INFLUENCE OF MICROCAPSULES ON THE PROPERTIES OF RAISED PRINTS

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Different standards and legislations define the parameters that have to be met so that the blind and visually impaired people can understand raised printed elements (Braille and tactile images). In this research, prints were made by the classic screen-printing technique and by special printing inks with thermally expandable microcapsules. For the purpose of the research, the properties of the inks, as well as the prints, were analyzed. Considering the fact that a printed surface can be recognized more easily with two senses rather than with one, pressure-sensitive fragrant microcapsules were additionally incorporated into the printing ink. The influence of fragrance microcapsules on the properties of printing inks and printed substrates was examined during the research. The analysis revealed that selected inks provide satisfactory results in height and touch recognition and that although incorporated fragrant microcapsules influence the properties of the inks and prints, fragrance contributes to easier recognition of raised printed elements.

Keywords: raised prints, microcapsules, fragrance microcapsules, screen printing, special printing inks, Braille

INTRODUCTION

Preparing appropriate and relevant printed material (literature) for blind and visually impaired people always presents a challenge for the manufacturers.[1] Perception of different printed objects by visually impaired or blind people depends mainly on their sense of touch and rarely on other senses (*e.g.* hearing and/or smelling). Prints made for persons with damaged eyesight have to follow the requirements of different standards, legislations and national documents, which define the specific parameters of prints.[2-7] Countries have different specifications for Braille character spacing and minimum height of the dots in the Braille cell. Standards differ in distance of horizontal/vertical dot-to-dot spacing, cell-to-cell and line-to-line dimensions, the diameter of the Braille dot and its height. Values of specific dimensions vary according to the chosen application of Braille and the printing technique by which it is going to be printed, but they all define minimal and sometimes maximal values.[8] For reading Braille, all mentioned parameters have to be fulfilled, but for "reading" tactile images mainly one parameter is important – the height of the printed element. The surface of raised prints has to be distinguishable from the unprinted area by sharp edges that define the beginning of another surface, while the latter can differ from another unprinted or printed area either by different touch effect or by the pattern of the printed surface.[9] According to the existing standards,[2,4-7] legislations[3] and national documents, the minimum height of prints, whether Braille dots or other raised surfaces, has to be at least 0.45 mm (with the exception of Swedish (0.25 mm) and Small English (0.33 mm) Braille type). In general, the higher is the print, the easier is the recognition of a printed surface, although optimum height must be taken into account. Recognition and reading by visually impaired or blind people strongly depend on the sensitivity of their fingertips, as well as on experience, which depends on the time of practice.[10] Several contradictory studies have been carried out to investigate the hypothesis that blind people can improve other senses, if one of them is damaged.[11-14] However, the majority of research papers endorse the opinion that the addition of fragrance can contribute to easier recognition of printed elements.

Our research was therefore limited to two important factors: the height of prints, achieved by the standard screen printing method, and the inclusion of an additional sense, *e.g*. smell, while reading/touching the printed elements. The adequate heights (specified in standards and regulations) of prints can be achieved with printing techniques, which are nowadays mainly used for Braille printing – digital printing and embossing. Both techniques have their advantages and disadvantages. Embossing demands proper printing substrates (*e.g*. paper), in the case of paper or board, the surface of prints gets damaged during usage and, besides that, this kind of prints take a lot of space, as they are very voluminous (printing on only one side of material, rather large surface of the Braille letter cell, *etc*.). With digital printing adequate height is usually achieved with printing of several layers, where accurate fitting of those layers usually presents a problem. These prints are nowadays mainly made by UV inks, where drying is a critical phase. Another drawback is the cracking of the surface of raised printed elements, which becomes unpleasant to touch. Also, printing Braille by the digital technique is a time-consuming process.[15]

In this research, screen-printing was selected as printing technique for Braille and tactile images. Although this technique is often mentioned in different patents and researches,[16-19] it has been rarely used in practice. It is one of the oldest printing techniques, which by changing various parameters during printing enables to achieve higher prints. By changing the parameters of the printing form, *e.g*. density of threads, diameter and shape of monofilament, photo emulsion thickness, *etc*., more printing ink is transferred onto the substrate. Higher thickness can also be achieved with an increased number of squeegee passages, which influences the speed of drying, as well as the costs of prints. One of the parameters that cannot be forgotten is the quality of the printing substrate (paper). Smoother substrates (*e.g*. coated) enable higher application of layers, while on uneven surfaces, printing ink passes into the pores of the substrate resulting in reduced thickness of prints.[20]

One of the goals of this research was to shorten the time of print production. This can be achieved by increasing the thickness of the printed ink layer (using all earlier mentioned possibilities) or by selecting different types of ink, by which thicker layers are obtained. For this purpose, we have used 3D printing inks with expandable microcapsules, which under proper conditions expand and thus enable higher prints without the use of multi-passages of squeegee or printing multiple layers of ink.

Considering that the recognition of a printed surface can be achieved more easily with two senses rather than with one, we have also added pressure-sensitive fragrant microcapsules into the 3D printing ink. The fragrance of essential oils is released from the microcapsules at rupture, which is caused by pressure (and friction). The release of fragrance can encourage the reader to relate the known smell with the printed elements, thus enabling easier recognition. The durability of prints plays, in this case, an important role – multiple passing of fingertips over the printed surface can damage and crack the surface, as well as the microcapsules. Fragrant microcapsules added into the printing ink change the properties of printing inks and those of the printed substrate, as demonstrated in this paper.

