

Functional printing: lightening paper through printing patterns

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Short abstract

A first successful proof of concept has been achieved in a European project back in 2020 allowing to demonstrate that the printing of a specific pattern of starch on a paper substrate can bring high levels of rigidity. Indeed, the printing of such a pattern makes the paper to swell into a new 3D-shape product. This new shape is responsible of the increase in bending stiffness. The goal of the project behind increasing rigidity levels, is to be able to reduce the weight of packaging papers and boards while maintaining mechanical properties. New research has been carried out to study this phenomenon and to better understand it. A new paper was chosen to carry out the studies, more representative of an industrial substrate that could be used for packaging applications. New printings have been realized, replacing starch with micro fibrillated cellulose (MFC) allowing high levels of rigidity with low levels of printed materials. Multiple designs have also been investigated in order to characterize the influence of the pattern on the created 3D-shape. Both design and formulation used for the printings has shown high impact on the final shape. It was shown that the grid should cover the largest possible amount of the substrate while maintaining holes large enough between the lines in order to allow the paper to swell into a new 3D-shape. Moreover, it has been demonstrated that results of MFC deposition are similar to the one with starch while printing far less dry matter on the substrate, which allows better lightening of paper at the end.

Keywords: 3D-shape paper substrate, starch, MFC, screen printing, lightening

1. Introduction and background

The paper is a highly regarded substrate in the packaging industry thanks to its recyclability and biodegradability and can be for a large number of applications an alternative to plastic. In a context of environmental awareness, the occidental societies push towards eco-design or reduction of packaging. One way to reduce packaging, is to lighten the substrate used such as paper and board. In that context, Centre Technique du Papier (CTP) has developed and patented a method to mold a paper substrate into a 3D-shape structure through a printing process. This concept comes from a European project – Sherpack – initiated back in 2017. The research has brought to light the possibility of deforming paper in a controlled shape through the printing of a specific pattern made up with a bio-based solution such as starch. Indeed, after having printed starch through screen printing process. The drying process of this printed pattern causes the paper to swell in a very specific and controlled manner. It was then shown that this new architected substrate presents high levels of rigidity compared to the initial state of paper and thus, allows to reduce the weight of paper used while maintaining rigidity levels. In this context, new research has been initiated in 2022 with a new project in order to better understand the swelling phenomenon, to apply it on new papers and to be able to print other pattern materials such as MFC.

2. Materials and methods

2.1. Substrates

An industrial paper from *Gascogne Papier* was mainly used in this study, Terrana® 70 gsm. It is a natural machine-glazed kraft paper made with virgin resinous fibres. The thickness is 92.7 µm.

Some other variations of basis weight could be used too.

2.2. Formulation and characterization

The starch-based formulation was prepared from a thermo-modified corn starch with low molecular weight from the Cargill Company. It was cooked at 90°C during 30 minutes with a suitable quantity of water to obtain a solution with a viscosity of 1350 mPa.s at 60°C, to be allowed on the screen-printing process. Its final dry content was around 40 wt. %.

The MFC formulation was prepared at CTP with a dry content around 3 wt. %. It is applied at ambient temperature (may vary between 19°C and 25°C).

2.3. Screen printing

The screen-printing machine used in this work is a semi-automatic printer, easy-to-handle and suitable for laboratory printings. The mesh used for the screens is the same for all: 43 threads/cm and 80 µm diameter. The formulation was put on the screen at the working temperature with a syringe. Then, the mobile table with the sample to print went under the screen, the squeegee made the ink going through the screen with set speed, pressure and angle. Due to the small volume of ink on the screen, the temperature went down very quickly to ambient temperature of the lab and only one sample is printed. Finally, the printing sample was dried at 60°C during 2 minutes inside the oven. The screen is cleaned for each sample. At ambient temperature, the high viscosity of the starch-based formulation decreases the amount of deposition.

The protocol is still the same with the MFC formulation, except for the temperature which is not relevant. The prints are made in a row, no cleaning between each sample.

