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ANALYSING THE REPRODUCTION QUALITY OF BRAILLE DOTS ON SELF-ADHESIVE LABELS PRODUCED WITH UV INKJET PRINTING

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Abstract: *Although modern digital technologies have successfully replaced many traditional methods of communication, including the use of braille for the blind and visually impaired, braille remains an important element of literacy for this vulnerable group. To accurately recognise the braille dots that make up the standardised characters, it is important that they have the correct dimensions, both in size and height. In this study, the reproduction quality of braille dots on self-adhesive labels was analysed. The elements were printed using the UV inkjet printing technique with a different number of passes (layers) to define and analyse the changes that occur with an increasing number of UV varnish layers. The samples were printed with 2, 4, 6, 8, 10 and 12 layers of UV varnish. The image analysis with the scanning electron microscope (SEM) focussed on the change in the diameter of the dots. The braille dots show deviations from the digitally defined diameter in the graphic prepress (1.60 mm), especially in the horizontal direction, which is due to the spreading of the varnish and the movement of the print head. The first layers of UV varnish behave differently depending on the substrate, while the application of further layers reduces deformation and improves dot formation. Lifting the print head led to a stronger spreading and deformation of the dots in both samples.*

Key words: Braille printing, UV inkjet, UV varnish, image analyses, visual impairment

1. INTRODUCTION

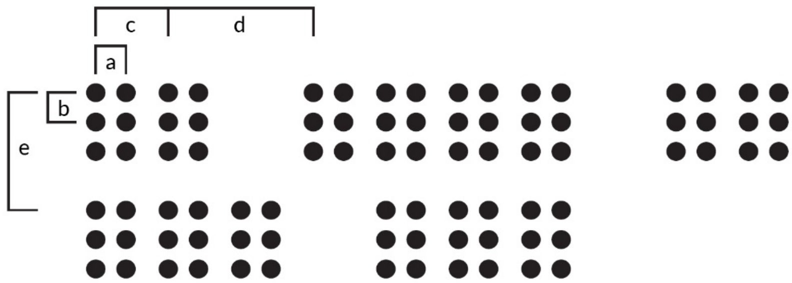
Visual impairment is a major global health problem. It is estimated that at least 2.2 billion people worldwide suffer from some form of visual impairment, including blindness (Pascolini & Mariotti, 2011; Hashemi et al., 2017; WHO, 2019). According to global statistics from 2020, 1.1 billion people live with a visual impairment. This includes 295 million people with moderate to severe impairment, 258 million with mild impairment and 43 million who are blind. In addition, 510 million people have near-vision impairment. Projections suggest that the number of people with severe or moderate visual impairment, including blindness, could rise to 1.7 billion by 2050 compared to 703 million in 2017 (Ackland, Resnikoff & Bourne, 2017; Bourne et al., 2017; IAPB, 2024). These statistics emphasise the urgent need for continued efforts to prevent, treat and integrate visually impaired people into society.
The integration of blind and visually impaired people into society represents a major social, humanitarian and economic challenge. One of the key factors in this process is the use of braille, which facilitates communication and navigation in everyday situations, e.g. when shopping, navigating in the environment, and accessing literature (Havenko et al., 2013). Since 2005, braille has been mandatory on pharmaceutical packaging in accordance with European Directive 2004/27/EC to facilitate access to information for blind and visually impaired people. According to this directive, braille must be uncontacted, with each braille cell representing a single letter, number, or punctuation mark (European Commission, 2005). Braille is only required on the outer, secondary packaging, which is normally made of cardboard. The product name does not have to be printed in braille on the primary packaging, such as blister packs, ampoules or bottles. However, in cases where only the primary packaging is used, such as large-volume bottles (500 ml, 1000 ml, etc.), a braille adhesive label can be applied during production (European Commission, 2005). It is expected that braille labelling will also be mandatory in the food and chemical industries in the future (Havenko et al., 2013). This emphasises the need to explore how braille can be applied to adhesive labels, which are often used for different types of packaging. In view of the specific tactile requirements and durability of the labels, this requires a careful selection of materials and printing technologies (Havenko et al., 2013).

Braille is not a language, but a universal code that can be adapted to many languages and enables people not only to read and write, but also to master spelling, punctuation, and text structure (American Foundation for the Blind, 2019; Royal Blind, 2019). The raised dots are felt by running a finger over them. They are an important tool for literacy and access to information, significantly improving the independence and social integration of people with visual impairments (European Commission, 2005; Royal Blind, 2019; VisionAware, 2019). This tactile writing system has become an important resource for the blind and visually impaired community worldwide.

Many countries, especially developed ones that produce braille have established their own standards that define the spacing between characters and the minimum height of the dots within each braille cell (Tiresias, 2008). As braille differs from country to country, standardisation has been introduced, including cell size (European Commission, 2005). For accurate recognition and high-quality reproduction of braille characters, the braille system must comply with certain standards and regulations (Rotar, 2021). The standards define the horizontal and vertical spacing between dots within a cell as well as the horizontal spacing between individual cells (i.e., between letters, numbers, or words). They also define the spacing between lines of braille text as well as the diameter and height of the braille dot.

