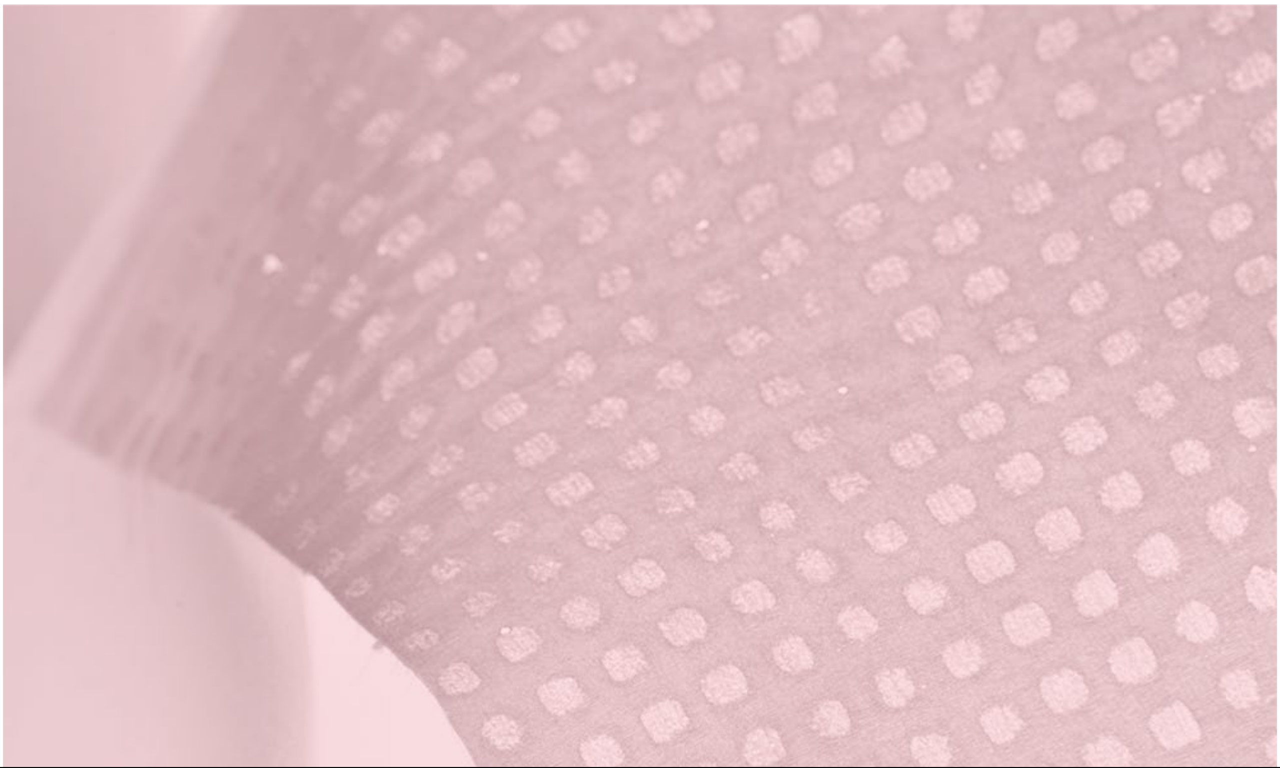

crimping and welding of textile-like papers

by
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A Mistra Future Fashion Report

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table of content

1. Introduction 5
2. Materials 6
3. Methods 6
3.1. Spot welding 6
3.2. Crimping and creping 7
3.3. Mechanical characterisation 8
4. Results 9
5. Conclusions 12

1. Introduction

Within the Mistra Future Fashion program we are currently exploring a Fast-Forward Fashion design concept, aiming at replacing part of conventional textiles by producing biobased, textile-like nonwovens on a paper machine. The Fast-Forward Fashion concept involves:

- An exploration of an alternative to standard modes of production and use for 'fast-fashion' application
- Focussing on LCA advantages through; lighter material choices; nonwoven fabric production; no launder; clear routes to recovery;
- A sliding scale of 'speed' from ultra-fast forward (shortest-life scenario) through to a more standard length of use with adaptations to production processes and end of life

The consumers experience of the textile-like material is important, why it is natural to consider the materials conformity to properties that are usually associated with textiles, such as softness, handfeel, flexibility, *stretch, strength*, drape and a sound dampening effect. To be able to influence the consumers perception and final acceptance of the material, there should be finishing and conversion processes that supports a large span of possible visual and haptic expressions. There are also a number of properties associated with wear and tear, such as strength, foldability and resilience to water from rain and perspiration, which must be fulfilled. Results on the perception of the textile-like paper materials produced within the Mistra Future Fashion program will later be reported in deliverable D3.1.3.1. From a sustainability perspective, it is important to limit the resources used to manufacture the base material, the processing into a final garment, the footprint during use phase and to consider viable recycling routes. Detailed results on the recyclability of the textile-like papers will be presented in deliverable D1.1.5.1. The purpose of the current work is to improve the understanding of how the choices made at the papermachine can influence the span of textile-like properties of the finished textile.

