Research Article

On the use of paper to facilitate recyclability of suspension packaging

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Abstract
Background of this research is suspension packaging: fragile goods are attached to a panel of cardboard by wrapping it in stretch film. The panel is then appropriately folded, and the whole thing is placed in a cardboard box of corresponding dimensions. The primary objective of this study is to identify paper types that might be used in future as a more sustainable alternative for stretch wrap film. The experimental methods that are utilized are basically variants of mechanical pulling tests on paper samples. Sample preparation and sample size are adopted from international standards, but displacement control is adopted to detect relevant stretchability properties. Some kraft papers show a high ultimate tensile stress and a moderate stretchability, mainly permanent stretch as expected. Although the ultimate tensile stress of paper from recycled fibers is lower, some of these paper grades show a considerable higher stretchability including a higher elastic stretch. It is concluded that both kraft paper and paper grades from recycled fibers may be applicable as a wrapping material for suspension packaging. Further experimental research is needed to identify appropriate wrapping parameters for each paper type.

Keywords Paper mechanical properties · Recyclable packaging · Suspension packaging · Horizontal stretch wrapping

1 Introduction

Many e-commerce goods need to be packaged prior to shipment to protect the goods during handling and transportation [1–8]. Often a corrugated cardboard box is used in which the goods are placed. Filling material is placed in the empty space around it, which prevents or limits movement in the corrugated box. Filling materials are PE bags filled with air, polystyrene flakes, crumpled paper, cardboard folded into a hollow form, etc. (examples shown in Fig. 1).

This widely used technique is characterized by many disadvantages:

- Many filling materials (such as polystyrene flakes or PE bags filled with air) are not very environmentally [9–15] friendly, at least in the perception of the end customer.
- Crumpled paper as a filling material is not very suitable for absorbing repeated large impacts.
- The cushioning materials must be applied to all six sides of the product. Even if this is done properly, the filling materials may shift during transport. In the final stage of delivery to the end customer, not all sides are then equally well protected.
- This packaging method is not easy to automate.

This is why "suspension packaging" (example shown in Fig. 2) is arousing great interest as a next generation packaging method.

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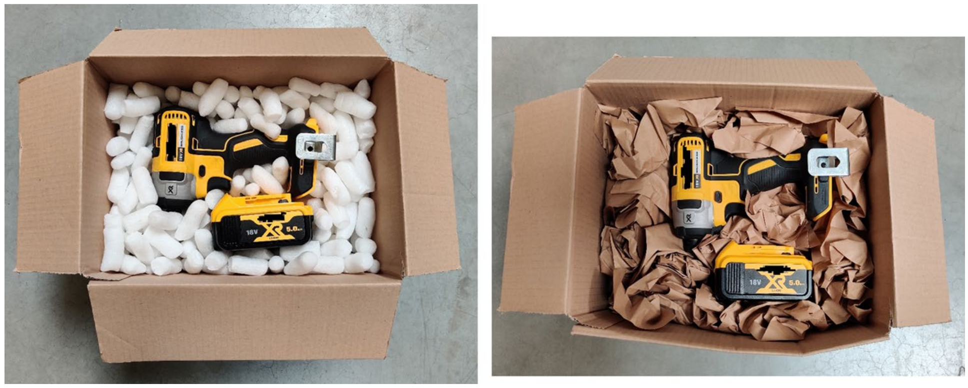


