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Improvement of Package Properties with Formed Functional Surface Features

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Abstract. Paperboard package properties can be improved by embossing functional features on package surfaces. Embossing is used in package manufacturing as an additional tool to improve the appearance of the packages. It can also be used to increase product safety by improving functionality and identifiability of packages. Creation of features directly on the base material without implementing additional components improves the sustainability level of package applications. To evaluate functionality of features, such as protective surface patterns, in the applicable practice, the following steps need to be gone through; design phase, tool manufacturing phase, pattern production phase and analysis phase. Bespoken toolsets were designed and manufactured to form a protective frame around commercial radio-frequency identification tag (RFID). The essential process parameters in the embossing experiments were the pressing force and the plate temperature which were optimized in preliminary tests. Methods for evaluating the performance of created embossed patterns were wear testing of package surfaces, topography measurement with a 3D profilometer and SEM-imaging for more detailed analysis. The results show that embossing is a suitable manufacturing method for creating targeted functional features on paperboard surfaces. With the formed surface features, the functionality of the packages was improved by protecting the identification labels.

1. Introduction

Embossing is a forming method used in package manufacturing as an additional tool to improve the appearance of the packages. It can also be used to increase product safety by improving functionality and identifiability of packages [1]. Other common applications for embossing are braille [12]. Usual materials used for embossing include coated and uncoated paperboards. Creation of features directly on the base material without implementing additional components improves the sustainability level of package applications.

Radio-frequency identification tags (RFID) or other sensors are used in packages in applications such as food safety monitoring, package tracking, inventory control and easy check-out [2] or the detection of toxic gases [3]. The RFID tags can be added into packages by either utilizing separate labels or printing the tags directly onto the material [4].

Packages and fibre-based materials can be subjected the various stresses during their production and usage, including moisture and temperature related effects [5,6, 19] and physical stresses such as compression [6,7] or abrasion [8]. The effects can damage the packaging, and in the context of smart packaging these stresses can damage the sensors and therefore effect the functionality and readability of the printed electronics.

As the functionality of the printed electronics in packaging is crucial to ensure the packaging functions as planned, ways to improve the durability of the sensors need to be investigated. The objectives of the paper were to investigate if protective surface patterns could be manufactured by embossing, and to investigate the effect of the protective surface patterns on the abrasion resistance of printed samples. A mechanical embossing device prototype was designed and manufactured [9] for the converting experiments. Embossed samples were manufactured from two commercial paperboards, and the samples were analysed accordingly.

2. Materials and Methods

2.1 Materials. Two commercial paperboards were used in the experiments, Kotkamills Aegle White 290 (KotkaMills, Kotka, Finland) and Stora Enso Foodbox 230 (Stora Enso, Imatra, Finland). The numbers in the materials denote the grammage as g/m^2. Aegle White 290 is a coated board with a three-layer fibre construction consisting of two bleached chemical pulp outer layers and a bleached chemithermomechanical pulp middle layer. Foodbox 230 is an uncoated folding boxboard with a three-layer fibre construction, with two outer layers made of bleached sulphate pulp (SBS) and a middle layer made of chemithermo-mechanical pulp (CTMP). The total thickness of the material is 370 µm. The materials were stored at 50 % relative humidity (RH) to ensure adequate humidity and to obtain the desired moisture content for the fibre-material. The moisture content was measured with a moisture analyser (Adams Equipment PMB 53, New York, USA). The measured moisture contents of the materials were 7.3 % for Aegle white and 8.3 % for Foodbox.

2.2 Methods. The samples were embossed utilizing a mechanical embossing device, integrated into a Shimadzu AGS-X 10kN electromechanical tensile & compression tester (Shimadzu, Tokyo, Japan), which enabled accurate position, speed, and force adjustment. The precise alignment of the embossing plates was ensured using vertical guide pillars and bushes. Bar-shaped heating elements were embedded in the base of the upper plate, which enabled the temperature control of the embossing process. The test device is shown in Fig. 1.