In the current study we have chosen to work with a mixture of bio-based materials as stock to the paper machine. Poly lactide staple fibres are soft and have thermoplastic properties that can be exploited in a thermic welding finishing process to increase material strength. Sulphate softwood paper pulp is used because of its low footprint compared to staple fibers, and microfibrillated cellulose from wood in small quantities is used to increase the material strength. The mixing of the components followed two distinctly different routes, starting with A) a material with relatively high PLA fibre content resulting in a soft, stretchy and weak material before finishing and B) a material with low PLA fibre content resulting in a stiff but strong material before finishing. It is envisioned that route A) materials could be recycled in a compost and that route B) materials could be recycled as a paper or paper board. The effect of crimping and welding finishing processes generally have opposite effect on the stretch and strength of the material. The research question of the current work thus becomes:

- What is the span of stretch and strength that can be obtained by crimping and welding of the textile-like materials A) and B) produced on the Stratex semipilot paper machine?

2. Materials

Route A):
A1) 90 g/m^2 paper composed of 40% unrefined, unbleached sulphate softwood pulp, 3% microfibrillated cellulose, and 57% polylactide (PLA) staple fibers.

A2) 120 g/m^2 paper composed of 40% refined bleached sulphate softwood, 3% microfibrillated cellulose, and 57% magenta coloured polylactide (PLA) staple fibers.

Route B):
B) 90 g/m2 paper composed of 95% unbleached sulphate softwood pulp, and 5% polylactide (PLA) staple fibers.

3. Methods

3.1. Spot welding

Welding is a common Industrial finishing method to increase the strength and to influence the esthetics of thermoplastic materials. Welding was performed using a hot tip in the 3D-printer Ultimaker^2 (figure 1). Square, zig-zag and Miura patterns were studied (figure 2), having a maximum of 2 mm between each welding spot (3 mm centre-to-centre distance). The effect of contact time of the hot tip was varied from half to double (50-200%) standard time to see its effect on mechanical properties of the square and zig-zag patterns.

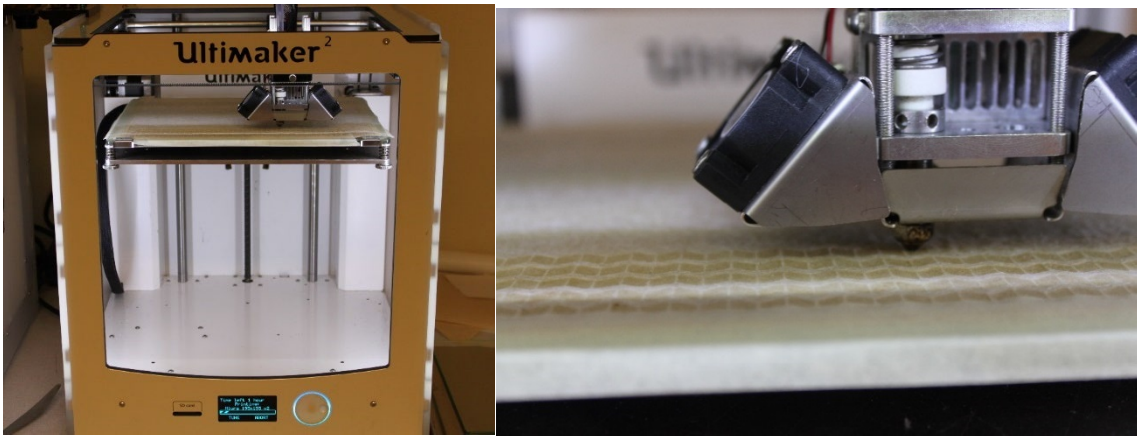

figure 1 Left: the Ultimaker^2 3D printer. Right: Spot welding of Miura pattern using the hot tip in the 3D printer

figure 2 The three different welding patterns that were used in the study. From left: square, zigzag, Miura welding patterns on A1 samples.

