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Evaluation of the Patternability of Fibre-Based Materials with Converting Experiments

Panu Tanninen[1,a*], Ville Leminen[1,b], Sami Matthews[1,c], Mahdi Merabtene[1,d] and Juha Varis[1,e]

[1]LUT University, Yliopistonkatu 34, 53850 Lappeenranta, Finland

[a]panu.tanninen@lut.fi, [b]ville.leminen@lut.fi, [c]sami.matthews@lut.fi, [d]mahdi.merabtene@lut.fi, [e]juha.varis@lut.fi

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Abstract. Paperboard based packaging products are renewable alternatives for packages made traditionally from oil-based polymer materials and can be used for packaging of various products [1]. Embossing is used in packaging solutions to increase the functionality and appearance of the products. It can also be used to increase product safety by improving distinctiveness and identifiability of packages [2].

The aim of the study was to evaluate the patternability of various fibre-based materials. It was desired that the accuracy and details of the embossed pattern would be the same in all samples, regardless of their different material properties. The realization of this was evaluated by several analyses related to the performance of the materials in the embossing process.

Eleven different sample materials were collected for the experiments so that the patternability could be studied extensively. The common denominator of the materials selected for testing was that they were all fibre-based paper and paperboard materials used in the packaging industry.

Set of embossing tools were developed, and precision machined from brass, for the experiments. A laboratory scale mechanical embossing device was utilized in modification of sample surfaces to study patternability of selected fibre-based sample materials. The main variables in the forming experiments were pressing force and tool temperature. The samples were observed primarily visually - with the naked eye, with a scanning electron microscope and a 3D-profilometer which was used in the topography analysis of the achieved patterns.

The results of the embossing test series confirmed that the height of the pattern increased as a function of pressing force and plate temperature and spring back occurred in all materials after the tool plates opened. It was deduced that the pattern dimensions of the embossing plate somewhat determined the achievable pattern height in the fibre-based sample materials, but the amount of springback did not change as a function of material thickness. Despite this finding, it was consistent that the amount of spring back was regularly reduced with higher tool temperatures.

The optimization study of the magnitude of the forming force showed that excessive use of force is not required, which is beneficial in reducing the risk of material damage during processing and adjustment of embossing devices. All samples differing significantly from each other were found to be suitable for embossing, indicating that patterns such as those tested could be added to a variety of packaging applications.

Introduction

Paperboard based packaging products are renewable alternatives for packages made traditionally from oil-based polymer materials and can be used for packaging of various products [1]. Embossing is used in packaging solutions to increase the functionality and appearance of the products. It can also be used to increase product safety by improving distinctiveness and identifiability of packages [2].

The forming process is a key technology in the package production process. Typical known technologies are folding, bending, spiral and parallel winding or embossing. These technologies have clear limitations in the geometrical design (e.g., sharp edges or forming degree) of packages or require several steps to produce formed structures [3]. Embossing is an example of compressive forming in the papermaking process. A certain forming resistance of the material has to be overcome to change the sheet shape [4]. During the paper forming, which is mainly realized through the gap-controlled processes of deep drawing and embossing, paper is stressed by a compressive force in the z-direction (out of plane). In both processes, paper is compressed in the tool gap depending on its ZD-compression behaviour and effective process parameters of forming pressure, temperature, and forming time. As a result, the thickness of the material decreases whereas simultaneously the density increases [5]. Out-of-plane properties are the key factors for the mechanical behaviour of paperboard materials, especially for converting operations, such as creasing and folding. In the creasing operation, shear deformation between fibres or fibre - fibre joints is the dominating deformation and damage mechanism [6]. In many other operations, such as embossing, printing, package forming etc., a good design of the out-of-plane properties also improves the operation performance [7].

The patterning properties of the materials differ from each other when using different processing parameters. Determining this behaviour in detail is necessary to identify use potential of each material.

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Materials and Methods

Eleven different sample materials were collected for the experiments so that the patternability could be studied extensively. The common denominator of the materials selected for testing was that they were all fibre-based paper and paperboard materials used in the packaging industry. They differed significantly from each other e.g., in basis weight and thickness. Sample materials sorted by material thickness are shown in Table 1.

Table 1. Sample materials used in embossing experiments.