Fig. 1 Examples of void filling in e-commerce packaging

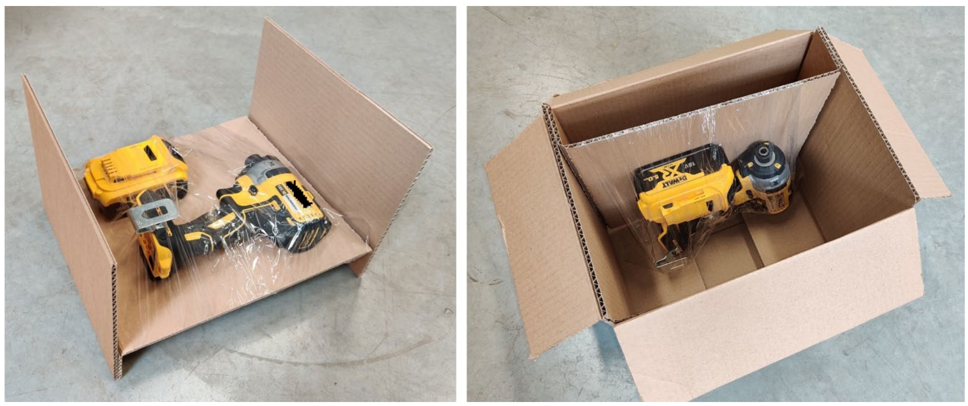


Fig. 2 Example of suspension packaging

2 Short description of suspension packaging

The basis of suspension packaging is a panel of cardboard. Given the desire to keep costs down, most often corrugated cardboard is used. Single or double fluted corrugated board types and all possible flute sizes can be considered. The panel is basically rectangular with the longest side in the machine direction of the corrugated cardboard, i.e., with the flutes parallel to the shortest side of the panel. The width of the panel is about 10 cm wider than the goods being packed. The goods are stacked on the panel with an uncovered area of about 5 cm wide on the left and right, and also an uncovered area in front and behind the goods. The length of these uncovered zones is about 20 cm more than the height of the goods. This allows the uncovered zones of the panel, 5 cm away from the goods, to be folded in a V-shape: 5 cm downwards and the rest of the panel upwards. The ascending parts of the V are then in total 10 cm higher than the goods and ensure that there is an air gap of 5 cm above and below the goods when the folded panel with the goods is pushed into a box. The inner dimensions of this box must match the outer dimensions of the pleated panel so that the panel cannot move inside the box. In some cases, illustrated by Fig. 3, the stiffness of a single corrugated cardboard panel is insufficient: the panel bends in the middle and ends up on the bottom of the box, so that shocks are transferred to the goods. This can be prevented by adding an extra strip of corrugated cardboard between the goods and the base panel, preferably with the flute direction perpendicular to the flute direction of the base panel. In extreme cases, extra folds can be provided in the base panel or a honeycomb panel can be used instead of a corrugated panel.

Fig. 3 Insufficient panel stiffness

The biggest challenge is to keep the goods in place on the panel during manipulation and transport of the box.

Classically, the goods are wrapped on the base panel with stretch film, typically 12.5 cm wide but wider or narrower film can be used as well. During winding, the base panel is supported over a large part of its length by a plate, roller conveyor or another system. The support is interrupted at the point where the film is wrapped to allow the film to be applied to the underside against the base panel (see Fig. 4). After one or a few cylindrical windings, there is a change to screw-type windings and finally to one or a few cylindrical windings. The number of windings required to keep the goods in place depends on the friction between the goods and the base panel on the one hand and the tensile force in the film on the other. In almost all cases, 1 cylindrical winding at the beginning and end of the windings and a screw winding with a pitch of 80% of the film width are sufficient. At least one side of stretch film has a cling layer. By pre-stretching the film during winding, the resulting tensile force in the film combined with the adhesive layer is sufficient to hold the film in place in relation to the corrugated board and the goods. It is not necessary to glue or fix the film in any other way. The elongation rate of the film during winding is also not very critical. Often a type of film is chosen with a pronounced flat-shaped tensile curve: the tensile force remains almost constant between two limits of elongation, e.g., between 50 and 300% elongation. If the strain in the film deviates (locally) from the intended value, e.g., at the transition from cylindrical to screw-shaped winding, at protrusions on the goods, at goods that deform during winding, …. this has little influence on the tensile force in the film. All in all, very fast effective winding (typically 3t/s) can be achieved so that the goods remain in place on the base panel.

As demonstrated in [16], well-designed suspension packaging provides as good protection as well-made polystyrene void-fill packaging. The packaging material of suspension packaging is only stretch film and cardboard. In principle, therefore, it is fully recyclable but requires the cardboard and the wrapping film to be separated. In practice, this does not always happen.