3.2. Crimping and creping

Crimping and creping are common industrial finishing methods to increase the stretch and softness of flat materials. Hand crimping was performed during more than 20 minutes using a procedure where the sheets were rolled over a fold several times, and further crimped and hammered to decrease the internal fiber bonds within the sheet. Sample A2 was sent to Micrex (micrex.com) for industrial dry creping. In figure 3 paper B before and after crimping is illustrated, and in figure 4 sample A2 after industrial creping is illustrated

figure 3 Left, untreated paper B. Right, paper B after hand crimping.

figure 4 Sample A2 showing left-right periodic undulations (~1mm) from industrial creping. The spot pattern comes from further welding treatment.

3.3. Mechanical characterisation

Samples were cut into 10 cm long and 1,5 cm wide stripes. The mechanical properties, strength and elongation at break, were characterized at 23°C and 50%RH in an MTS for all samples, see table 1. Six stripes for each sample were characterized to get at representative average value.

table 1 Samples and finishing treatments.

Sample	Paper	Weld	Crepe
A1	A1	-	-
A1_Sq0.5	A1	Square, 50% time	-
A1_Sq1	A1	Square, 100% time	-
A1_Sq2	A1	Square, 200% time	-
A1_Zz0.5	A1	Zigzag, 50% time	-
A1_Zz1	A1	Zigzag, 100% time	-
A1_Zz2	A1	Zigzag, 200% time	-
A1_Miu1	A1	Miura, 100% time	-
A2_Cr	A2	-	Micrex™
A2_Sq1_Cr	A2	Square, 100% time	Micrex™
B	B	-	-
B_Cr	B	-	Hand crimped
B_Sq1_Cr	B	Square, 100% time	Hand crimped

4. Results

The mechanical properties of all samples are compiled in table 2 and are visualized in figure 5-8. From the clustering of results in figure 7, it is meaningful to divide the results into the three sample categories A1, A2, and B. The A2 sample category, i.e. creped samples comprising a large part PLA fibres, show very large strain at break (50-60%) compared to the other samples (1-9%). These creped A2 samples are not stiff, see very flat initial slope in figure 5, but rather flexible with some drape. The square welding pattern worked as expected as it improved the material strength (+25% force at break) but somewhat decreased the strain at break from 60% to 50%. The B samples, containing small amount of PLA fibers (5%), show distinctly different properties. Unfinished B samples show little textile-like character since they are stiff and produce a metallic sound during handling. Sample B's large stiffness can be observed in figure 5, having a very steep initial slope. In combination with its large stiffness, sample B also shows a considerably higher strength (force at break = ×7-28!) than any sample from the A1 or A2 series. This is natural since the sulphate pulp fibers creates stronger fiber-fiber bonds within the sheet than sheet having similar ratio of wood pulp and PLA fibers. Hand crimping was explored as a method to decrease the fiber-fiber bonds within sample B, assuming this would increase the stretch and textile-like character, at the expense of some strength. The hand crimping had the desired effect which could be observed directly by the dull almost silent sound that was created during handling of the sample, and the significantly decreased stiffness, which can be seen in figure 5 showing a flatter initial slope for the crimped sample B. Furthermore, the crimping treatment increased the strain at break by 30%, at the expense of a decreased force at break by almost 60%. This decreased strength could be somewhat counteracted by the addition of a square welding pattern (see figure 2) that increased the force at break by almost 10%.

The effect of welding on sample A1 is presented in figure 7-8. figure 8 shows that the different welding patterns group nicely into the three distinctly different groups "Miura", "square", and "zig-zag" patterns. All welding patterns increased strength by about 100%, and the square and the zig-zag patterns also increased the strain at break. The most natural reason for this is probably that the Miura pattern contains a larger stiffened and welded part of the sample, hence limiting the materials ability to move and adapt to the applied force. The zig-zag pattern showed the best results as it also increased the strain at break by about 60% compared to the unwelded sample. The force – strain curves for an untreated and a zigzag welded sample are presented in figure 6, showing increased stiffness (initial slope), strength and strain at break. The welding time (50%, 100%, 200%) was found to have only limited effect on the mechanical properties. It must be noted that although a 100% strength increase is very good from a relative perspective, the absolute strength of the welded A1 samples is still small compared to what usually is needed for the wear and tear of traditional textiles.

table 2 Samples and mechanical properties.