	Sample name	Grammage [gsm]	Thickness [µm]	Producer
1	HD-95	95	90	Arjowiggins
2	Novapress 100	100	96	Stora Enso
3	BergaClassic Preprint 100	100	123	Stora Enso
4	Finesse Premium 150	150	124	UPM
5	Tringa Lux 140	140	188	Paptic
6	Isla Duo 195	195	254	Kotkamills
7	Cupforma Natura Aqua+ 215	215	280	Stora Enso
8	Aegle White 200	200	287	Kotkamills
9	Foodbox 230	230	369	Stora Enso
10	Pankasilk 290	290	590	Pankaboard
11	Pankasilk 360	360	751	Pankaboard

Set of embossing tools presented in Fig. 1 were developed, and precision machined from brass, for the experiments. The study was carried out as part of the ECOtronics project and its logo that includes 10 mm high text was selected as a pattern to be produced with embossing tools. Pattern depth in the female plate was selected to be 380 µm and the clearance of the tools was selected according to the thickness of the material to be embossed. In order to achieve the maximum pattern height with thicker materials, the pattern to be made should have been larger and simpler. However, a similar pattern accuracy and height was targeted for all materials and the dimensioning of the female and male plates was done accordingly.

Figure 1. A pair of embossing plates (male plate on the right and female on the right) that produce a test pattern used in the forming experiments.

A laboratory scale mechanical embossing device, developed by LUT Packaging Technology in accordance with the DFMA principles for prototyping (Design for Manufacture and Assembly) [8], presented in Fig. 2 was utilized in modification of sample surfaces to study patternability of selected fibre-based sample materials. The device was installed to Shimadzu AGS-X material tester (electromechanical tabletop frame tester) which enables accurate position, speed and force adjustment. Precise alignment of the embossing plates is ensured in the device with vertical guide pillars and bushes. To enhance the formability of sample materials during processing [9], bar-shaped heating elements are embedded in the base of the upper plate which enables temperature control of the forming process. Although the strength properties and thereby formability of most fibre-based materials differ in machine (MD) and cross direction (CD) [10], the patterning was done on the samples with the embossed text only in the machine direction (MD) to limit number of specimens. The main variables in the forming experiments were pressing force and tool temperature. At elevated mould temperatures, a pattern with greater height can be accomplished due to reduced amount of springback [2].

Figure 2. Embossing device used in the experiments that is installed to the tabletop frame tester.

In the preliminary tests, the constant parameters of pressing speed (5 mm/s) and dwell time (100 ms) values were selected for the entire test series. Three different embossing plate temperature settings (23ºC, 40ºC and 80ºC) and four different pressing force settings (2 kN, 4 kN, 6 kN and 8 kN) were selected as variables for the test series. Because the material sheet to be moulded is clamped during processing in embossing (i.e., it is a fixed blank process), other adjustment parameters were not required, in contrast to processes utilizing a sliding blank [11]. The samples were observed in the preliminary tests primarily visually - with the naked eye and the results were also confirmed by SEM (Scanning Electron Microscope) imaging in cases where damaging of the material surface was suspected. It was noted that the extent of the damage could be practically seen with a measuring device capable of lower magnifications, such as a stereomicroscope [12]. Results of SEM-imaging were particularly exploited to determine suitable pressing force range for sample materials. Excessive force caused the surface layer of the material to cut at the outer edge of the pattern, which can be seen in Fig. 3.

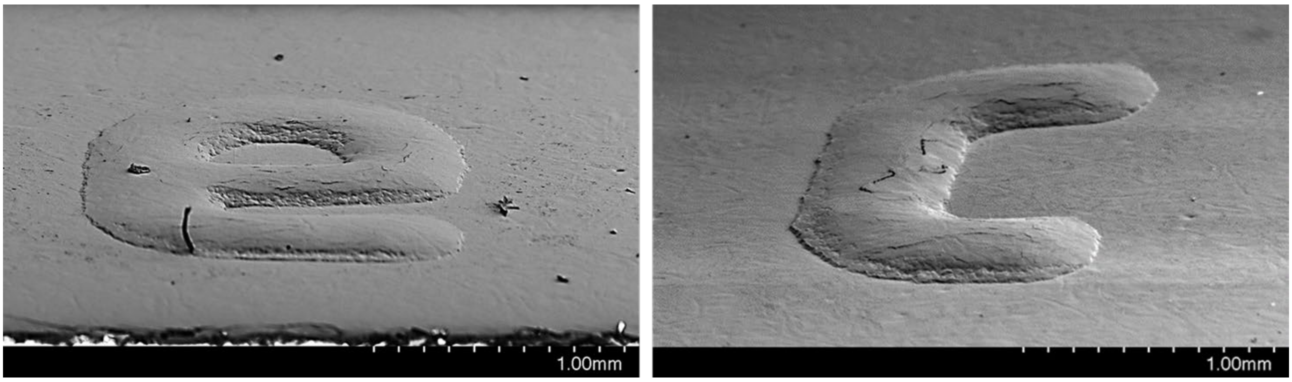

Figure 3. SEM-images of a single letter of the embossed text on a paperboard surface (Sample 9 - Foodbox 230).