2.4. Grid patterns

Several grid patterns were investigated in this study. For beginning, we focused on orthogonal patterns (Figure 1) with lines, spaced of 2.5 mm, 5 mm, 10 mm and 15 mm, of different widths (Figure 1). Each configuration results in different covering ratios (CoR), i.e. % of printed surface: 51%, 28% and 7%.

2.5. Bending resistance

The bending resistance is measured with a Lorentzen & Wettre device according to the method described in the standard ISO 2493-1. The width of the sample is 38 mm and the length of measure is 10 mm. It is a constant rate of deflection method where the reaction of the substrate is measured after a bending deformation of 5 degrees.

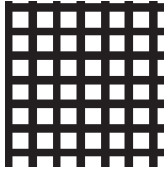
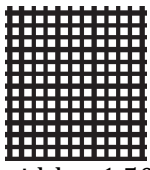
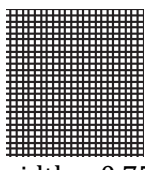
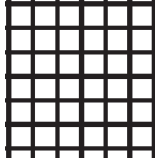
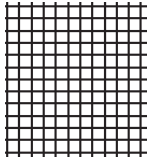
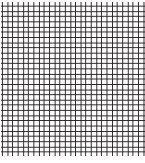
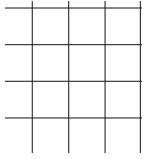
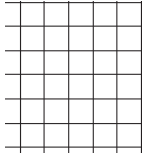
Space	15 mm	10 mm	5 mm	2.5 mm
CoR 51%		 width = 3.00	 width = 1.50	 width = 0.75
CoR 28%		 width = 1.50	 width = 0.75	 width = 0.37
CoR 7%	 width = 0.60	 width = 0.40		

Figure 1: Orthogonal patterns with spaces and widths (in mm) to match 51%, 28% and 7% CoR.

3. Results and discussion

3.1. Impact of the pattern

Figure 2 (c) displays the topography map of the reference orthogonal grid pattern used in the Sherpack project (space = 5.0 mm and width = 1.5 mm, and a CoR = 51%). The 3D-shape is well defined, each square-based summit can be replicated in two directions of a 2D-plan.

Several grid patterns were studied: the orthogonal pattern which is the reference, the point-based pattern which can be regarded as the negative of the orthogonal one, and a light grid pattern which is an orthogonal pattern with missing parts of the grid. Long story short, the non-orthogonal grid patterns do not provide enough control onto the paper surface and allow a chaotic behaviour hard to predict.

This study will focus on the orthogonal grid patterns which provide the best values regarding the bending stiffness. Figure 2 (g) displays the topography map of the grid patterns with the largest space. The expected summits in the centres of the non-printing areas are nowhere to be seen. The centres of the non-printing areas are too far from the starch to be influenced by it. There are insufficient constraints to sustain the dome shape which results in a truncated dome. The less constraints there are, the more the behaviour of the structured paper is close to the reference paper.

Figure 2 (h) displays a well-defined dome shape but the height is lacking. The phenomenon of structuration is limited by the low width of the printed lines. The behaviour of the substrate is close to the reference paper.