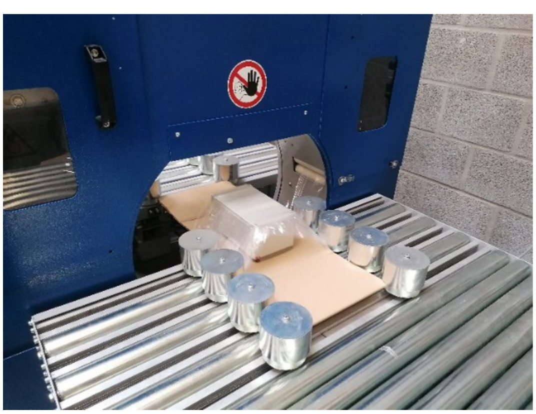


Fig. 4 Stretch wrapping machine

This study investigates whether it would be possible to develop a variant of suspension packaging that uses paper instead of stretch wrap film. Advantages and bottlenecks for wrapping with paper are identified. Possible paper types to avoid or reduce these bottlenecks are identified based on their mechanical properties.

3 Wrapping paper versus stretch wrap film

When wrapping paper around the goods on the base panel made of cardboard, the following additional difficulties or bottlenecks arise:

- paper does not have a cling layer so that the beginning and end of the strip of wrapped paper must be held in place by, for example, gluing, staples, adhesive tape, etc. For practical reasons, the beginning and end of the strip of paper are preferably attached to the bottom of the base panel.
- Like most materials, paper is somewhat stretchable [17–22] but much less than stretch film. A wrapping with paper must be designed and applied in such a way that the maximum strain at which the paper tears is not reached anywhere, neither during wrapping nor during manipulations or transport.
- the elastic elongation of paper is only a small fraction of the total elongation [23–25] of paper, so there is a risk that the tensile force in the winding will be lost under shock loading and the goods will shift on the base panel.
- Paper is sensitive to moisture, which means that its tensile strength and elasticity may decrease in a humid environment, unless the paper is water-repellent coated. In view of the ecological reason for this research, only paper types coated with organic material are considered [26–39].

Apart from the ecological advantages, paper as a wrapping material also has some major technical advantages over stretch film:

- if the tensile force varies over a winding, the paper tends to shift slightly under the influence of vibration [40, 41], so that the tensile force becomes constant between the starting point and the end point of the strip of paper attached to the base panel. In concrete terms, this means that the average tensile force rather than the instantaneous tensile force needs to be regulated during winding to the extent that the instantaneous tensile force is sufficient to keep the paper in place.

- the stiffness of paper is significantly higher than that of stretch film: for the same weight per surface area, the force required for an equally small extension is a factor of 5 to 10 higher (confirmed by the results of this research presented under paragraph 4.4, more specifically the stretch film (SF) curve in figures 6 and 7 below) with paper than with plastic stretch film or, to put it another way: the strip required for the same tensile force is much narrower with paper than with plastic stretch film.

These advantages must be placed in the context of the wrapping process itself:

1. A narrower strip of wrapping material means that the interruption in the support of the base panel can be shorter. This makes the winding process less susceptible to failure.
2. The narrower the strip of winding material, the easier it is to change direction during winding, e.g., the transition from cylindrical to helical winding and vice versa.
3. If the strap of the winding material pulls the base panel upwards during winding, the tension in the winding material must be limited in order to prevent the base panel from tipping over with the goods. The tensile force in the areas that have been wound with a limited tensile force increases during further manipulations in the case of winding with paper because the tensile force is evenly distributed.

These conceptual considerations lead to the conclusion that paper could be an appropriate winding material, provided the selection of a paper type.

1. With significant stretchability in the longitudinal direction (machine direction).
2. Of which at least part of the stretchability is elastic. This offers the least chance of the goods coming loose from the base panel as a result of impact forces or vibrations.
3. With a high tensile stress. This may be advantageous because fewer windings or windings with narrower strips may suffice.
4. Withstanding tensile forces in combination with smaller transverse forces since this is inevitably the case with directional changes during winding or when winding on erratic shapes.
5. which is sustainably coated or can be coated in a sustainable way so that its mechanical properties are preserved during transport in humid conditions.

The present study, therefore, focuses on the search for papers combining these five mechanical properties [42–47]. Several types of commercially available paper have been collected and tested for this purpose.