In all embossing tests, the obtained patterns were evaluated with an optical 3D-profilometer (Keyence VR 3200) by measuring the topography of the achieved patterns. Height of the embossed pattern was measured along the centreline of the ECOtronics text as shown in Fig. 4.

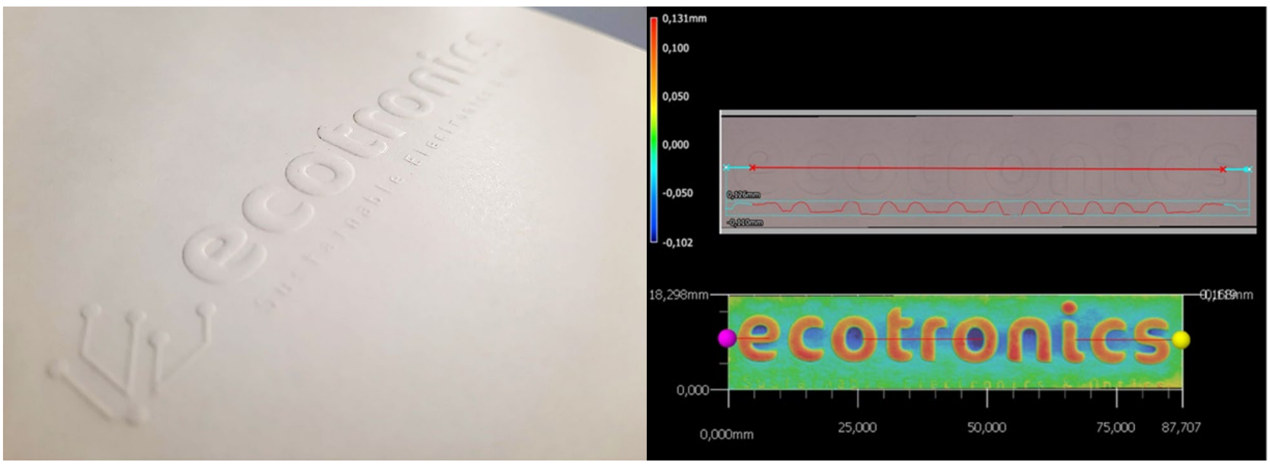

Figure 4. An embossed pattern on the surface of the paperboard and the topography of the same pattern measured with a 3D-profilometer.

Materials were stored for several days before testing in laboratory conditions (50%RH and 23ºC) to stabilize their moisture content. All forming tests were also performed in the same premises and conditions. The moisture content of the sample materials was measured during the experiments and the results ranged from 6.7 to 7.3%.

Results and Discussion

Immediately at the beginning of the examination of the patterned samples, it was discovered that none of the samples had been damaged during embossing process. This proved the success of the parameter optimization in the preliminary experiments and thus the differences between the samples would be in the quality and dimensions of the pattern.

The heights of the patterns achieved by embossing

The heights of the patterns were estimated by averaging the heights of the pattern peaks over the entire text. The results presented in Fig. 5 show that the height of the pattern increases as a function of pressing force and plate temperature, as expected.