For pharmaceutical purposes, braille must be printed in the Marburg Medium font and the name of the medicine must appear in lower case. This standard was developed specifically for pharmaceutical packaging and labelling and is used throughout the European Union, known as Marburg Medium Braille (Tiresias, 2008; PharmaBraille, 2019). It was recommended by the European Commission (European Commission, 2005; ECMA, 2006) and complies with both European and North American pharmaceutical industry standards.

The Marburg Medium braille standard defines the dot diameter as 1.3 to 1.6 mm and specifies the spacing between braille cells (PharmaBraille, 2019; ECMA, 2006) (Figure 1).



a. Horizontal spacing between dots: 2.5 mm (centre to centre)
b. Vertical spacing between dots: 2.5 mm (centre to centre)
c. Spacing between characters: 6.0 mm (cell to cell)
d. Spacing between words: 12.0 mm (between cells with a single space in between)
e. Spacing between lines: 10.0 mm
Tolerances: ±0.1 mm

Figure 1: Dimensions of braille cell spacing (ECMA, 2008)

Digital printing is becoming increasingly popular, and it is possible to create reliefs, including braille dots, on various substrates such as self-adhesive labels. Digital inkjet printing technology makes it possible to print on a variety range of materials with highly viscous transparent UV varnish. Some studies have shown the possibility of using UV inkjet printing technology to create braille dots on different types of materials (Golob, Rotar & Šulc, 2011; Golob et al., 2013; Klisarić, Novaković & Milić, 2013; Golob et al., 2014; Urbas et al., 2016; Rotar et al., 2020; Miloš, Vujičić & Majnarić, 2021). One study investigated certain technical aspects of reproducing braille dots on adhesive labels using this printing technique (Havenko et al., 2013). Miloš, Vujčić and Majnarić (2021) investigated the potential of reproducing braille using UV inkjet printing on self-adhesive labels that were previously printed using flexographic printing. The study found that 12 layers of UV varnish produce high-quality, readable braille that represents an optimal balance between quality and cost. The study was conducted with blind and visually impaired people, who gave the 12-layer samples high ratings for legibility and quality. Increasing the number of layers further improves readability, but also increases material consumption and time. The dots had a domed shape and their height reached an optimal level at 12 layers, approaching standards such as the ECMA Euro Braille

standard (0.50 mm). The study concludes that UV inkjet printing is suitable for reproducing braille and suggests further research into the effects of different substrates and the durability of the prints.
In their 2021 review paper, Vujčić et al. provided an overview of the state in the field of UV inkjet printed braille. They concluded that printing braille using digital UV inkjet technology has a promising future. However, they emphasised the need for a series of detailed studies. In their opinion, these studies should focus on different types of substrates, different types of varnishes, resistance to mechanical impact, print durability, working conditions and similar factors.
The reproduction of braille dots using UV inkjet printing on self-adhesive labels is still little researched. The aim was to determine whether it is possible to reproduce braille dots in a suitable shape and diameter and to assess how the appearance and diameter of the dots change with an increasing number of layers of varnish.

2. MATERIALS AND METHODS

In this study, the quality of braille reproduction was analysed in terms of the diameter dimensions of braille dots printed with UV varnish on a Roland VersaUV LEC-540 device using two types of self-adhesive papers/films. These papers are used in various applications, mainly for product labelling.
Two types of self-adhesive papers/films were used: MP CHROM 90V EP KR80 (Muflon, Slovenia) and JAC SERILUX 70100. MP CHROM 90V EP KR80 is suitable for all types of labels that require good print quality. It is a white, uncoated, glossy paper with good mechanical properties. This material achieves good print quality with all conventional printing techniques in label production. It is also suitable for thermal transfer printing (Muflon, n.d.). JAC SERILUX 70100 is a transparent, glossy PVC film used for the production of high-quality labels for indoor and outdoor use. This film is characterised by high tear resistance and good resistance to ageing, water resistance and light fastness, depending on the specific application. JAC SERILUX films are suitable for screen and UV offset printing (JAC, 2021). The properties of the self-adhesive papers/films used are listed in Table 1. The data was taken from the manufacturers' technical data sheets and refers to the top layer (face material) of the respective papers/films.

Table 1: Characteristics of the self-adhesive papers/films used (Muflon, n.d.; JAC, 2021)

	Paper type	Weight (g/m^2) ISO 536	Thickness (µm) ISO 534
Sample 1	MP CHROM 90V EP KR80	90	74
Sample 2	JAC SERILUX 70100	114	90

Braille cells containing all six dots were printed. The braille cell was produced with a dot diameter of 1.6 mm in accordance with the Marburg Medium braille standard. The braille dots were printed with a liquid UV varnish that was applied directly to the substrate and cured with UV light. The varnish droplets are very small, only 6 pl, and cure under LED light. This process enables printing on non-absorbent substrates as curing is immediate and prevents the ink from smearing. The diameter of the droplets formed is less than 20 µm. An ECO-UV varnish with the following composition was used (Roland, 2019): 1,6-hexamethylene diacrylate 20-30%, 2-methoxyethyl acrylate 20-24%, benzyl acrylate 10-25%, N-vinyl caprolactam 10-20%, and diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 5-10%. The samples were printed with different numbers of varnish layers to assess the changes in the formation of braille dots and the changes in diameter with increasing numbers of varnish layers. Full braille cells were printed with 2, 4, 6, 8, 10 and 12 layers. A maximum of 12 layers of varnish were applied, as previous studies have shown that this number results in high-quality, legible braille (Miloš, Vujčić & Majnarić, 2021). A glossy mode was used for printing (drying with a single UV lamp), with a print resolution of 740 × 1440 dpi. The print direction was set to bidirectional and the dither method was used for screening. Printing was done in high-quality with a larger number of varnish layers, higher resolution and lower printing speed. After applying 7 layers of varnish, the print head was lifted to prevent it from catching on the previously formed braille dots and causing damage.