EXPERIMENTAL

Materials

Paper substrate

The structure and properties of a paper substrate play a significant role in the quality of prints. For the present investigation, two different types of cellulose paper substrates (Papirnica Vevče, Slovenia) were chosen:

- uncoated, wood-free Superprint paper, machine-finished and surface sized, with a grammage (weight) of 150 g/m^2, according to the manufacturer's product specifications, (in this research indicated as SP), and
- two-side coated, wood-free Biomatt paper, with high whiteness (bright white) and a grammage (weight) of 120 g/m^2, according to the manufacturer's product specifications, (in this research indicated as BM).

Printing inks

Prints were made with three different ready-to-use printing inks (Achitex Minerva Spa, Italy):

- Minerfoam SR (in this research indicated as MF SR) containing an acrylic polymer and expandable microcapsules composed of vinylidene chloride-acrylonitrile copolymer. MF SR properties: density: 1.05 g/cm^3, viscosity 110 dPa·s and pH value 8.5.
- Minerfoam FL (in this research indicated as MF FL) containing an acrylic polymer and expandable microcapsules composed of acrylonitrile

copolymer. MF FL properties: density 0.95 g/cm^3, viscosity 110 dPa·s and pH value 9.1.

- Elastil Comprente (in this research indicated as EC), which was a highly elastic water-based paste with acrylic binders, without expandable microcapsules. EC properties: density 0.95 g/cm^3, viscosity 110 dPa·s and pH value 8.2.

MF SR and MF FL printing inks enable special 3D effects due to the presence of thermally expandable microcapsules. Expandable microcapsules are composed of a wall and a core material, which is a liquid expanding agent, such as a low boiling hydrocarbon or other volatile material.[21] During the core vaporization at elevated temperature, the pressure inside the microcapsules increases and expands the wall by several times.[22,23] The degree of expansion depends on the time and the temperature (above 130 °C) at which expanding occurs, as well as the properties of the paper substrate and the amount of printing ink.[24,25] Printing ink MF SR offers a rubbery effect, while MF FL offers a velvet effect. EC is an ordinary effect-free printing ink, which was chosen for comparing the prints.

Preparation of fragrant microcapsules

Fragrant microcapsules were prepared by "*in situ*" polymerization in an industrial 200-L reactor system.[26] An industrial mixture of essential oils of lavender, rosemary and sage (Aero, d.d., Slovenia) was used as core, while the precondensate of melamine-formaldehyde resins (Melamin, d.d., Slovenia) was used for the formation of microcapsule walls. Anionic polyelectrolyte on the basis of polyacrylic acid (Aero, d.d., Slovenia) was used as modifier. The synthesis was performed by the following steps: (1) preparation of an aqueous solution of modifier, (2) addition of core material and formation of oil in water (O/W) emulsion, (3) addition of wall material and heating to 70-80 °C, (4) formation of the wall in the process of the polycondensation of melamine-formaldehyde resin at raised temperature, (5) cooling of the system and addition of ammonia for the removal of the residual free formaldehyde.

The properties of the microcapsules in aqueous solution are presented in Table 1 and the size distribution curve is shown in Figure 1.

The size distribution curve of fragrant microcapsules in aqueous suspension is narrow (Fig. 1) with average diameters from 2 to 5 µm. A fraction of small microcapsules (<1 µm) is probably a residual of redundant wall material from the microencapsulation process.

For the purpose of the research, 5, 10 and 15 wt% of aqueous fragrant microcapsule suspension was added into the printing inks.

Process of printing on paper substrates

Printing was performed on an Automatic Screen Printing Machine SD 05, RokuPrint, GmbH. Properties of screen printing form: PET mash with the density of 43 threads/cm; monofilament diameter of 80 µm; angle of threads 0°; load tension of 15 N. All prints were made with one passage of squeegee.

Considering the two types of paper substrate (SP and BM), three types of printing inks (MF SR, MF FL and EC) and fragrant microcapsule concentrations added into printing inks (0, 5, 10 and 15 wt%), altogether 24 different printing samples were prepared (Table 2).

After printing, all samples were dried in a drying tunnel SHRINK MACHINE BS-B400, for 40 seconds, at 100 °C. Immediately after drying, expansion of prints was performed in a heating oven BINDER FD 115, for 3 minutes at 150 °C.

Testing methods

Before and after printing, the following properties were measured on the paper substrates: pH value was measured according to standard ISO 6588-1:2012.[27] Grammage was measured according to the method described in standard EN ISO 536:2012.[28] Thickness was measured on a Mitutoyo apparatus, No: 2050 F–10 with a load of 500 cN/cm^2 on the sample area of measurement of 1 cm^2 and according to standard ISO 534:2011.[29] Roughness of paper substrates was determined by the Bendtsen method, as described in standard ISO 8791-2.[30] Air permeance was measured on a Bendtsen apparatus according to the method described in standard ISO 5636-3.[31]

Table 1
Properties of aqueous suspension of synthesized fragrant microcapsules

Parameter	Value
Average size of microcapsules, µm	4.3
Viscosity, dPa·s	2.07
Percentage share of microcapsules, wt%	30
pH value	6.4
Share of free formaldehyde, %	<0.2
Thermal stability/permeability of the wall, %, after 3 h at 135 °C	<3