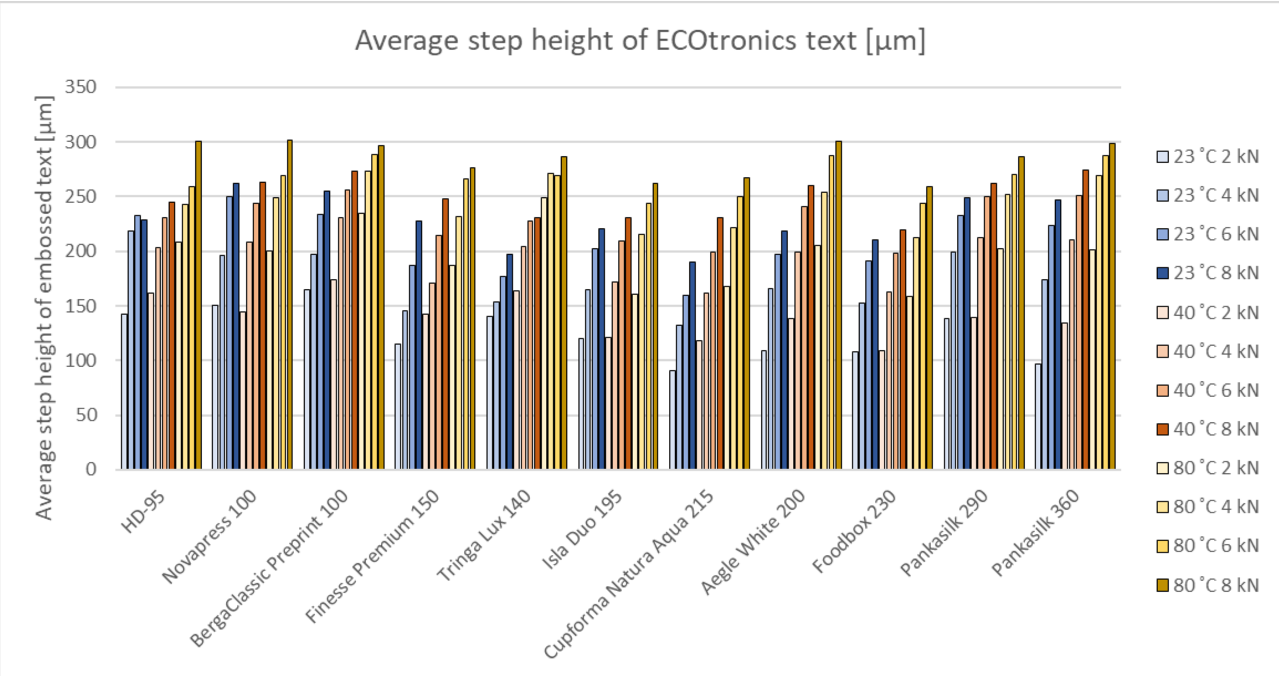

Figure 5. Pattern height average in embossed samples.

Pattern height was roughly on the same level in best performing samples, since 380 µm female plate pattern depth determines achievable pattern height. The best results were slightly over 300 µm, which indicates that spring back occurred in all materials after the tool plates opened. The amount of spring back was regularly reduced when higher tool temperatures were used.

Effect of pressing force increase on pattern height

It can be seen in Fig. 6 that the effect of the increase in pressing force on the forming result is that most of the pattern height is obtained with the two smallest force settings (2 and 4 kN).

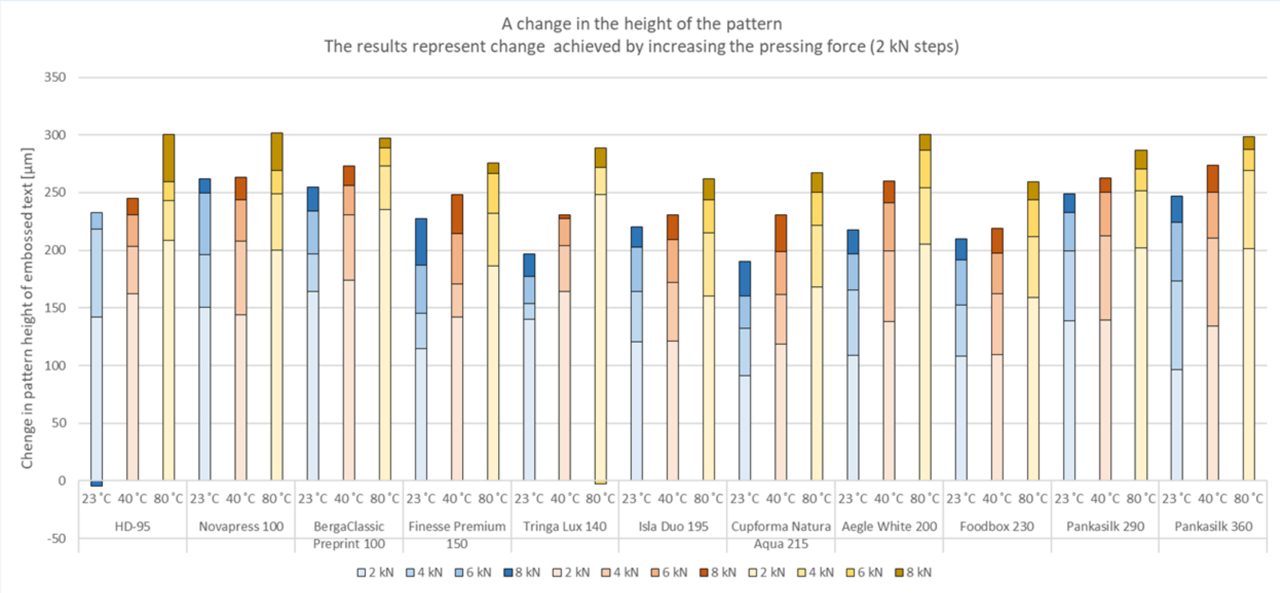

Figure 6. Effect of pressing force on the height of the embossed pattern.