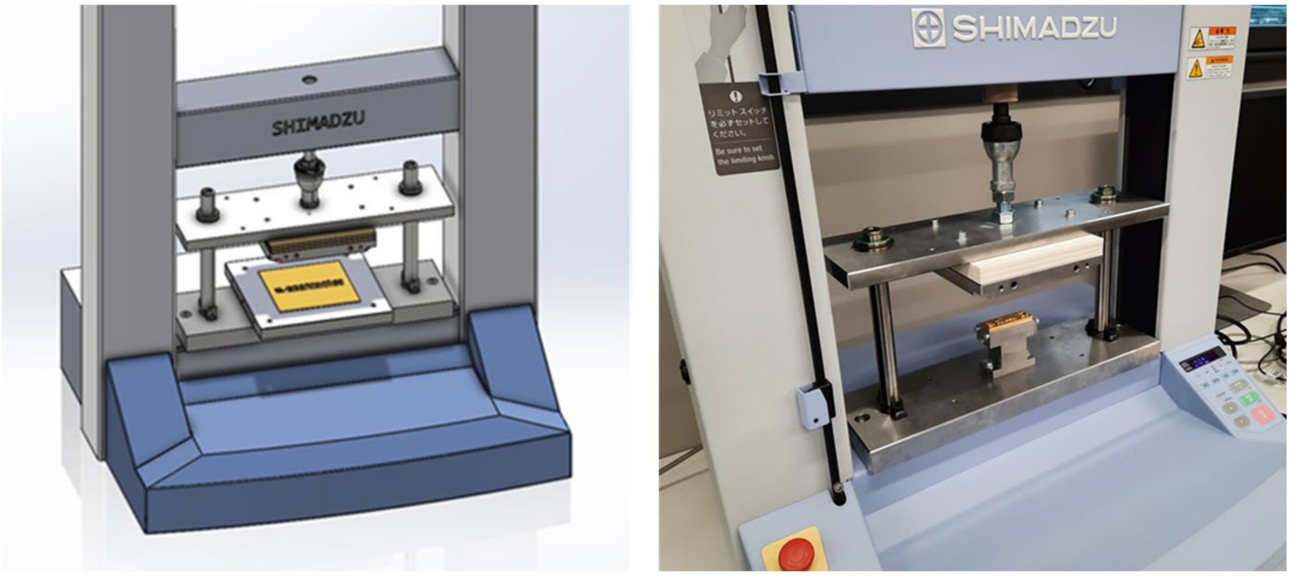

Fig. 1. The mechanical embossing device design (left) and finalized device (right).

The embossing toolsets were designed to form a protective frame around a 23 mm printed area. The toolsets were machined from brass. The shape and size of the feature were chosen to be representative of those commonly used in packaging tags. In addition, a logo representing package design possibilities was implemented in the design. The toolset is shown in Fig. 2.

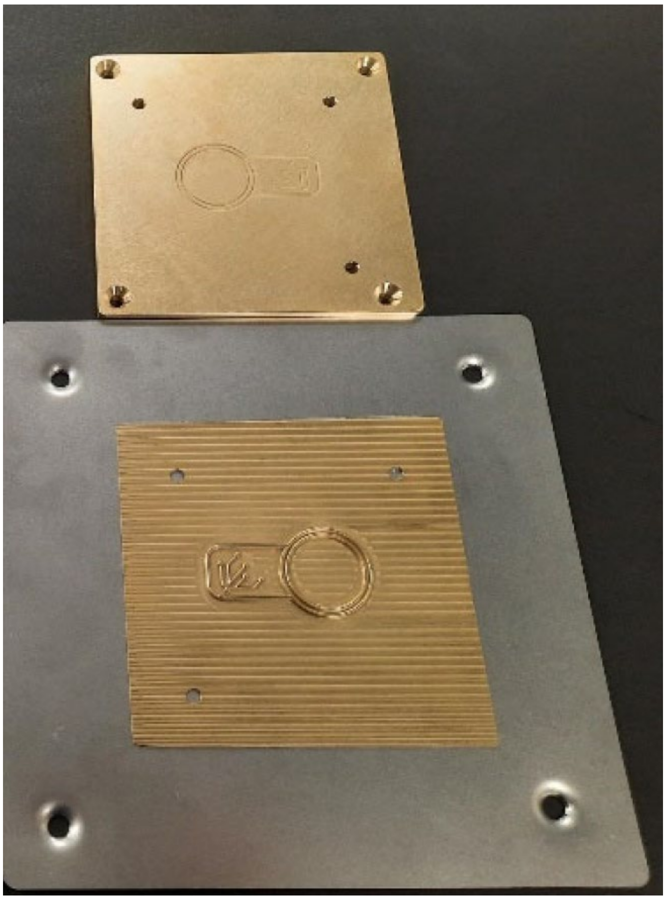

Fig. 2. The toolset used for the embossing experiments.