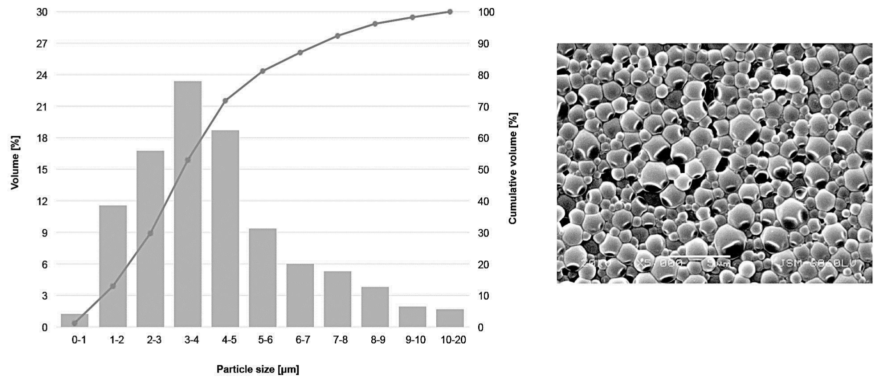

Figure 1: Size distribution curve for fragrant microcapsules (measurements of microcapsule diameter by SEM at 5.000x magnification)

Table 2
Printing samples

Substrate	Printing ink	Conc. of fragrant microcapsules, wt%			
SP	MF SR	0	5	10	15
	MF FR	0	5	10	15
	EC	0	5	10	15
BM	MF SR	0	5	10	15
	MF FR	0	5	10	15
	EC	0	5	10	15

Water absorptiveness (Cobb value) was measured on the front and back (rear) sides of the substrate according to standard ISO 535:1995.[32] Height of capillary rise was measured in machine direction (hereinafter U_{MD}) and cross-direction (hereinafter U_{CD}) by the Klemm method, according to standard ISO 8787:1996 [33]; the dimension of the samples was 175 mm x 15 mm, slightly shorter than prescribed by the standard. Bending stiffness was measured according to the method described in ASTM D1388:14,[34] which is suitable for textiles and also for paper. Bending stiffness was measured in machine (U_{CD}) and cross- (U_{MD}) direction and calculated by the equation:

$$U_{MD\ or\ CD} = G \cdot \left(l/_2\right)^3;\ [mg \cdot cm] \tag{1}$$

where $U_{MD\ or\ CD}$ presents bending stiffness in machine or cross- direction [cm], and G presents grammage [mg·cm]. Overall (total) bending stiffness (U_T) was then calculated according to the equation:

$$U_T = \sqrt{U_{MD} \cdot U_{CD}};\ [mg \cdot cm] \tag{2}$$

Image analyses of the prints and of the morphological properties of selected substrates were performed with a Leica EZ4 HD optical microscope and a scanning electron microscope (SEM) JSM 6060 LV, Jeol.

The following measurements were carried out on printing inks: viscosity of prepared printing inks was measured on a rotational viscometer Thermo Haake Viscoteste VT-02, at room temperature, with the rotational frequency of 62.5 spins/min in the area of 0.3-4000 dPa·s. Measurements were performed according to the DIN EN ISO 3219:1994-10 standard.[35] The pH value was measured with a WTW pH 315i SET Portable Field pH Meter – 2A10-1012.

Printed substrates were also examined by blind people, and their impressions are presented together with individual results of testing.

RESULTS AND DISCUSSION

Properties of paper substrates

The surface morphology and cross-section of two paper substrates – SP and BM – were examined with SEM. It was established that the surface of substrate SP was not completely closed; the substrate had clearly visible cellulose fibers and macropores, which resulted in surface roughness (Figs. 2A-1, 2A-2). Substrate BM had a coated and smooth surface (Fig. 2B-1) with surface micropores (Fig. 2B-2). The results of the measured properties of substrates BM and SP are shown in Table 3.

According to the results listed in Table 3, the two side coated paper substrate BM was thinner, had lower grammage and slightly lower density compared to the uncoated paper substrate SP. The

BM substrate also had lower water absorptiveness ($Cobb_{60}$) and lower height of capillary rise in MD and CD direction compared to substrate SP. The difference in height of capillary rise between MD and CD was negligible for both substrates. According to the measured values of water absorptiveness and height of capillary rise, both substrates were characterized as hydrophilic. BM had higher tensile strength and strain in both directions than substrate SP. Substrate SP had higher bending stiffness value than BM, which stems from higher grammage.

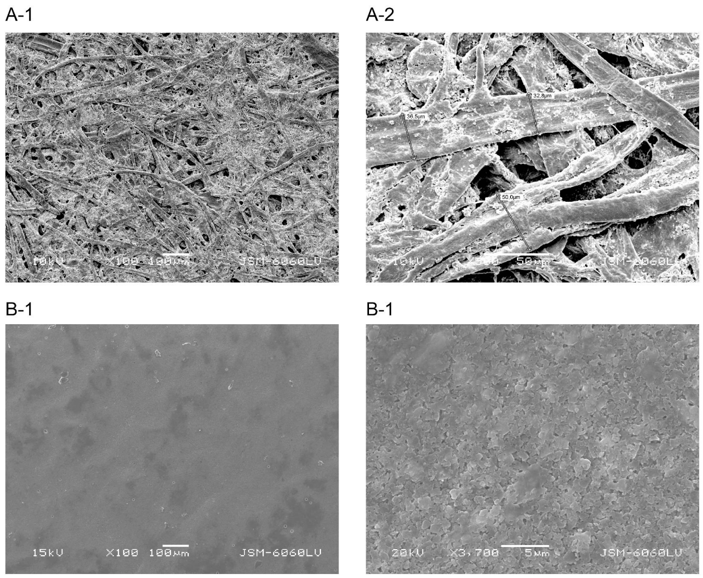

Figure 2: Surface of substrates A) SP (SEM, A-1: 100x magnification, A-2: 500x magnification) and B) BM (SEM, B-1: 100x magnification, B-2: 3.700x magnification)