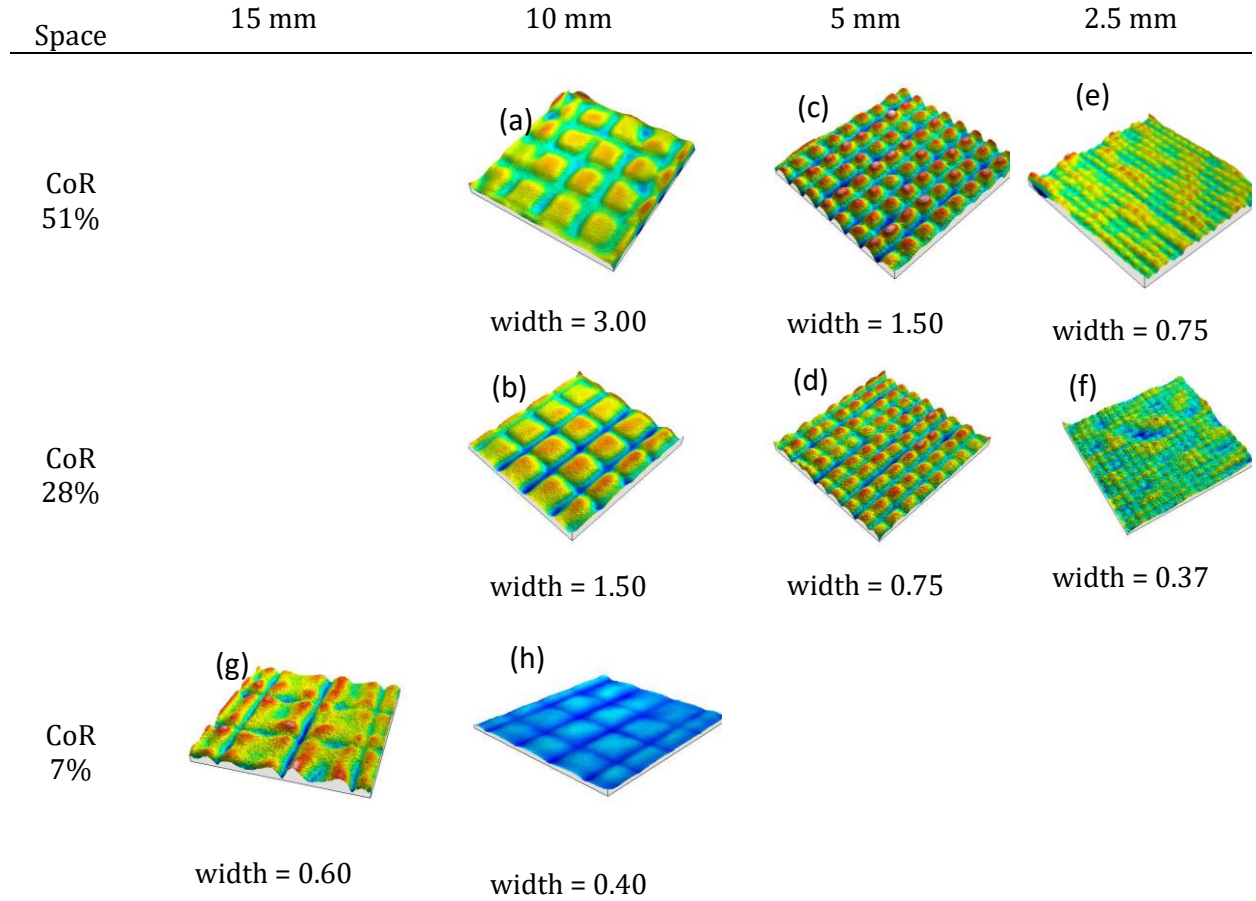


Figure 2: Topography maps of the orthogonal grid patterns with starch formulation. Color legends are not absolute and cannot be used for comparison.

In the case where the lines of the grid are close to each other, as show on Figure 2 (e) and (f), the paper does not have any range to be deformed. The dome shape is replicable but the height, valley to summit, is low. The constraints onto the paper are too significant, the surface is not homogeneous anymore. The result is a bit chaotic without range of control.

The grid patterns, with 5 mm and 10 mm space between the lines, are the most suitable for the 3D-shape formation. The paper maintains a deformation into a plan. There is enough space between the lines for the paper to respond to the constraints of the starch. The width of the lines above 0.6 mm are thick enough to imply constraints onto the surface paper.

3.2. Impact of the formulation

The MFC are used with a dry content of 3 wt. %. The 3D-shape phenomenon with the MFC is quite similar to the one with the starch formulation. The height (valley to summit) is less significant with the MFC. As shown on Figure 3 (b), the deformation is smoother.

The basis weight of the paper is 70 gsm. The MFC formulation allows to stay very close to the basis weight of the substrate thanks to its very low dry content. The starch is very effective as shown on Figure 3 (a), the more it is onto the paper, the more height is achieved but also the more the basis weight increases.