A Canon Pixma Pro-10 Inkjet printer (Canon, Tokyo, Japan) with print resolution of 4800x2400 dpi was used to print a shape presenting an NFC-antenna to the paperboard sheets. Half of the printed samples were embossed with a shape designed to protect a round, 23 mm diameter NFC-antenna. Embossing force of 6 kN and female embossing tool temperature of 80 ˚C was used. The samples were stored according to ASTM D4332 [10] before testing. A printed and embossed sample is presented in Fig. 3.

Fig. 3. The printed antenna pattern surrounded by the embossed protective frame.

Wear testing of the printed and embossed samples was conducted to determine protection provided by embossing. A modified testing procedure according to the ASTM D5264−98 [11] standard was performed. A wear testing device developed for testing durability of folded carton boxes was used for testing. The device uses an electric motor and an arm mechanism to create an oscillating motion of a surface. The sample was placed on a weighed 100 x 100 mm sample holder which is placed on top of the oscillating surface. The device is pictured in Fig. 4.

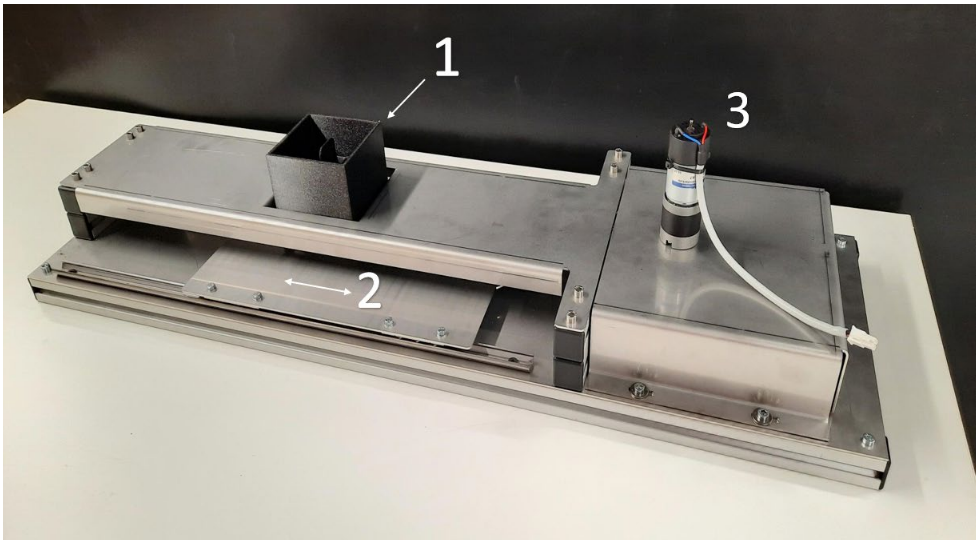

Fig. 4. The wear testing device: 1. sample holder, 2. oscillating surface, 3. driving motor.

Paperboard was used as the wearing surface on top of the moving plate and moving speed of 200 mm/s was used. 240 g of weight was placed on the sample holder resulting in total weight of 500 g. Weight is used to emulate content inside a package. Wear time of 1, 2, 3 and 5 minutes was used, resulting in 12, 24, 36 and 60 meters of movement. Testing was conducted in 50 % RH and 23 ˚C.

Wear of the printed samples was evaluated visually after testing. To further evaluate the amount of wear, samples were scanned using Canon Imagerunner advance DX C5840i (Canon, Tokyo, Japan). The scanned image of the print was converted to an image containing only black and white pixels and the total area of black pixels was measured.

The embossed samples were analysed using a Keyence VR-3200 (Keyence, Ithaca, USA) wide area 3D-measurement system. The samples were analysed before and after wear testing with line profile measurement. The surface topography of the embossed protective frame and the measurement line positions are shown in Fig. 5.