Table 3
Properties of substrates SP and BM

Property	Substrate	
	SP	BM
pH	7.74	7.74
Grammage, g/m^2	146.45	114.55
Thickness, mm	0.155	0.117
Density, g/cm^3	0.95	0.98
Paper roughness, ml/min (side A/side B)	148.6/138.0	64.2/102.0
Air permeance, µm/Pa.s (side A/side B)	0.142/0.153	impermeable
Water absorptiveness ($Cobb_{60}$), g/m^2 (Side A/side B)	74.9/60.2	19.2/27.9
Height of capillary rise, mm (MD/CD)	19/17	13/12
Tensile strength, kN/m (MD/CD)	5.3/3.13	6.01/3.36
Tensile strain at maximum load, % (MD/CD)	1.89/3.8	1.89/4.89
Bending stiffness, mg·cm	1069.57	1002.37

Properties of printing inks

All three printed inks were observed by SEM before use in order to get a better insight into the size, shape and distribution of expandable microcapsules (Fig. 3, A to C).

Microscopic images in Figure 3A, B and C show significant differences among all three inks. MF SR printing ink has a lot of smaller expandable microcapsules, while MF FL printing ink has larger, but not so numerous expandable microcapsules. According to the measurements, which were performed with SEM, the average diameter of expandable microcapsules in printing ink MF SR and MF FL was 11.6 µm and 30.7 µm, respectively. Particles in EC printing ink (Fig. 3C) are irregular shaped and do not belong to expandable microcapsules.

In order to prepare the printing inks for printing on substrates, the aqueous suspension of fragrant microcapsules was added in 0, 5, 10 and 15 wt%. With the addition of the aqueous suspension of fragrant microcapsules (η = 2.07 dPa·s) into the printing inks (η = 110 dPa·s), the initial viscosity of the inks decreased with the increasing concentration of the added aqueous suspension of fragrant microcapsules (Fig. 4).

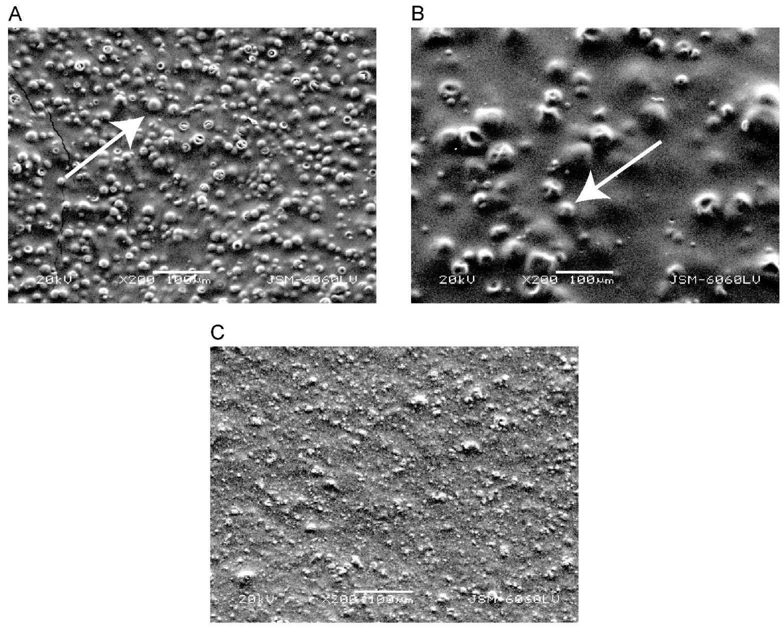

Figure 3: Microscopic images of printing inks A) MF SR (SEM, 200x magnification), B) MF FL (SEM, 200x magnification) and C) EC (SEM, 200x magnification); white arrows point to unexpanded microcapsules in printing inks MF SR and MF FL

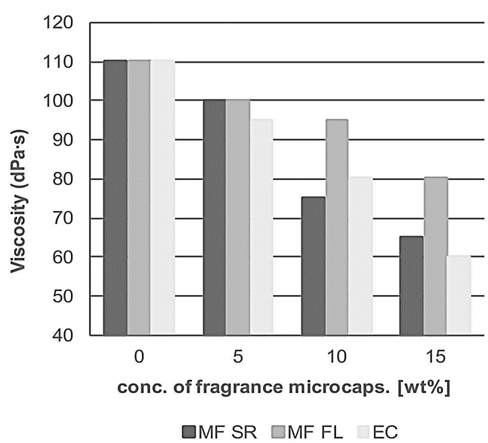

Figure 4: Printing ink viscosity as a function of amount of fragrant microcapsule suspension added (0, 5, 10 and 15 wt%)