4 Mechanical properties of paper

4.1 General

All types of paper have been conditioned in the same way as far as possible from the moment of arrival at the test laboratory. All test specimens were cut with the same type of knife and stored for at least 1 week in the same room at 20–21 °C and a humidity of 50–55%. For all tensile tests described below, specimen of 15 mm by 220 mm was used. The distance between the clamps of the tensile test machine at the moment of clamping is 180 mm. All clamps are mechanical clamps, and the claws themselves are coated with PU. All other parameters are also chosen in accordance with ISO1924-2:2008. All test specimens are taken in the length direction of the paper (machine direction), i.e., the distance of 220 mm is parallel to the direction of production of the paper. The grammages mentioned below are the averages of the measured values of the test specimen.

4.2 Short description of the paper types

10 paper types have been provided by suppliers worldwide. Two paper types (C and D) have been supplied with 5 types of organic coating to increases damp resistance of the paper. The coatings are almost invisible and do not influence the recyclability of the paper. The suppliers did not want to share details on these coatings. An overview of the paper types and the data provided by the suppliers can be found in Table 1. A picture of the texture of each paper type can be found in appendix 1, Figs. 14,15,16,17,18,19,20,21,22,23.

4.3 Short description of tests performed

Tensile tests: conventional tensile test according to ISO 1924-2:2008 [48], 10 identical test specimens per paper type. The force–elongation curves are measured up to breakage of the test specimen.

Elastic contraction test after loading to 30 N: the conventional tensile test is stopped at a force of 30 N, after which the reverse movement is started while measuring the force as a function of the elongation of the test specimen.

Table 1 Overview of paper types

Paper code	Area density	Origin	Fiber type	Treatment	Intended use
	g/m^2				
A	100	Europe	Kraft	Bleached + organic coating	Bags
B	99	Europe	Kraft	Organic coating	Trays
C1	117	Europe	Recycled	Organic coating	Bags
C2	107	Europe	Recycled	Organic coating	Bags
C3	116	Europe	Recycled	Organic coating	Bags
C4	114	Europe	Recycled	Organic coating	Bags
C5	99	Europe	Recycled	Organic coating	Bags
D1	202	Europe	Recycled	Organic coating	Trays
D2	218	Europe	Recycled	Organic coating	Trays
D3	195	Europe	Recycled	Organic coating	Trays
D4	221	Europe	Recycled	Organic coating	Trays
D5	201	Europe	Recycled	Organic coating	Trays
E	35	Canada	Recycled	None	Towels
F	94	Europe	Recycled	Crepe	Decoration
G	79	USA	Recycled	None	Packaging
H	90	USA	Recycled	Plastic coating	Packaging
I	58	Europe	Kraft	None	Packaging
P	52	2,63	Kraft	Bleached	Printing

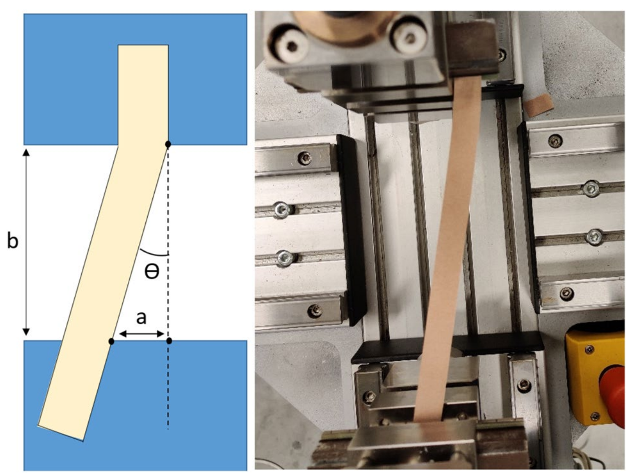


Fig. 5 Top view of test specimen clamped under angle Θ

Elastic contraction test after loading up to 50% of the average tensile strength.