The image analysis was performed on images taken with a scanning electron microscope (SEM) JSM-6060 LV (Jeol, Japan). The SEM images at different magnifications were used together with ImageJ software for digital image analysis. Before the samples could be analysed, they had to be prepared. The elements to be viewed under the SEM microscope were isolated. The samples were then attached to metal holders adapted to the samples and the SEM microscope using double-sided adhesive tape. The holders with the samples were placed in a fine coater where a thin layer of gold was applied to the sample surface under an electric current (30 mA). The coating process lasted 90 seconds and the applied gold layer thickness was 9.2 nm. The coating was performed using a JFC 1300 Auto Fine Coater (Jeol, Japan). The prepared samples were then placed in the SEM for observation and the desired images were captured. The samples were viewed from above to obtain information about the morphology of the braille dot surfaces, the shape and diameter/size of the printed braille dots (or cells), possible bleeding, etc. The observations were performed at different magnifications to obtain adequate and precise information (Milošević, 2019; Rotar, 2021).

The captured images were analysed using ImageJ software to measure the diameter of the braille dots. First, a calibration had to be carried out in order to obtain precise results. Then the measurements were taken. Due to the observed differences in diameter in the horizontal and vertical directions, the measurements were carried out in both directions. Ten measurements were taken in both the horizontal and vertical directions and the average of the measurements was calculated. It is important to emphasise that the diameter of the dots was measured from the edge where the height of the dot began to increase (Figure 2). This measurement method was chosen to reflect the circumference of the dot that would be tactilely recognised when reading braille by moving the finger over the dots.

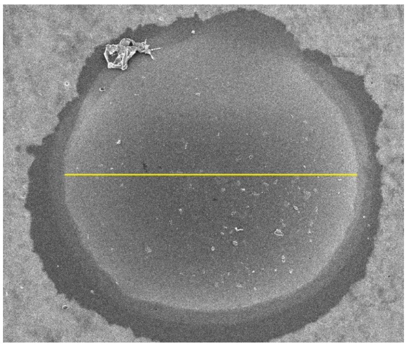


Figure 2: Display of diameter measurements on a braille dot formed by applying 12 layers of UV varnish

3. RESULTS AND DISCUSSION

3.1 Sample 1

Figure 3 shows a diagram depicting the measured values of the diameter of the braille dots in horizontal and vertical direction for a different number of varnish layers: 2, 4, 6, 8, 10 and 12 for sample 1. The diagram emphasises the maximum standard value according to the Marburg Medium standard, namely the diameter of the braille dots as digitally defined in the graphic prepress and set at 1.60 mm.

The examination of the measured diameter of the dot in sample 1 shows deviations from the digitally defined diameter in the graphic prepress (1.60 mm). The horizontal diameter is larger than the vertical diameter, which indicates that the vertical measurement is closer to the standard value. This indicates a larger deformation in the horizontal direction, which is probably due to the movement of the print head and affects the trajectory of the varnish droplets before the UV light initiates drying.

After applying two layers of UV varnish, the vertical dot diameter is slightly larger (1.617 mm) than the standard, while the horizontal diameter increases significantly to 1.767 mm and exceeds the standard by 0.167 mm. This results in an elliptical shape as shown in Figure 4a (*with a yellow circle marking the standard diameter in the SEM images*). The horizontal bleeding of the dot is probably caused by the movement of the print head in the horizontal direction, as previously mentioned. When the varnish droplets are applied in this direction and absorbed by the surface of the paper, this leads to an increase in diameter along this axis.

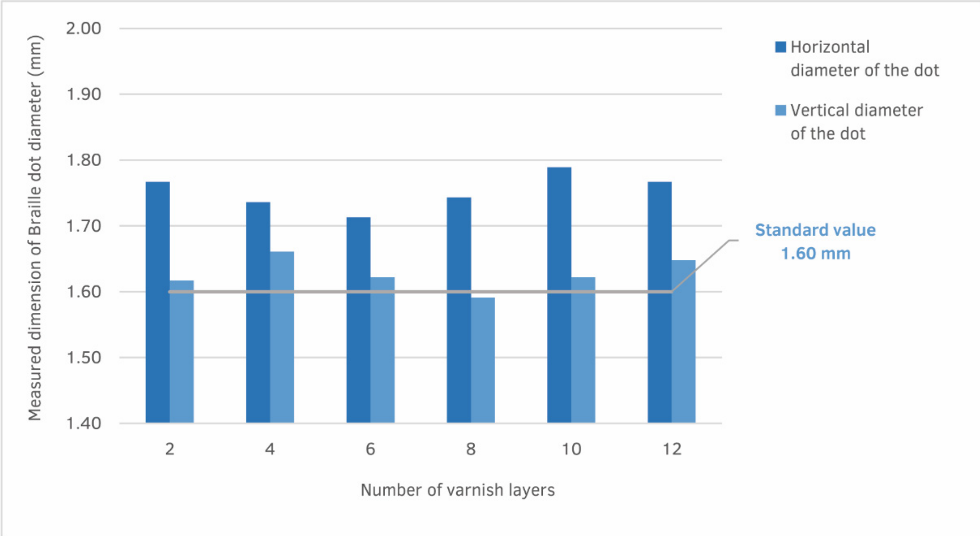


Figure 3: Measured dimensions of the diameter of the braille dots in horizontal and vertical direction printed with 2, 4, 6, 8, 10 and 12 layers of UV varnish on sample 1