Sample ID	Thickness [mm]	Grammage [g/m^2]	Strain at break [%]	Force at break [N]
A1	240	90	1,00	3,65
A1_Sq0.5	245	90	1,31	7,39
A1_Sq1	235	90	1,35	6,50
A1_Sq2	230	90	1,37	6,78
A1_Zz0.5	202	90	1,51	8,23
A1_Zz1	230	90	1,69	7,80
A1_Zz2	244	90	1,72	8,03
A1_Miu1	260	90	0,96	6,28
A2_Cr	507	120	60	9,9
A2_Sq1_Cr	473	120	50	14,7
B	140	90	6,8	105
B_Cr	175	90	9	43,5
B_Sq1_Cr	170	90	8	47,7

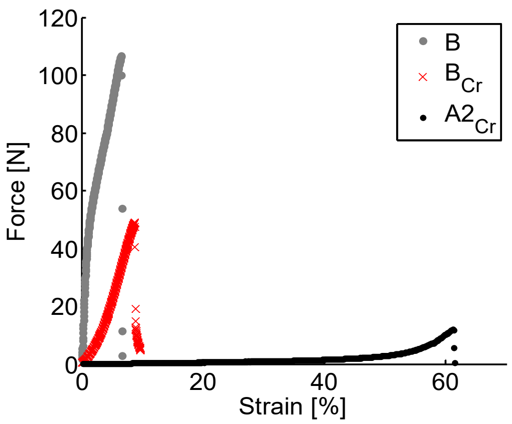

figure 5 Force-strain curves for samples B, B_Cr, and A2_Cr.

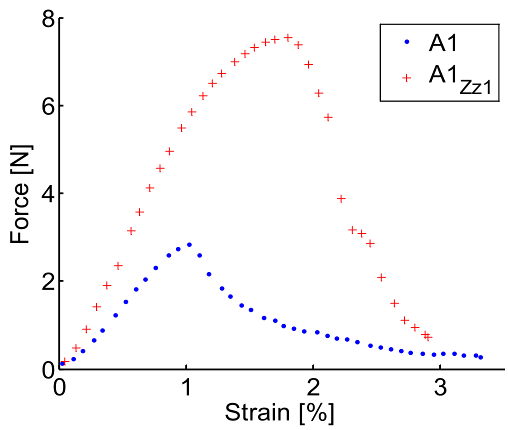

figure 6 Force-strain curves for samples A1 and A1_Zz.

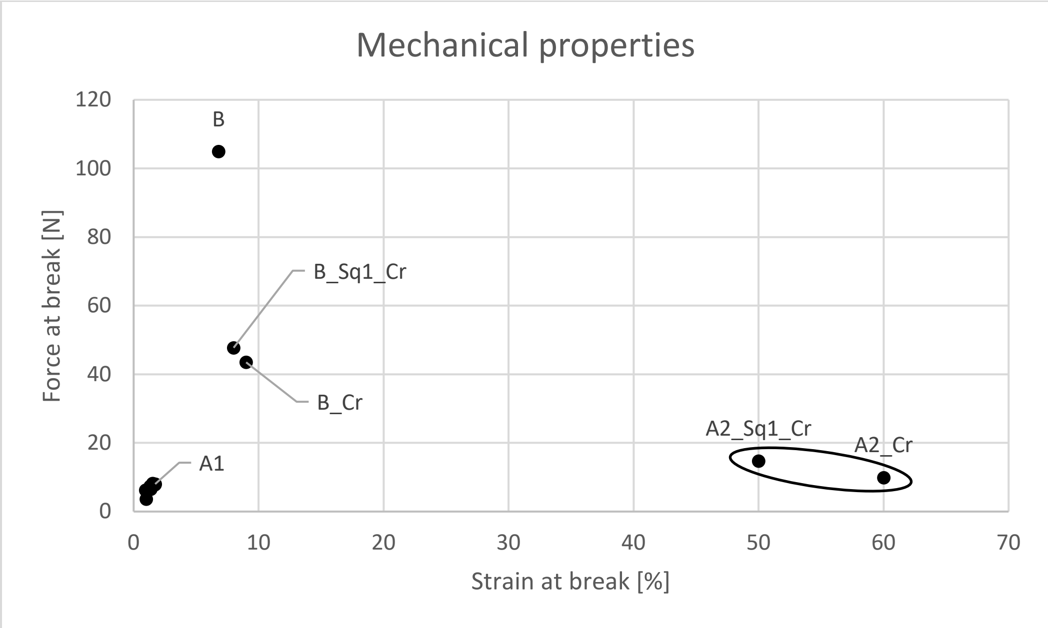

figure 7 Force at break vs strain at break for all samples. Circles enfold A1, A2, and B paper samples repectively.