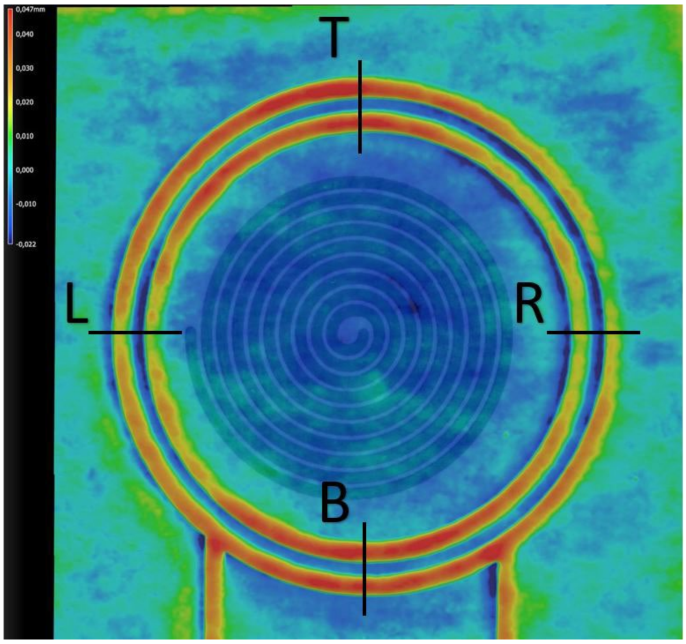

Fig. 5. The surface topography of the embossed protective frame and the line measurement positions in the surface of the embossed sample around the printed sample.

It must be noted, that even though the surface topography analysis using white light 3D-profilometry is an effective way to analyse shapes in packaging material surfaces [15,17] due to the used method deep and thin grooves can distort the measurement result, which means that between the two higher peaks the measurement accuracy can be reduced due to the light not reaching the bottom of the shapes of these kinds of geometries, when it is reflected from certain directions [14, 15]. This is visible when comparing positions L and R with positions T and B.

3. Results and Discussion

The surface topography and embossing height of an embossed protective frame can be seen in Fig. 6.

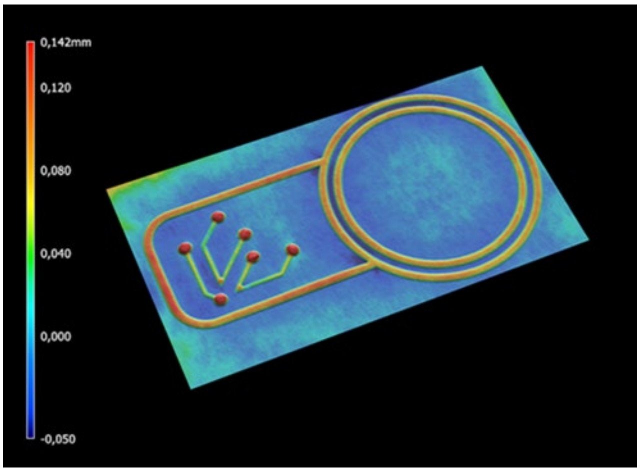

Fig. 6. The surface topography with corresponding heights of an embossed protective frame.

The results of the wear testing with the Aegle White material can be seen in Fig. 7.