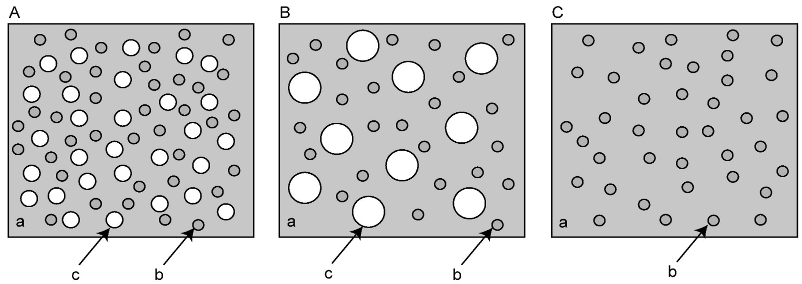

Figure 5: Three different systems of printing inks with blended fragrant microcapsules: A) MF SR, B) MF FL and C) EC; (a – printing ink, b – fragrant microcapsules, c – expandable microcapsules

The different behavior of the printing ink viscosity upon the addition of fragrant microcapsules (Fig. 4) is probably explained by the rheological properties of inks, which are influenced by size, shape, distribution of particles and interactions between particles and medium. The shape of all containing particles (expandable microcapsules and fragrant microcapsules) was the same – spherical, so it had no significant influence on viscosity. On the other hand, the viscosity was probably influenced by different sizes of particles and their distribution.

The average diameter of expandable microcapsules in printing inks MF SR and MF FL was 11.6 µm and 30.7 µm, respectively, while the average diameter of fragrant microcapsules was 4.3 µm. When 15 wt% aqueous suspension of fragrant microcapsules was added into each printing ink, the highest reduction in viscosity was observed for sample EC, where only fragrant microcapsules were present in the printing ink (Fig. 5C). Sample MF SR had a similar viscosity value, which contained a higher concentration of smaller expandable microcapsules and added fragrant microcapsules (Fig. 5A). On the other hand, the lowest reduction in viscosity was noticed for MF FL, which had a small amount of larger expandable microcapsules and an equal share of added fragrant microcapsules to that of the other two inks (Fig. 5B).

Two printing inks presented in Figure 5, namely 5A and 5B, were polydisperse systems with expandable and fragrant microcapsules, whose sizes differed. For each suspension, there is a certain inflection point, when viscosity starts to increase after a decrease. We presume that, in this study, the inflection point was not achieved, probably because a small quantity of fragrant microcapsules was added to the inks (<15 wt%). We assumed that there were no interactions between expandable and fragrant microcapsules and therefore no influence on the viscosity. Further research on the topic of viscosity change will be performed in the next stages of our work.

The microcapsule suspension had acid character (6.4), while all printing inks were alkaline (MF SR 8.5, MF FL 9.1 and EC 8.2). By adding microcapsule aqueous suspension into the printing inks, the initial pH values of all inks decreased. The change was most obvious in the case of MF SR, which became acidic (6.6) and the smallest with MF FL and EC, which still had an alkaline character, 8.4 and 7.5, respectively.

Properties of printed paper substrates

Properties of paper substrates printed without fragrant microcapsules

Both paper substrates – BM and SP – were printed with three printing inks – MF SR, MF FL and EC. SEM images of cross-sections of paper substrate SP samples (presented in Fig. 6) clearly show that the surface morphology of the samples printed with the three printing inks was apparently different. In the case of the MF SR printing ink, the surface of the SP substrate was covered with small, numerous and densely packed expanded microcapsules (Fig. 6A); in the case of MF FL, the microcapsules on the surface were larger, less numerous and sparsely distributed, so the base layer of the printing ink could be seen through the layer of expanded microcapsules (Fig. 6B); the surface of the SP substrate, printed with EC printing ink, was fully covered with ink and quite smooth (Fig. 6C). Observation of images and further measurements confirm our prediction that higher thickness of prints was achieved with MF SR and MF FL due to the presence of expandable microcapsules, which, during the process of expansion, increased in size on the surface of prints. Different size and distribution of expanded microcapsules contributed to different surface effects – velvet for MF FL and rubbery for MF SR, which gave a pleasant touch to the prints. The same phenomenon was also observed for the BM paper substrate.

Analyses on the size of microcapsules performed by SEM have confirmed that the degree of expansion depends on the properties of the paper substrate. The average size of unexpanded expandable microcapsules of the MF FL printing ink was 30.7 µm. When printed and expanded on the SP substrate, the expandable microcapsules expanded to an average diameter of up to 81.8 µm and on the BM paper substrate up to 91.7 µm. The size distribution curves for expandable microcapsules expanded on the SP and BM substrates are presented in Figures 7 and 8.

Results have shown that the size distribution curve of expanded microcapsules on the SP substrate is wider, while for BM it is narrower (Figs. 7 and 8), which suggests that expandable microcapsules were expanded more evenly on the smother coated surface of BM. On the contrary, the porous surface of the SP substrate influenced the equal expansion of microcapsules mainly because part of the printing ink penetrated into the structure of the substrate, in which the expansion of microcapsules was hindered. This conclusion can also be confirmed by the size distribution curves in Figure 7, which represents the distribution on the SP rough material, where unexpanded microcapsules in the range of 22.2-30.6 µm are still presented, while in Figure 8, all microcapsules are larger (>44.4 µm) than unexpanded microcapsules (original size of microcapsules in MF FL was 30.7 µm). The same phenomenon was also observed with MF SR printing ink on both substrates.