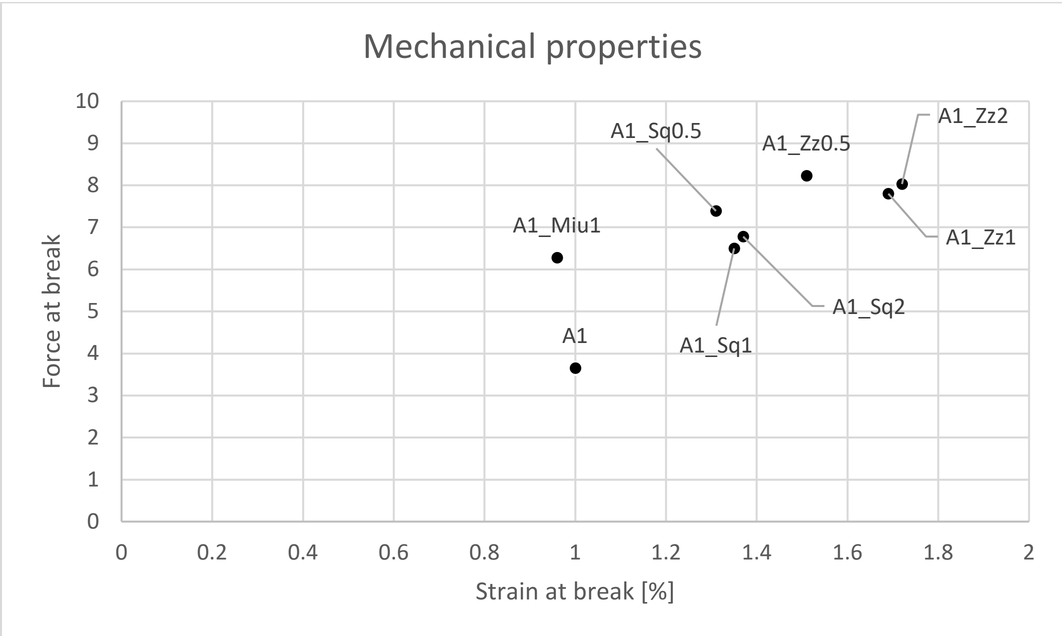

figure 8 Force at break vs strain at break for A1 paper samples. Circle enfolds the square and zigzag welding patterns.

5. Conclusions

The purpose of the current work is to improve the understanding of how the choices made at the papermachine can influence the span of textile-like properties of the finished textile. Textile-like papers were prepared at the semipilot Stratex papermachine at RISE Bioeconomy following a route A) with a high polylactide fiber content and B) with a low poly lactide fiber content. These papers were later treated by crimping and welding processes to combine a textile-like character with a good strength.

This study clearly shows that crimping and welding finishing treatments can significantly alter the character and mechanical properties of the raw papers. Samples with low PLA fiber content showed excellent strength but little textile-like character before any finishing treatment. Hand crimping imbued some stretch and a muffled textile-like sound into the samples. The strain at break increased by 30%, at the expense of a 60% decreased strength. Samples with a large PLA fiber content showed considerably smaller strength but were much softer to the touch. Application of a spot welding pattern having a center-to-center distance of 3 mm did not only increase the sample strength by up to 100%, but also increased the strain at break by up to 60%. Industrial dry crepe treatment of samples with a large PLA fiber content resulted in samples with excellent stretch and some drape.

These results demonstrate that crimping and welding are powerful finishing techniques that can be used to tailor a span of different properties out of one raw base material. Put in another way, these results illustrate a way to cost effectively produce large quantities of a single generic material in a paper machine, that later can be converted or tailored into a multitude of products fitting the needs of the many.

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Mistra Future Fashion is a research program that focuses on how to turn today's fashion industry and consumer habits toward sustainable fashion and behavior. Guided by the principles of the circular economy model, the program operates cross disciplinary and involves 60+ partners from the fashion ecosystem. Its unique system perspective combines new methods for design, production, use and recycling with relevant aspects such as new business models, policies, consumer science, life-cycle-assessments, system analysis, chemistry, engineering etc.

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