Subsequent varnish layers touch the previously printed, polymerised layers and not the substrate directly. They are printed using the same graphic prepress. The first layer penetrates the substrate, fills surface irregularities and creates a more uniform surface, reducing dot deformation and improving precision (Urbas et al., 2016). Bleeding of the varnish is minimised and depends on whether and to what extent, the varnish flows over the edges of the previously polymerised layers. With reduced bleeding, the application of subsequent layers of varnish leads to an increase in the dot height and reduced bleeding in the dot base (Miloš, Vujčić & Majnarić, 2021). It is noticeable that the horizontal and vertical diameters become narrower, which leads to a rounder dot shape, especially at 4 (Figure 4b) and 6 layers (Figure 4c). In addition, the surface tension changes, which leads to less bleeding of the UV varnish and a more precise formation of the braille dot. This was also shown with a different type of material in the study by Urbas et al. (2016), where the material was first fully coated with UV varnish, and then the braille dots were applied.

Considering that after the application of 6 layers of varnish, the height of the dot has increased and that the SEM images also show that the dot has a spherical, dome-shaped form (Figure 4c), this significantly influences the behaviour when applying the subsequent layers of varnish. It is also important that the print head was lifted after the application of 7 layers of varnish so as not to damage the dot due to its greater height. Under the influence of gravity, varnish droplets flow down the dome shape of the previously formed layers. Depending on the direction and manner in which the varnish droplets flow before polymerisation, the deformation of the dot at its base, its bleeding and its change in shape varies, as can be seen in Figure 4d when 8 layers of varnish are applied. Increased bleeding and reduced print accuracy also occur when you raise the print head and increase the distance to the print substrate. In preliminary studies, a subjective analysis was carried out to evaluate the changes in the appearance of the dot surfaces during the successive layer-by-layer application of UV varnish. It was clearly established that in all samples analysed, more bleeding occurred after applying 8 layers of varnish, i.e. after applying the first layer after lifting the print head. It is a challenge to maintain printing precision at such small dimensions, especially when a larger number of layers of UV varnish are applied and the multiple movements of the material under the print head can lead to a shift in the area to be printed. This was observed in all samples analysed, but also in other samples that were not the subject of this study. For samples produced with 8 layers of varnish, it is difficult to accurately recognise the edge of the raised dot formed with 8 layers of varnish, especially in the horizontal direction. New layers of varnish bleed and polymerise unevenly over the previously formed raised dot, making its edges much harder to see and causing the formed varnish layers to blend together. It is important to emphasise that, due to the factors mentioned, it is not possible to measure the diameter of the given dots with high precision. Therefore, the results should be taken with caution.

In eight-layer samples, the bleeding of the varnish leads to a deformation of the dot base, which probably does not significantly affect legibility or tactile sensation, but can reduce the height increases and

sometimes merge dots. This deformation can lead to increased varnish consumption and aesthetic problems that are visible to the naked eye.
With the application of additional varnish (10 layers), the diameter of the raised dot increases, and its edges become more defined. This is because the varnish remains on the new base of the dot that has formed after the application of 8 layers. Here you can also see an increase in the height of the dot, and you can see the diameters created by applying different numbers of varnish layers, as shown in Figure 4e.
For the sample with 12 varnish layers, the dot diameter is also clearly defined. It approaches the standard value (1.60 mm), and the dot height continues to increase (Figure 4f).