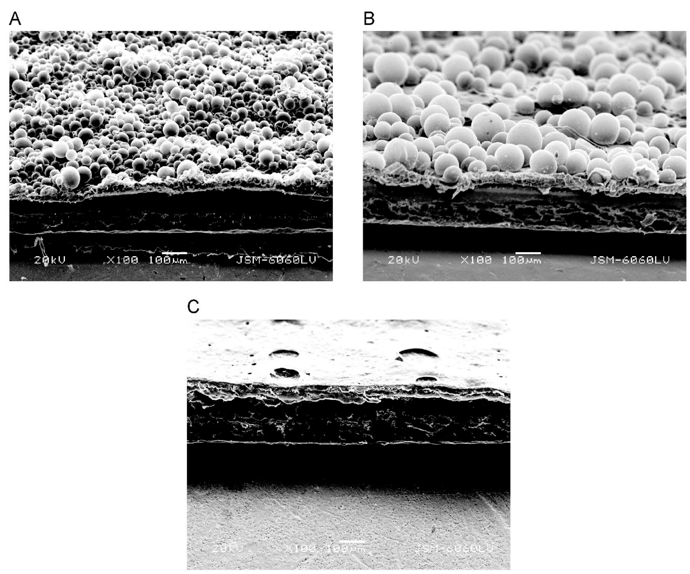

Figure 6: Microscopic images of longitudinal cross-section of substrate SP printed with three different printing inks: A) MF SR, B) MF FL and C) EC (SEM, 100x magnification)

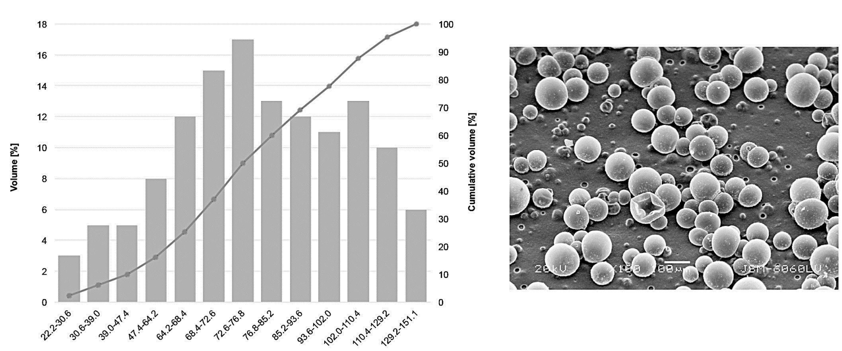

Figure 7: Size distribution curve for expanded microcapsules of MF FL on substrate SP (SEM analyses at 100x magnification)

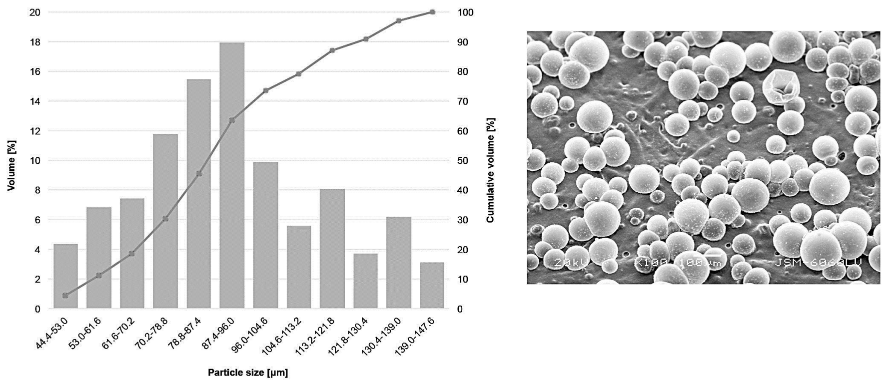

Figure 8: Size distribution curve for expanded microcapsules of MF FL on substrate BM (SEM analyses at 100x magnification)

Table 4
Thickness of prints on substrates SP and BM with three different inks (MF SR, MF FL and EC) without fragrant microcapsules

Printing ink	Thickness of prints, mm	
	SP	BM
MF SR	0.128	0.132
MF FL	0.076	0.089
EC	0.023	0.029

The thickness of the prints made with expandable microcapsules (MF SR and MF FL) was much higher than that of the prints made with ordinary EC printing ink, as can be seen from Table 4 (note: the thickness of prints presents only the printed layer of ink without substrate). In addition, the prints made with printing ink MF SR had higher thickness than those made with printing ink MF FL. The explanation of this difference can be found in the distribution of expanded microcapsules after they were printed on the surface of the substrate (Fig. 6). A slightly higher thickness of prints was achieved on the coated BM printing substrate, compared to the prints made on the uncoated, more porous SP substrate, regardless of the printing inks used (this observation agrees with the conclusions of A. Willfahrt *et al.*[20]).

The results in Table 4 confirm that a significant difference in thickness could be achieved by the use of expandable printing inks, although the height of printed elements is still a bit lower than that recommended by some standards for raised prints. However, it should be emphasized that all samples were printed with only one passage of squeegee, therefore we believe that the height could be increased with two or more printing layers and with a slightly modified process of screen printing. Although, the thickness of prints was slightly lower than recommended, the raised elements were still recognized by blind people and even more, they were excited about the interesting tactile surfaces.