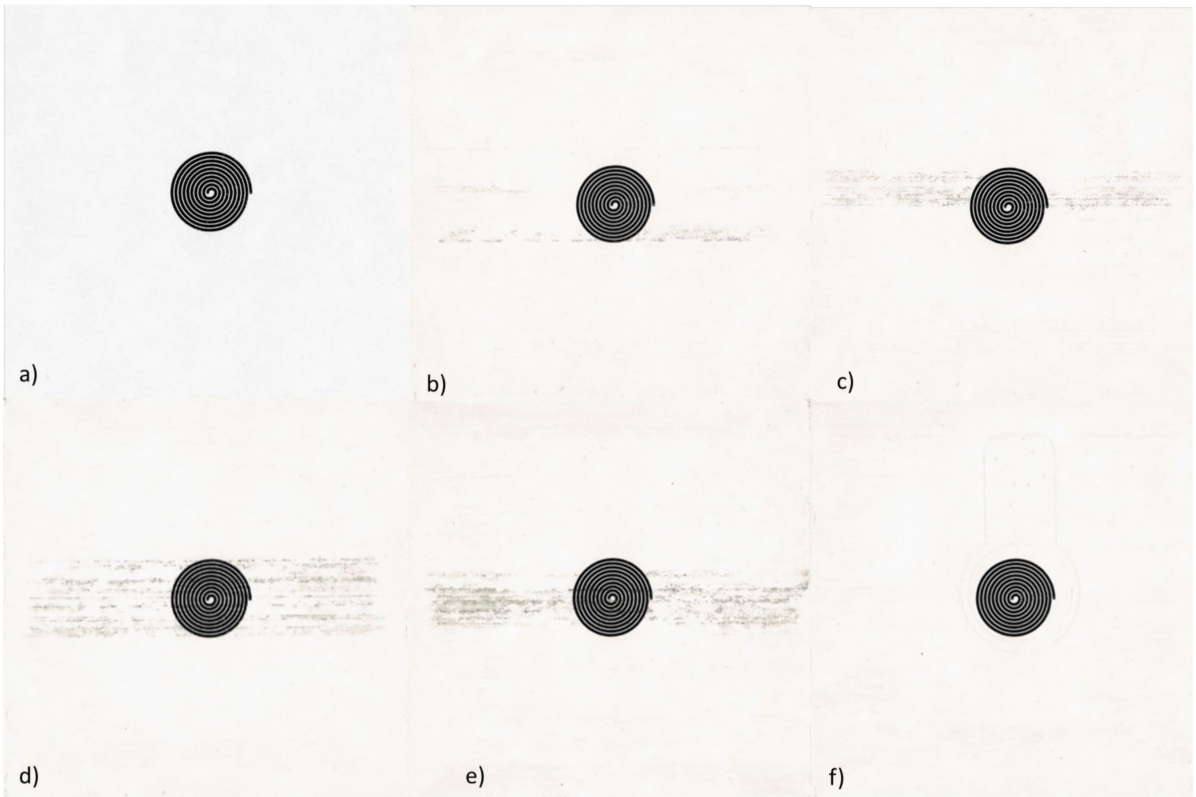

Fig. 7. Printed samples before (a) and after wear testing of 1 min (b), 2 min (c), 3 min (d), 5 min (e) and a sample with the protective embossed frame after 5 min (f).

The unprotected Aegle White samples showed clear signs of wear at 1 minute, gradually increasing to 5 minutes of wear. The embossed Aegle White samples showed no visual sign of wear even after 5 minutes of wear testing. Unprotected Foodbox samples (Fig. 8) had no visible wear even at 5 minutes wear time.

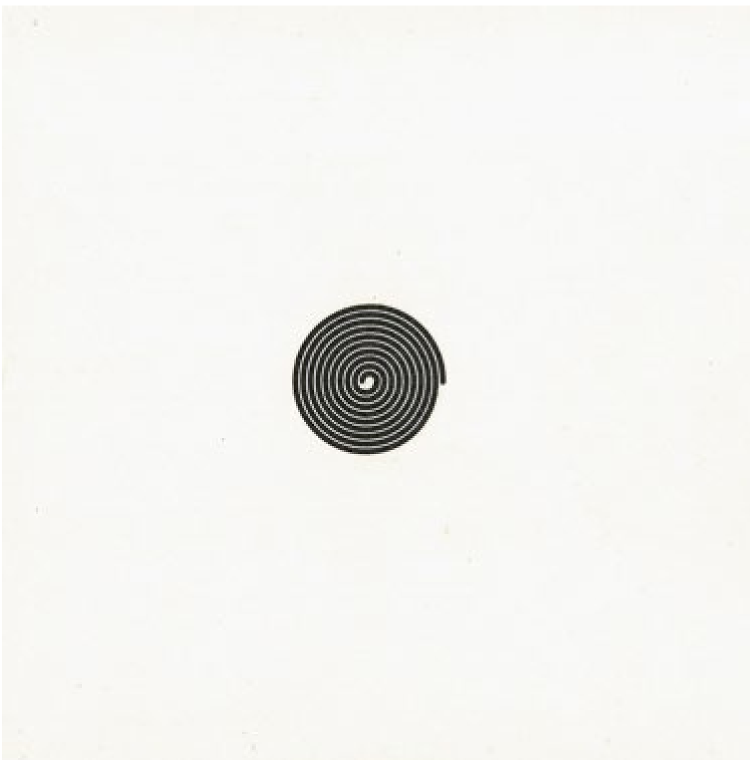

Fig. 8. Printed Foodbox sample after 5 minutes of wear testing.