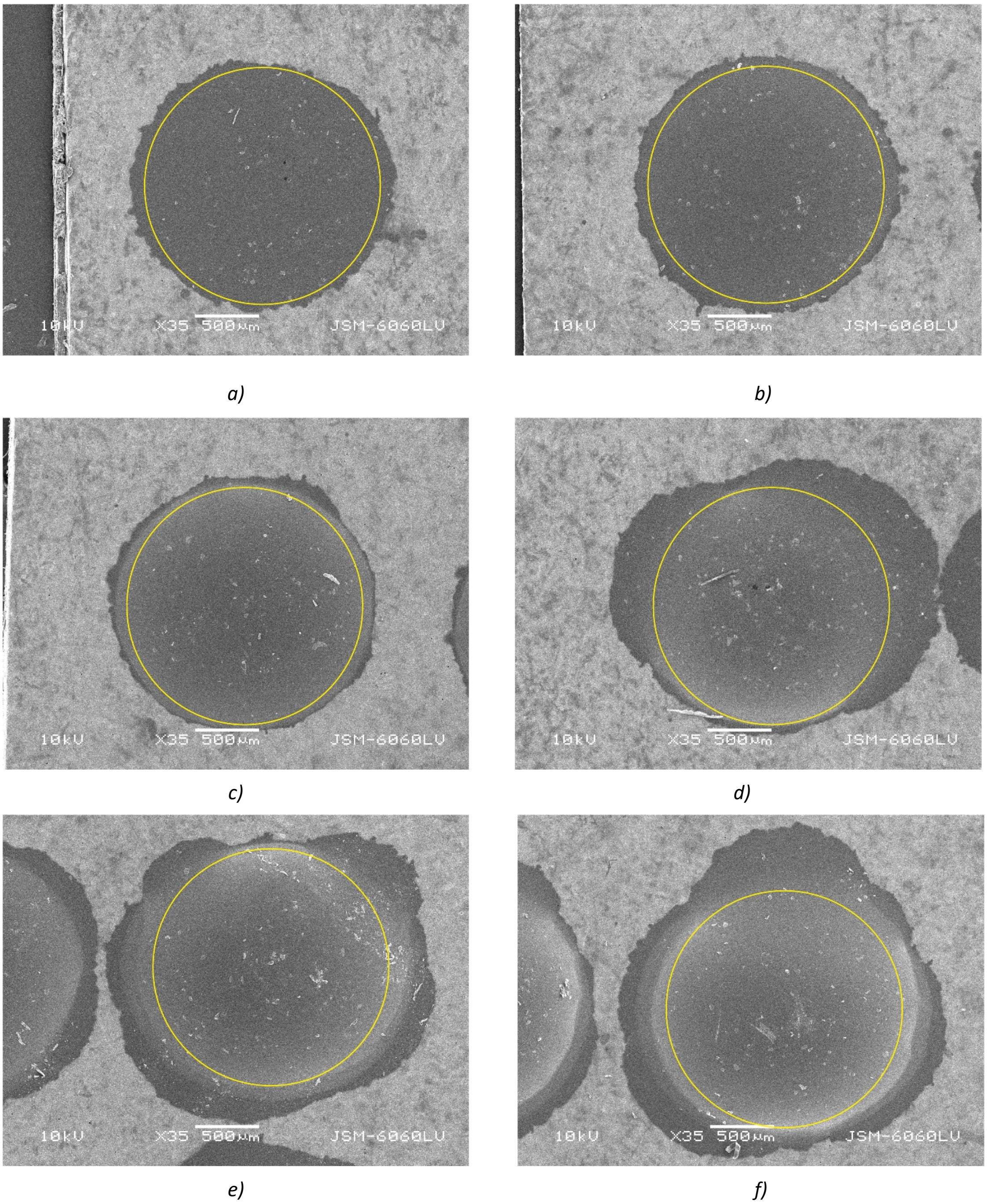


Figure 4: Braille dot surface printed with 2 (a), 4 (b), 6 (c), 8 (d), 10 (e) and with 12 layers of UV varnish (f) on sample 1 (SEM; 35× magnification)

Table 2 shows the average values of the diameters of the braille dots, measured horizontally and vertically on sample 1, with the values of the standard deviation and the deviation from the standard value of the dot diameter in per cent.

Table 2: Average values of the diameter of the braille dots, measured horizontally (Hor.) and vertically (Vert.), with standard deviation and the percentage of deviation from the standard value, for sample 1

	2 layers of UV varnish		4 layers of UV varnish		6 layers of UV varnish		8 layers of UV varnish		10 layers of UV varnish		12 layers of UV varnish	
Braille dot diameter	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.
Standard dot diameter	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
Average dot diameter (mm)	1.767	1.617	1.736	1.661	1.713	1.622	1.743	1.591	1.789	1.622	1.767	1.648
Stdev (mm)	0.022	0.012	0.007	0.010	0.006	0.006	0.017	0.007	0.012	0.006	0.005	0.014
Deviation from the standard value (%)	10.467	1.085	8.506	3.800	7.088	1.402	8.926	-0.544	11.809	1.402	10.437	3.001

3.2 Sample 2

Figure 5 shows a diagram depicting the measured values of the diameter of the braille dots in horizontal and vertical direction for a different number of applied varnish layers: 2, 4, 6, 8, 10 and 12 for sample 2. The diagram emphasises the maximum standard value according to the Marburg Medium standard, i.e. the digitally defined diameter of the braille dots in the graphic prepress of 1.60 mm.

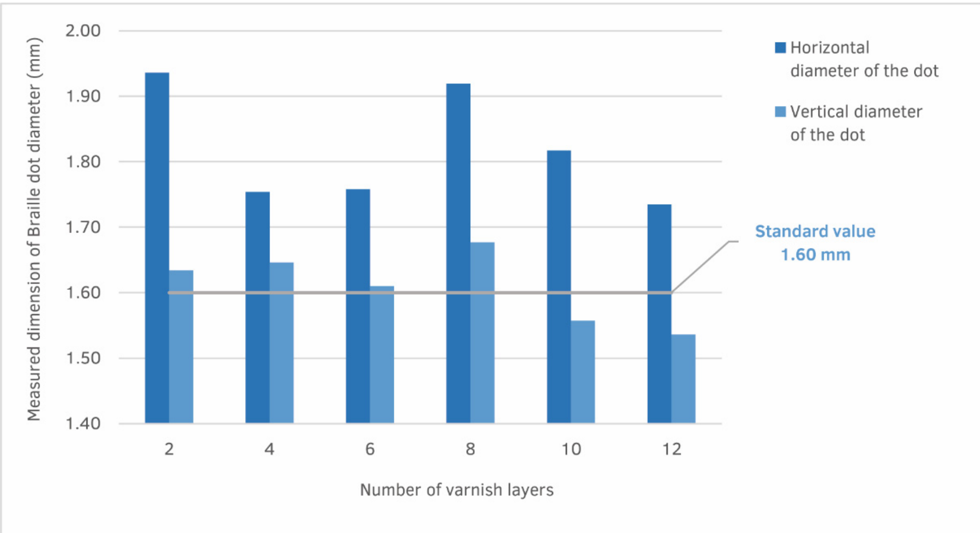


Figure 5: Measured dimensions of the diameter of the braille dots in horizontal and vertical direction printed with 2, 4, 6, 8, 10 and 12 layers of UV varnish on sample 2