For example, with Aegle White 200 sample material, the portion of the maximum result obtained with each pressing force increase steps:

- 2 kN → 205.5 µm (68,4 %)
- 4 kN → + 48.5 µm (16.1 %)
- 6 kN → + 33.0 µm (11.0 %)
- 8 kN →+ 13.5 µm (4.5 %)

Change in the pattern height in relation to the thickness of the sample materials

When the results are evaluated in relation to the original thickness of the sample materials, the thinnest materials could be formed significantly which can be seen in Fig. 7. These samples also thinned more during processing, and the achieved patterns cannot be assumed to withstand the stresses to which they are subjected in packaging use. This is not a problem with patterns formed into thicker materials.

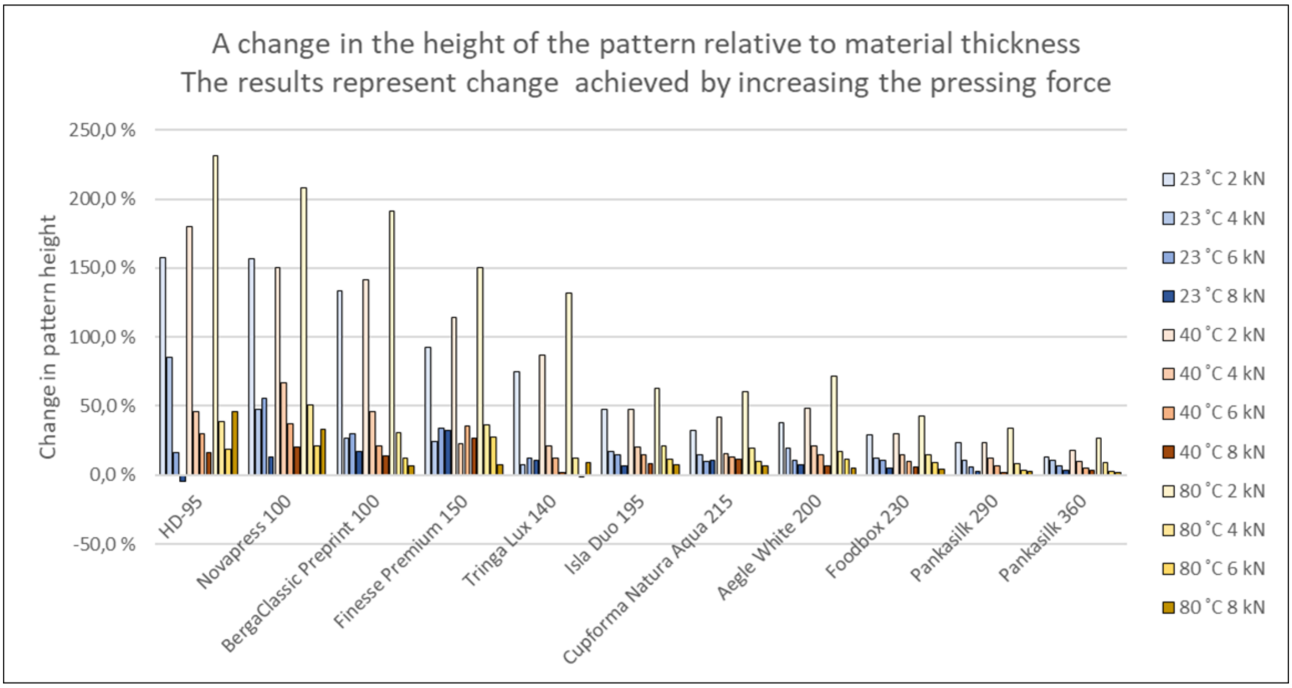

Figure 7. A change in the pattern height in relation to material thickness.

A wider range of measurements was also made for some of the sample materials, which makes it possible to describe the patternability in more detail. Fig. 8 shows the consistent increase in pattern height of the Foodbox 230 sample as a function of pressing force and tool temperature.