This notable difference between the two materials shows, that the printed substrate also has a significant effect on the rub resistance of the printed area. This indicates, that depending on the used material, the use of embossing to protect printed elements, such as sensors can be either very beneficial or not necessary at all.

The results for Aegle White are quantified in Fig. 9, where the effect of the embossed protective frame on the ink spreading can also be clearly seen. The analysis shows, that there was very minor spreading, when the embossed protective frame was used.

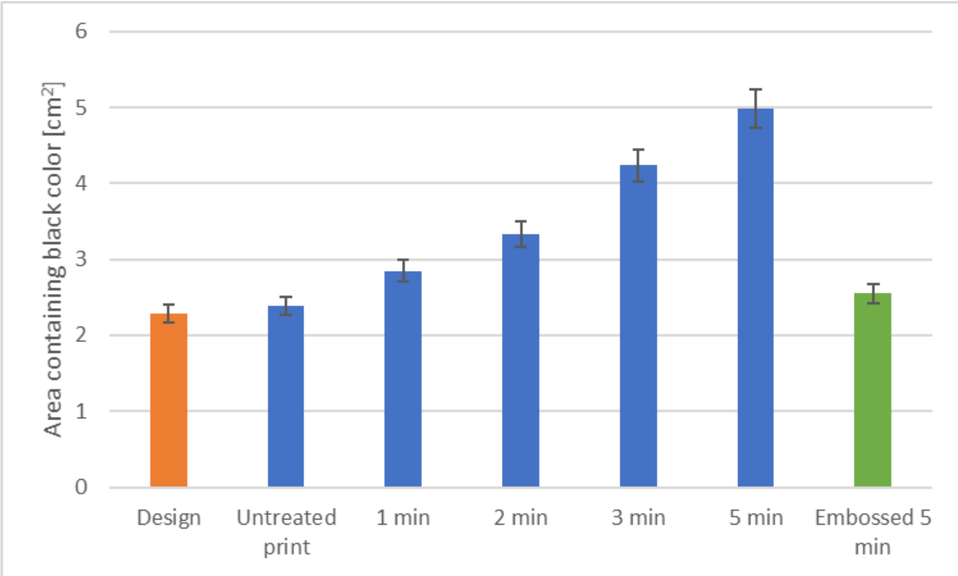

Fig. 9. Results of the wear tested samples for the samples printed on Aegle White, with wear testing times varying from one to five minutes.

The effect of wear testing on the height of the embossed frame showed minor changes in the tested samples for both materials, after 5 minutes of wear testing varying between 4-7 µm and 1-4 µm for the Foodbox and Aegle White, respectively. These results indicate that the embossed protective frames can be manufactured in packages. Moreover, the results show, that the embossed protective frames prevent ink spreading effectively not only for a shorter period, but under prolonged abrasion. In addition to the analysis and measurements shown above, scanning electron microscopy (SEM) analysis was performed to analyse the embossed shapes for cracks or other defects, which is known to decrease the performance of formed packages [13, 16]. Such defects were not found, so it can be assumed that the embossing of the protective frames did not damage the material, and the used embossing parameters were suitable to form the protective frame around the printed sensors. These results can be utilized in packaging design and manufacturing, to provide sustainable protection for sensitive sensors or other printed elements in packaging without adding any additional material or elements. Further research should be conducted to investigate the effects of abrasive rubbing or other mechanical stresses on the functionality of printed electronics or other packaging prints, which has already been researched to some extent [8, 18], but not in relation to the formed protective elements.

4. Conclusions

The results show that embossing of paperboard can be used to manufacture protective frames around printed elements, such as sensors or other printed electronics sustainably, without adding any additional material or elements into the packages. Embossing of the material can be performed with heated tools without any cracking of the material surface. The wear testing of printed materials showed significant spreading of the printed patterns on the Aegle White material without the embossed protective frame. Subsequently no visual spreading of the inks was observed when the embossed protective frame was used.

These results show that the wear resistance and therefore reliability of printed elements, such as sensors in paperboard packages can be significantly improved by utilizing embossing to form a protective frame around the printed sensors. The results also show that the printed substrate has a major impact on the spreading of the inks, as with the other tested material there was no spreading observed.

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