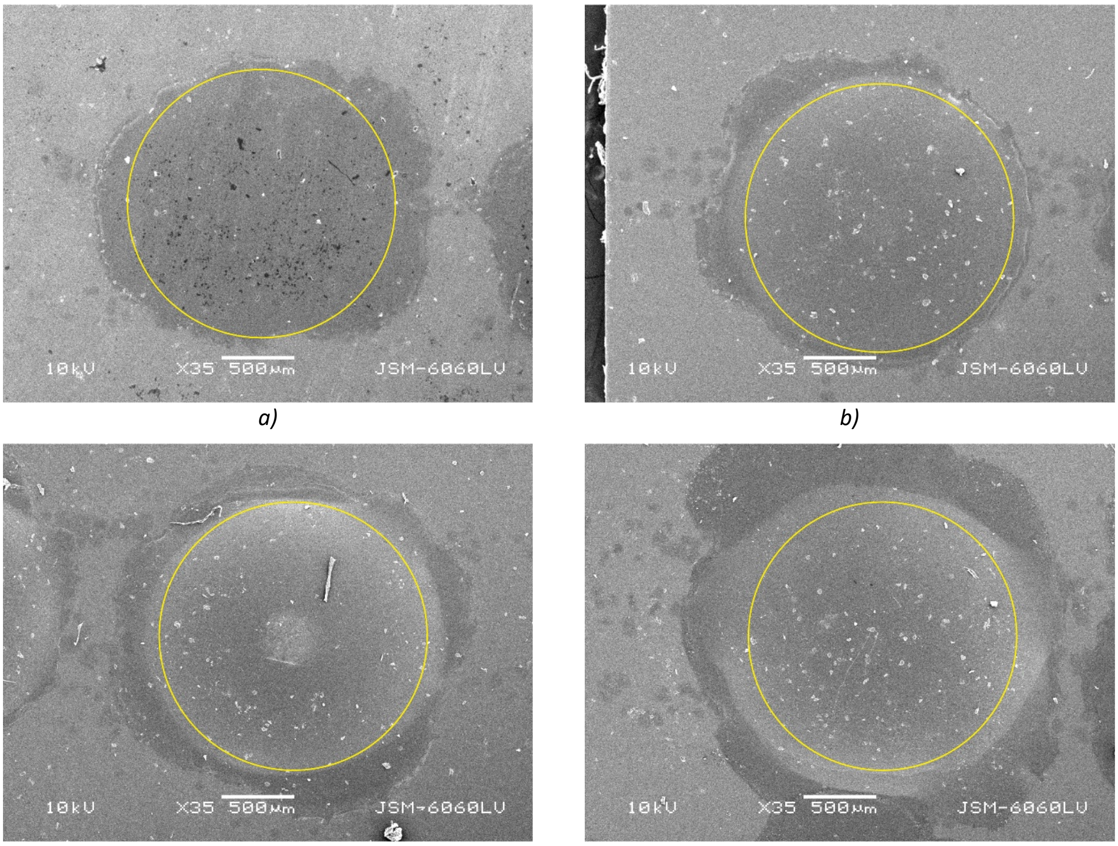
In sample 2, deviations from the defined dot diameter of 1.60 mm are observed. The horizontal measurements show a larger diameter than the vertical ones, with the horizontal deformation being larger than the standard value, while the vertical measurements are closer to this value. As already mentioned, this horizontal deformation is probably due to the movement of the print head.

The analysis of the dot, which was formed by applying two layers of UV varnish, shows that the vertical diameter is slightly larger than the standard. The horizontal diameter has increased significantly to 1.936 mm, which is 0.336 mm above the standard (1.60 mm). This difference indicates an elliptical shape, as can be seen on the SEM image (Figure 6a). The dot appears "blurred" as it bleeds strongly. This is probably due to the non-absorbent printing substrate, which prevents the droplets from adhering to each other and bleeding horizontally before polymerisation.

Subsequent varnish layers are applied to already polymerised layers, which leads to less bleeding and more precise dot formation. The change in surface tension leads to an increase in height and a decrease in bleeding at the base of the dot. The bleeding of the varnish is minimised and depends on whether and to what extent the varnish flows over the edges of the previously polymerised layers. With four layers of varnish, the horizontal diameter is 1.754 mm, which is only 0.154 mm above the standard, compared to the difference of 0.336 mm observed in a sample with two layers of UV varnish (Figure 6b). A similar trend can be observed with six layers (Figure 6c). Here, the horizontal diameter is 1.758 mm and the vertical diameter is almost ideal at 1.610 mm.