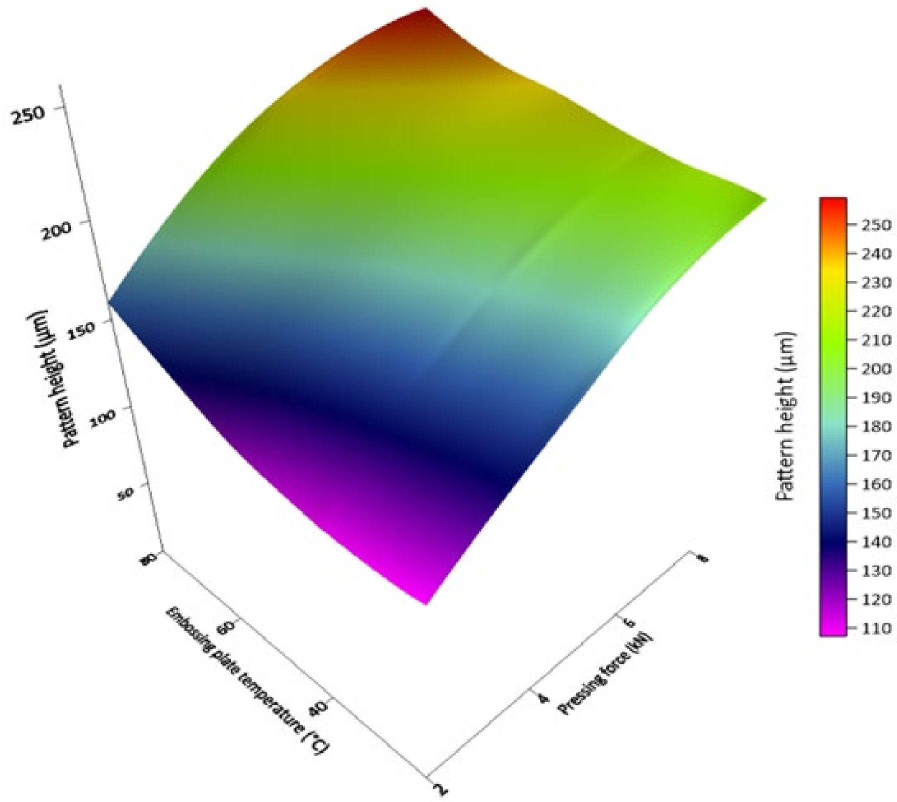

Figure 8. Patternability of the Foodbox 230 sample material.

The results of the experiments summarized in Table 2 shows that the highest patterns could be produced by embossing the thinnest materials, but the same result was also obtained with the Aegle 200 sample representing the thicker samples. It should be noted that although the thinnest materials enable good embossing result, the stiffness properties of the materials are not sufficient considering the durability of the pattern in many applications.

Table 2. Summary of test results related to embossing of fibre-based materials

	Sample name	Thickness [µm]	Maximum pattern height [µm], Plate temp 80ºC, Press. force 8 kN	The height of the pattern in relation to the material thickness
1	HD-95	90	300,5	333,9 %
2	Novapress 100	96	301,5	314,1 %
3	BergaClassic Preprint 100	123	297	241,5 %
4	Finesse Premium 150	124	276	222,6 %
5	Tringa Lux 140	188	286,5	152,4 %
6	Isla Duo 195	254	262	103,1 %
7	Cupforma Natura Aqua+ 215	280	267,5	95,5 %
8	Aegle White 200	287	300,5	104,7 %
9	Foodbox 230	369	259,3	70,3 %
10	Pankasilk 290	590	286,5	48,6 %
11	Pankasilk 360	751	298,5	39,7 %

Conclusions

The results of the embossing test series confirmed that the height of the pattern increased as a function of pressing force and plate temperature, as expected. Furthermore, the results indicated that spring back occurred in all materials after the tool plates opened. It was deduced that the pattern dimensions of the embossing plate somewhat determined the achievable pattern height in the fibre-based sample materials, but the amount of springback did not change as a function of material thickness. Despite this finding, it was consistent that the amount of spring back was regularly reduced with higher tool temperatures.

The optimization study of the magnitude of the forming force showed that most of the pattern height was obtained with relatively small force settings. Excessive use of force is not required, which is beneficial in reducing the risk of material damage during processing and adjustment of embossing devices.

To conclude, all samples differing significantly from each other were found to be suitable for embossing, indicating that patterns such as those tested could be added to a variety of packaging applications. The combined results enable a selection of the most suitable materials to produce advanced sample packages from the embossing point of view.

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