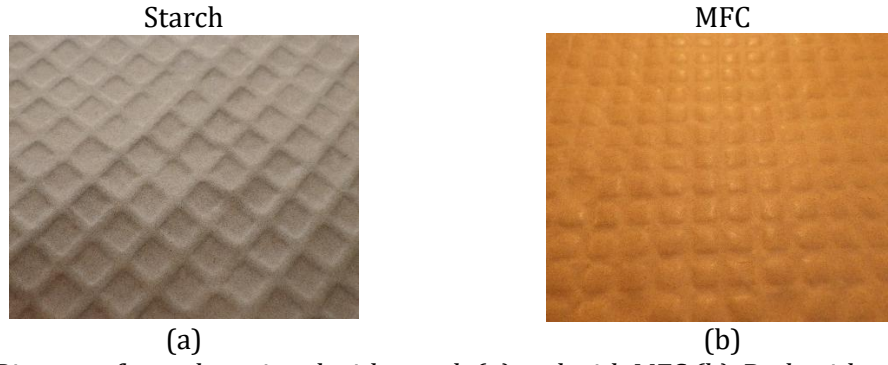


Figure 3: Pictures of samples printed with starch (a) and with MFC (b). Both with a 51% CoR, 10 mm space and 3.00 mm width.

Table 1: Basis weight of the printed samples with starch versus with MFC.

Space	10 mm		5 mm	
	Starch	MFC	Starch	MFC
CoR 51%	86.8 gsm	70.5 gsm	85.8 gsm	72.0 gsm
CoR 28%	77.5 gsm	70.4 gsm	78.3 gsm	70.7 gsm

3.3. Prints characterization

3.3.1. Bending resistance

Table 2: Values of the bending resistance in **mN.m** of Terrana depending on basis weight.

	70 gsm	85 gsm	110 gsm
Terrana	0.21 ±0.03	0.50 ±0.06	0.81 ±0.10

Table 3 displays an advantage of the grid patterns with 10 mm space between lines over the 5 mm space ones. The increase in the bending resistance is the result of greater height (valley to summit). The color legends on Figure 2 are not absolute and do not show any difference between (a) and (c). The height in (a) is about 500 μm and about 250 μm in (c).

Table 3: Values of the bending resistance in **mN.m**. Terrana 70 gsm with starch and MFC grid printed.

Space	10 mm			5 mm	
	Terrana 70gsm	Starch	MFC	Starch	MFC
CoR 51%	0.21 ±0.03	0.61 ±0.09	0.43 ±0.09	0.51 ±0.10	0.39 ±0.12
CoR 28%		0.40 ±0.04	0.34 ±0.05	0.37 ±0.05	0.29 ±0.03

By combination between the Table 1 and Table 2, the gain of the structuration of the substrate is shown on Table 3.

Table 4: Values of the gain in bending resistance in %. Terrana 70 gsm with starch and MFC grid printed.

Space	10 mm		5 mm	
	Starch	MFC	Starch	MFC
CoR 51%	290	205	243	186
CoR 28%	190	162	176	138

As shown on Tables 2 and 3, the samples with a CoR of 51% are close to the Terrana 85 gsm regarding the bending stiffness. Meaning it becomes possible to replace a Terrana 85 gsm by a Terrana 70 gsm printed with starch or MFC grid patterns. In the case of starch deposition, what is saved in paper fibres is spent onto the grid pattern (Table 1). The starch deposition has a good response in improving the bending stiffness but has limitations in the lightening process (Table 4).

3.3.2. Burst, tear and strength resistance

Regarding other mechanical properties, the grid patterns do not induce any change. There are no pro or con and the results are the same with the starch or the MFC.

4. Conclusions

This project allows a better understanding of the application range of grid patterns onto a paper substrate. The structuration of the paper depends on the level of constraint applied onto the surface of the substrate. Too many constraints bring a chaotic structuration with less control. Not enough constraints do not allow the paper to change its initial behaviour. It is a fine tune between a strong motor – the width of the line – and a release space – space between lines that allows the best height, valley to summit, thus the best response to the bending stiffness. In addition, the MFC bring an interesting behaviour to the topic. The results of the MFC deposition are similar to the ones with the starch and at the same time the basis weight of the final product is maintained close to the substrate itself. Which can be at the end of the day, a marketing leverage in an industrial development, where the weight reduction is a strong motivation for ecology and economy.

Acknowledgements

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