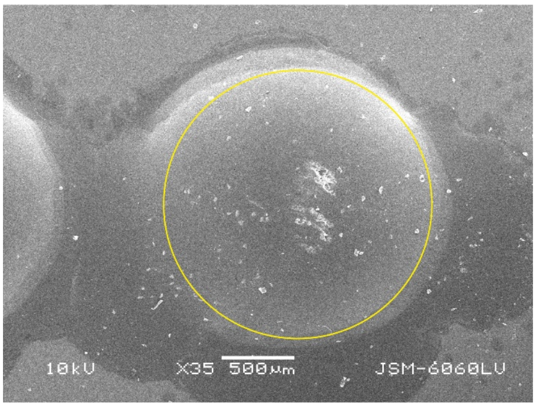
The SEM images (Figure 6c) show a greater height of the dot and a dome-like shape after six layers. After applying seven layers, the print head was lifted to prevent damage to the dot due to its increased height. Varnish droplets bleed unevenly due to gravity and affect the deformation of the dot (Figure 6d). The increased bleeding and reduced print accuracy are also due to the increased distance of the print head from the substrate. Although the deformation is noticeable in this sample, especially at the base of the dot, the edges are clearer, and we can conclude that there is no significant deformation in the shape of the dot. When examining the diameters, it can be seen that the horizontal diameter of 1.919 mm is well above the standard value and approaches the diameter measured after the application of two varnish layers. The vertical diameter has also increased slightly to 1.677 mm. As mentioned, the noticeable bleeding of the varnish due to gravity leads to larger diameters in both directions, with the diameter in the horizontal direction, being more pronounced, which is probably caused by the horizontal movement of the print head during the printing process.

After the application of ten layers of varnish, the horizontal diameter is 1.817 mm, while after the application of twelve layers it is 1.735 mm. The vertical diameter is 1.557 mm after ten layers and 1.536 mm after twelve layers, which is below the specified standard value. Here, too, a clear increase in dot height can be observed, as the varnish remains on the previously polymerised layers, which have become larger when eight layers are applied and form the basis for the subsequent layers (Figures 6e and 6f).

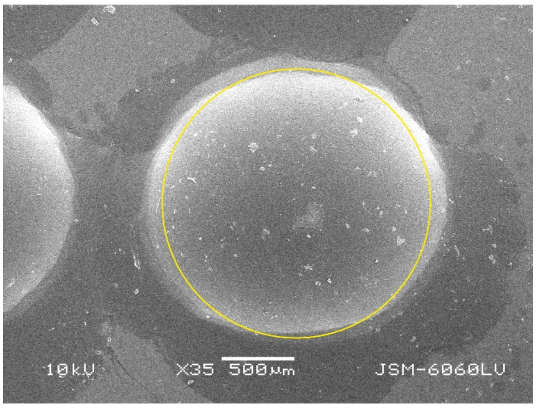


a) b) c) d)

Figure 6 (part 1): Braille dot surface printed with 2 (a), 4 (b), 6 (c), 8 (d), 10 (e) and with 12 layers of UV varnish (f) on sample 2 (SEM; 35× magnification)



e)



f)

Figure 6 (part 2): Braille dot surface printed with 2 (a), 4 (b), 6 (c), 8 (d), 10 (e) and with 12 layers of UV varnish (f) on sample 2 (SEM; 35× magnification)

Table 3 shows the average values of the diameters of the braille dots, measured horizontally and vertically on sample 2, with the values of the standard deviation and the deviation from the standard value for the dot diameter in per cent.

Table 3: Average values of the diameter of the braille dots, measured horizontally (Hor.) and vertically (Vert.), with standard deviation and the percentage of deviation from the standard value, for sample 2

	2 layers of UV varnish		4 layers of UV varnish		6 layers of UV varnish		8 layers of UV varnish		10 layers of UV varnish		12 layers of UV varnish	
Braille dot diameter	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.
Standard dot diameter	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
Average dot diameter	1.936	1.634	1.754	1.646	1.758	1.610	1.919	1.677	1.817	1.557	1.735	1.536
Stdev (mm)	0.012	0.018	0.017	0.007	0.007	0.005	0.018	0.007	0.012	0.006	0.006	0.024
Deviation from the	21.025	2.126	9.622	2.850	9.879	0.648	19.924	4.826	13.559	-2.716	8.461	-3.983

When comparing the SEM images of sample 1 and sample 2, it can be observed that the height of the dots in sample 2 is more pronounced. This can be attributed to the non-absorbent nature of the substrate, which allows the varnish layers to remain on the surface of the sample and prevents partial absorption, as in the previous sample. In further investigations, it would be beneficial to measure the height of the dots and determine the differences in height obtained with the same number of varnish layers on different samples to determine the optimum number of layers for the desired height.

The comparison of the samples also shows that the bleeding of the varnish in sample 1 is much less pronounced, especially in samples that were printed with a lower number of UV varnish layers. This difference can be explained by the absorbent/non-absorbent properties of the respective materials. The dots in sample 1 are more precisely shaped before the application of eight layers of varnish, while the bleeding and deformation of the braille dot shape in sample 2 are noticeable from the beginning when only two layers of UV varnish are applied. Therefore, the properties of the materials, including surface characteristics, fibre direction, roughness, absorptivity and similar factors are of great importance. These properties should be further investigated to substantiate and confirm our conclusions.

