Fišerová, M., Kováč, M., Hegyi, S., 2021b: Passive UHF RFID tags with thermal-transfer-printed antennas. Materials and Technology 55(2): 277-282.
13. Gullichsen, J., Paulapuro, H., 1999: Papermaking science and technology, Papermaking Part 3, Finishing. Book 10, Chapter 1, Eds. Juha Ehrola, Ari Hernesniemi, Harri Kuosa, Markku Kyytsönen, Pekka Linnonmaa, Tapio Maenpaa, Reijo Pietikainen, Rob Stapels, Mikko Tani and Hannu Vuorikari, (book 10), Published by Fapet Oy, Helsinki, Finland. Pp 14-140.
14. Häggblom-Ahnger, U., Komulainen, P., 2003. Paperin ja Kartongin Valmistus, Helsinki: Opetushallitus. Pp 1-279.
15. Kaplanová, M., Syrový, T., Držková, M., Hejduk, J., Svoboda, J, Holická, H., Dohnal, M., Vališ, J., Veselý, M., Otáhalová, L., Panák, O., 2009: Polygrafické materiály (Polygraphic materials) (in Slovak). In: Pp 123-174, Moderní polygrafie. Svaz polygrafických podnikatelů.
16. Kasajová, M., Gigac J., 2013: Comparison of print mottle and surface topography testing methods. Nordic Pulp Paper Research Journal 28(3): 443–449.
17. Kavčič, U., Pivar, M., Dokič, M., Svetec, D.G., Pavlovič, L., Muck, T., 2014: UHF RFID tags with printed antennas on recycled papers and cardboards. Materials and Technology 48(2): 261-267.
18. Kipphan, H., 2001: Technologies and production methods. In: Handbook of print media. Springer. Pp 4-1173. DOI:10.1007/978-3-540-29900-4 (eBook).
19. Kiviranta, A., 2000: Paperboard Grades. Paper and Board Grades. Helsinki, Finland: Fapet Oy. Pp 55-75.
20. Leinonen, H., Lares, M., Tani, M., 2001: Long nip calendaring. Quality and productivity. Wochenblatt für Papierfabrikation 129(20): 1320-1324.
21. Lyashenko, A., Salun, L., Dörsam, E., 2012: Hot stamping technology for functional printing. Advances in Printing and Media Technology. In: Proceedings of the 39th International Research Conference of iarigai Ljubljana, Slovenia, September 2012, Vol. XXXIX: 64-74.
22. Maddipatla, D., Narakathu, B.B., Atashbar, M., 2020: Recent Progress in Manufacturing Techniques of Printed and Flexible Sensors. A Review. Biosensors 10(12): 199-222.
23. Morfa, A., Rödlmeier, T., Jürgensen, N., Stolz, S., Hernandez-Sosa, G., 2016: Comparison of biodegradable substrates for printed organic electronic devices. Cellulose 23(6): 3809–3817.
24. Salmerón, J.F., Molina-Lopez, F., Briand, D.; Ruan, J.J., Rivadeneyra, A., Carvajal, M.A., Capitán-Vallvey, L.F., de Rooij, N.F., Palma, A.J., 2014: Properties and printability of inkjet and screen-printed silver patterns for RFID antennas. Journal of Electronic Materials 43: 604-617.
25. Suganuma, K., 2014: Introduction to printed electronics. Springer Science & Business. Media: Berlin/Heidelberg, Germany, 74: 1-124.

26. Tan, M.J., Owh, C., Chee, P.L., Kyaw, A.K.K., Kai, D., Loh, X.J., 2016: Biodegradable electronics: Cornerstone for sustainable electronics and transient applications. Journal of Materials Chemistry C(4): 5531-5558.
27. Turkani, V.S., Maddipatla, D., Narakathu, B.B., Bazuin, B.J., Atashbar, M.Z., 2018: A carbon nanotube based NTC thermistor using additive print manufacturing processes. Sensors and Actuators A: Physical 279: 1–9.
28. Voigt, M.M., Guite, A., Chung, D.Y., Khan, R.U.A., Campbell, A.J., Bradley, D.D.C., Meng, F., Steinke, J.H.G., Tierney, S., McCulloch, I., Penxten, H., Lutsen, L., Douheret, O., Manca, J., Brockmann, U., Sönnichsen, K., Hülsenberg, D., Bock, W., Barron, C., Blanckaert, N., Springer, S., Grupp, J., Mosley, A., 2010: Polymer field-effect transistors fabricated by the sequential gravure printing of polythiophene, two insulator ayers, and a metal ink gate. Advanced Functional Materials 20(2): 239-246.
29. Wiklund, J., Karakoç, A., Palko, T., Yiğitler, H., Ruttik, K., Jäntti, R., Paltakari, J., 2021: A review on printed electronics: Fabrication methods, inks, substrates, applications and environmental impacts. Journal of Manufacturing and Materials Processing 53: 89-124.
30. Xiao, G., Zhang, Z., Fukutani, H., Tao, Y., Lang, S., 2018: Improving the Q -factor of printed HF RFID loop antennas on flexible substrates by condensing the microstructures of conductors. IEEE Journal of Radio Frequency Identification.
31. Zeng, X., Yang, C., Chiang, J.F., Li, J., 2017: Innovating e-waste management: From macroscopic to microscopic scales. Science of the Total Environment 575: 1-5.

JURAJ GIGAC*, MÁRIA FIŠEROVÁ
PULP AND PAPER RESEARCH INSTITUTE
DÚBRAVSKÁ CESTA 14
841 04 BRATISLAVA
SLOVAK REPUBLIC
*Corresponding author: gigac@vupc.sk