Properties of prints with added fragrant microcapsules

After fragrant microcapsules were added into the printing inks and printed, their distribution in the samples was observed by SEM. The fragrant microcapsules most likely penetrated with printing inks into the structure of the SP substrate, while in the case of the two-side coated BM substrate, they probably also stayed within the ink printed layer on the surface of the substrate. For identifying fragrant microcapsules, cross-sections of the printed samples were prepared and examined. Although SEM images were taken at higher magnifications, fragrant microcapsules could not be seen inside the ink on cross-section. However, SEM analyses have shown that fragrant microcapsules were loaded on the surface of larger expanded microcapsules (Fig. 9).

The intensity of smell on the prints was not determined analytically in this research, although subjective assessment of fragrance was performed by different persons with scratching and smelling the samples after one week and after a few months. Regardless of the added amount of aqueous suspension of fragrant microcapsules, the smell was detected in all prints on both substrates after one week, a few months and even after one year, which indicates that microcapsules were not damaged and that essential oil was still enclosed in the core.

Mixing fragrant microcapsules into the printing inks had some other influences on the properties of the prints. Reduced printing ink viscosity by adding fragrant microcapsules influenced the surface of the printed samples. The edges of the prints without fragrant microcapsules (Figs. 10A-1, 10A-2) were sharp and rough (on Figs. 10A-1 and 10A-2, the pattern of printing mash can also be noticed), while the prints made with the highest concentration of fragrant microcapsule suspension (15 wt%) were more jagged and blurred (Figs. 10B-1, 10B-2).

As the viscosity of the printing ink decreases with an increasing concentration of the aqueous solution of fragrant microcapsules, it penetrates more easily into the substrate, leaving less ink on the surface of the substrate and decreases thickness (Fig. 11).

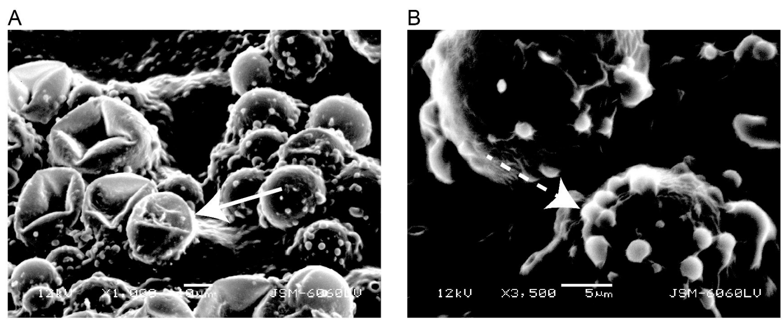

Figure 9: Microscopic images of printing inks A) MF SR 15 (SEM, 1.000x magnification) and B) MF FL 15 (SEM, 3.500x magnification); white solid arrow points to expanded microcapsules, white dotted arrow points to fragrant microcapsules loaded on the surface of expanded microcapsules

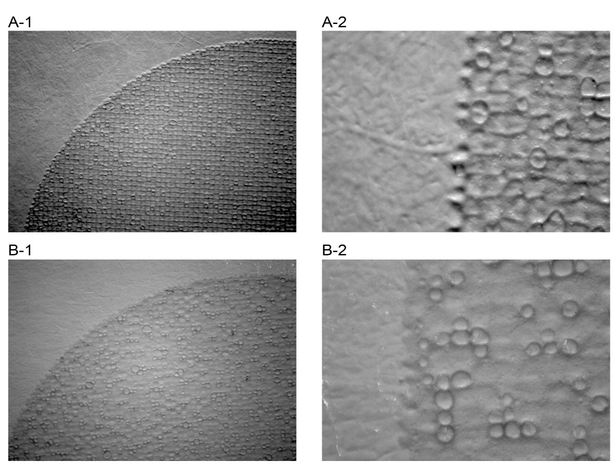

Figure 10: Microscopic images of edges of prints of A) BM EC 0 (optical microscope, A-1: 8x and A-2: 35x magnification) and B) BM EC 15 (optical microscope, B-1: 8x and B-2: 35x magnification)

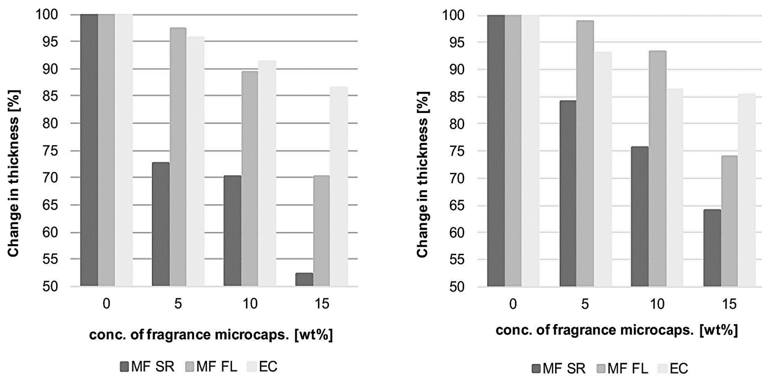

Figure 11: Thickness of prints made with MF SR, MF FL and EC printing inks with 0, 5, 10 and 15 wt% of aqueous solution of fragrant microcapsules on substrates A) SP and B) BM