Regarding the analysis itself, there are certain limitations worth mentioning. The cross-section of the dots, the appearance of their profiles, and the height values with a specific number of layers of varnish were not available during the analysis of the dot diameter and its changes with an increased number of layers. It is significant to have these representations and analyses since many assumptions and changes that occur with an increasing number of varnish layers are based on changes in dot height and profile appearance.

Furthermore, the height of the dot is a key parameter for braille readability. Miloš, Vujčić, and Majnarić (2021) concluded in their research that applying 12 layers of UV varnish results in optimal height and braille legibility. However, it is essential to verify the heights achieved with a given material and the number of layers applied, so that the optimal number can be chosen when producing braille for specific purposes.

4. CONCLUSIONS

Based on the measurements and analysis of the diameter dimensions of braille dots printed with UV inkjet technology and UV varnish, it is clear that there is a discrepancy between the digitally specified dimensions and the actual measured values. The horizontal bleed of the dots is particularly pronounced, which can be attributed to the movement of the print head in this direction and the behaviour of the varnish during application and drying. The diameter of the dots measured in the horizontal direction is consistently larger than the diameter measured in the vertical direction, while the vertical dimensions are closer to the maximum standard value of 1.60 mm, according to the Marburg Medium standard.

The application of the first layers of the UV varnish leads to an interaction between the varnish and the substrate, whereby the substrate in sample 1 absorbs the varnish, while the surface of sample 2 is non absorbent, which leads to a stronger bleeding of the varnish until polymerisation occurs. The application of the first varnish layers changes the surface structure of the samples, including their roughness, surface tension and similar properties. This has also been shown in previous studies (Urbas et al., 2016; Rotar et al., 2020), but it would certainly be beneficial for future research to investigate the properties of the analysed samples to support the conclusions drawn. Furthermore, when more layers are applied, the varnish comes into contact with the previously polymerised UV varnish layers, resulting in smaller dot deformations and better vertical formation of the dots. In the study by Miloš, Vujčić and Majnarić (2021), similar results were observed, and similar conclusions were drawn. This trend was observed in samples with 4 and 6 layers of varnish, where the dots increasingly approached a round shape and standard values.

Although previous research (Urbas et al., 2016; Miloš, Vujčić & Majnarić, 2021) has shown that braille dots are formed more accurately when applied on a previously polymerised layer, it must be taken into account that some substrates may not be suitable for varnishing before applying the braille dot and that the varnishing itself affects the surface, colourimetry, and other properties of the samples (Majnarić, Bolanča Mirković & Golubović, 2012), which could have a negative impact on the perception of the given samples and their print quality. In our opinion, the surface of the printing material should be completely coated with varnish before the Braille dots are applied to prevent the varnish from bleeding in sample 1. In the case of sample 2 (PVC foil), however, the inherent properties of the material mean that full-surface coating is not necessary. With further application of varnish layers, especially after the application of 8 layers, there is an increased bleeding of the varnish, which is attributed to the lifting of the print head and the gravity flow of the varnish from the height of the already formed dome-shaped dots. It was emphasised that in a preliminary study, in which a subjective evaluation and analysis of samples printed layer by layer with UV varnish was carried out, increased bleeding of the varnish was visible to the naked eye after the print head was lifted. This was observed in all samples analysed, not just those that were the subject of this study, and affected the precision of the dot edges, which can be clearly seen in the SEM images. Although this deformation may affect the aesthetic appearance of the dots, it is not expected to significantly affect the legibility of the braille, as the dots remain dome-shaped and are presumably tactilely recognisable.

This research demonstrated the importance of analysing the production of braille on different substrates. The self-adhesive materials used for the product labels have been carefully selected. They are two types: a paper and a PVC film, to determine whether the materials themselves have a significant impact on the formation of braille dots using UV inkjet printing technology. This impacts the accuracy of the dot edges, as shown in the SEM images. It was found that the dots on sample 1 (paper) were more clearly and precisely formed than on sample 2 (PVC film). This research enabled certain conclusions and assumptions to be made why there was a difference in the formation of braille dots, i.e., the behaviour of UV varnish on the given materials, but it would be necessary to investigate the absorptivity of the materials, their roughness, contact angle, and similar parameters to confirm the given conclusions.

In addition to the given analyses, it is recommended that future research focus on the measurement of the height of the dots, as this parameter is of great importance for the legibility of braille. Furthermore, analysing the cross-sections of the dots, performing profilometric measurements and using a 3D microscope could provide additional information about the topography of the dots and contribute to a better understanding of the deformations that occur when multiple layers of varnish are applied. Future research could also consider the possibility of reducing the dot diameter with each subsequent layer to minimise the bleeding of the subsequent layers over the edges of the previously polymerised UV varnish layers. A series of samples could also be created where the horizontal bleed is compensated to achieve more accurate and consistent braille dots. The ability to print without lifting the print head should also be considered.

This study confirms certain conclusions from previous research (Urbas et al., 2016; Rotar et al., 2020; Miloš, Vujčić & Majnarić, 2021) conducted on other substrates, but also contributes from the aspect of analysing the behaviour of UV varnish on the given self-adhesive label materials and shows a clear difference in the formation of braille dots depending on the printing substrate. This research also opens up new ideas and provides guidance for future studies, both on these and other types of materials that could be used for the production of braille using UV inkjet printing technology. Future research should confirm the presented and provide further insights to establish clearer guidelines for the production of braille on these materials.

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