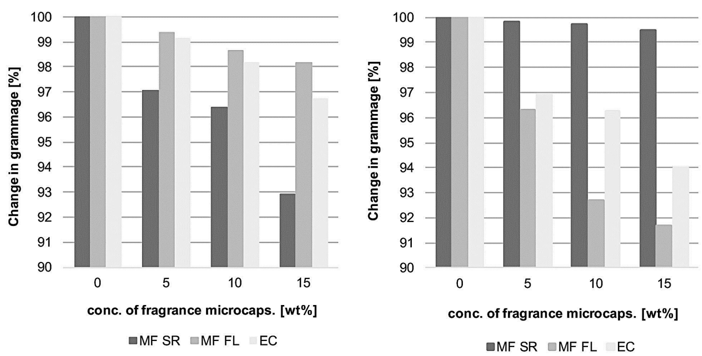

Figure 12: Grammage of printed samples made with MF SR, MF FL and EC printing inks with 0, 5, 10 and 15 wt% of aqueous solution of fragrant microcapsules on substrates A) SP and B) BM

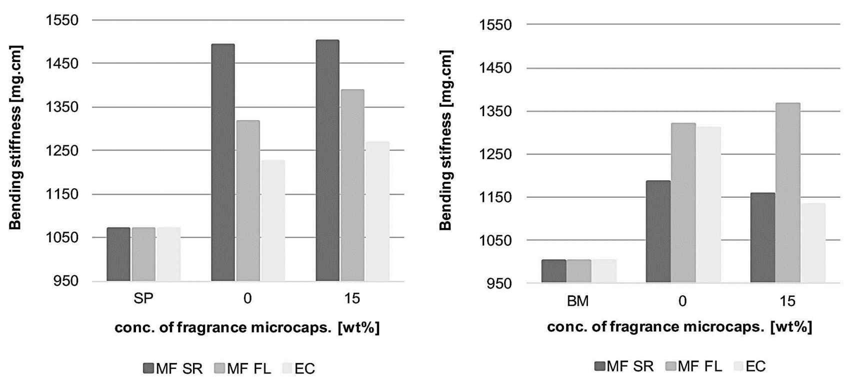

Figure 13: Bending stiffness of printed samples made with MF SR, MF FL and EC printing inks on substrates A) SP and B) BM

The main difference in height among printing inks with different concentrations of aqueous suspension of fragrant microcapsules was observed in MF SR (by almost 50% on SP and 40% on BM substrate), while minor difference in thickness was determined for prints with EC (change in thickness was by about 15% on both substrates).

Adding fragrant microcapsules into 3D printing inks also influenced the grammage of the samples, as presented in Figure 12. The grammage of printed SP and BM substrates decreases with the increasing concentration of fragrant microcapsule suspension added into the printing inks (Fig. 11). When the aqueous suspension of microcapsules was added, the share of basic printing ink decreased for the same volume of ink. In the processes of drying and expanding of microspheres, the water evaporated from the printed layer and consequently the grammage of the printed samples was reduced.

The quantity of the aqueous solution of fragrant microcapsules also influenced the overall (total) bending stiffness of the printed samples. The bending stiffness of substrates SP and BM increased regardless of the printing ink used, MF SR, MF FL or EC (Fig. 13).

The prints with added fragrant microcapsules were tested by a small group of blind and visually impaired people. Alongside the interesting tactile surfaces, they were impressed by the fragrance of the prints, which helped easier recognition of printed objects (*e.g*. printed smelly banana, heady coffee *etc*.). However, the tested group was small and thus not representative, therefore more testing of prints with incorporated fragrant microcapsules of adequate height for smell recognition will be performed in continuation of this research.

CONCLUSION

In this study, the influence of expandable microcapsules in printing inks, together with the addition of an aqueous suspension of fragrant microcapsules, on the properties of raised prints was investigated. The following conclusions can be drawn:

- printing inks with expandable microcapsules give higher thickness of prints compared to ordinary screen printing ink;
- the combination of expanding printing inks and the screen printing technique enables the achievement of adequate recognizable height of prints with only one passage of squeegee; though these thicknesses do not meet the values recommended in standards, appropriate thickness could be achieved with two or more printing layers and with a slightly modified process of printing;
- the addition of an aqueous solution of fragrant microcapsules into ready-to-use screen printing inks caused no problems; SEM analyses confirmed that the distribution of added fragrant microcapsules was even and that smaller fragrant microcapsules were loaded on the surface of much bigger expandable ones;
- the addition of an aqueous suspension of fragrant microcapsules in concentrations up to 15 wt% enables adequate printing, despite the decrease in ink viscosity and pH value; however jagged and blurred edges appeared on the printed surface; this problem could be solved easily by selecting a different density of the screen printing mesh;
- the viscosity of printing inks decreases with an increased concentration of the aqueous solution of fragrant microcapsules, and thus a decrease in the thickness of prints is noticed;
- fragrant microcapsules could be detected by smell on all prints, even on prints with lower added concentration; the fragrance, which was released after rubbing the surface of the prints, was present even after a certain time (a few months), which led us to the conclusion that the use of fragrant microcapsules on prints made with expandable inks is the right choice;
- though this research has shown that screen printing, with the use of proper printing inks, enables successful printing of raised elements, we believe that further research on some parameters still has to be done.

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