Tear tests: As far as is known, there are no standardized tests available to check to what extent the screw angle can be changed during winding. Therefore, a variant of the conventional tensile test is used: the distance between the clamps is set at 180 mm. The test specimen is clamped in one clamp parallel to the pulling direction and in the other clamp at an angle Θ, where $\tan\theta = a/b$ (Fig. 5). The test specimen is pre-stressed with negligible preload during clamping.

4.4 Results of the material tests

The measured force–elongation curves for all test specimen are added in appendix 2, Figs. 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41. In Fig. 6, the values of the force at given elongation are averaged out for the 10 test specimen per paper type. This shows a very clear effect of the post-treatment and coating of paper types C and D, which also means, among other things, that the forces are not proportional to the grammages per m^2. Figure 7, therefore, shows standardized curves (force per grammage and per width as a function of elongation). For information purposes, Figs. 6 and 7 also include a curve for a typical plastic stretch film (SF) with a grammage of 100 g/m^2. A summary of the most important values with associated standard deviation can be found in Table 2.

In the context of the desired properties for paper winding, it was decided after these tensile tests to focus on paper types A, B, C and D for the elastic contraction tests and the tear tests. Paper I is not retained, although it is about as strong as paper A and B, but the elongation at break is much lower. Paper F is also not retained after comparison with papers C and D because F consists of new fibers, and the strength at lower values of elongation is much lower than for paper D and even paper C.

Table 3 summarizes the averaged results of the tests on the elastic contraction after a force of 30 N. The total elongation at 30 N is shown in column "total elongation", and the remaining elongation after returning to a force of 0 N is shown in column "permanent elongation". The other

Fig. 6 Averaged results of tensile tests

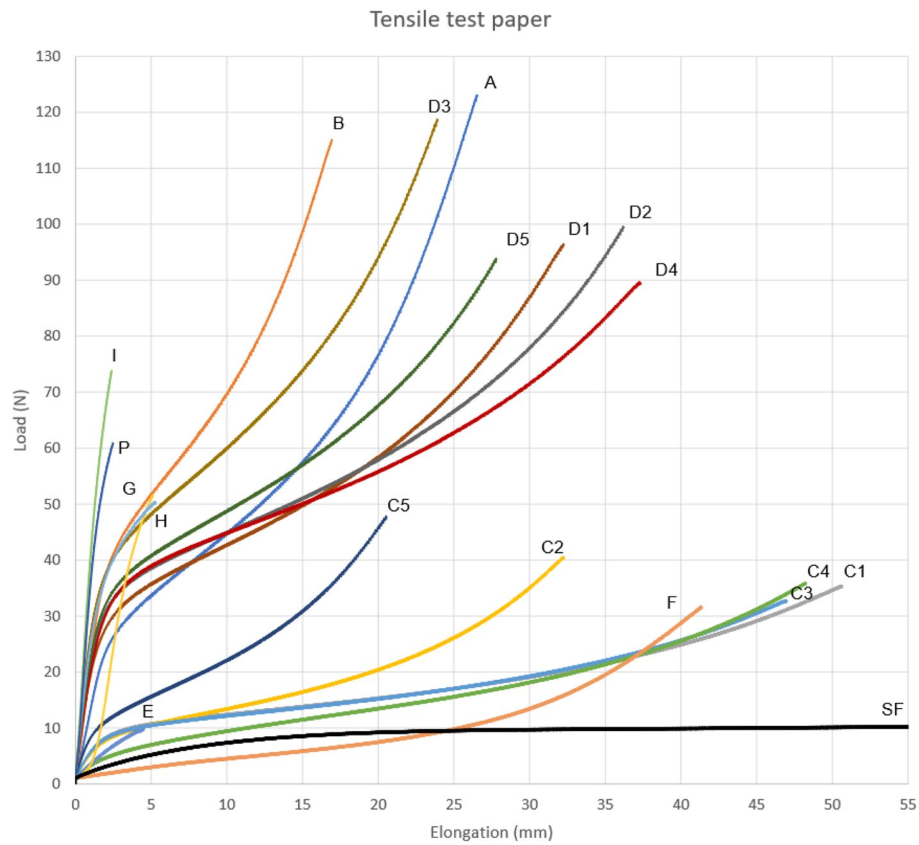


Fig. 7 Normalized averaged results of tensile tests

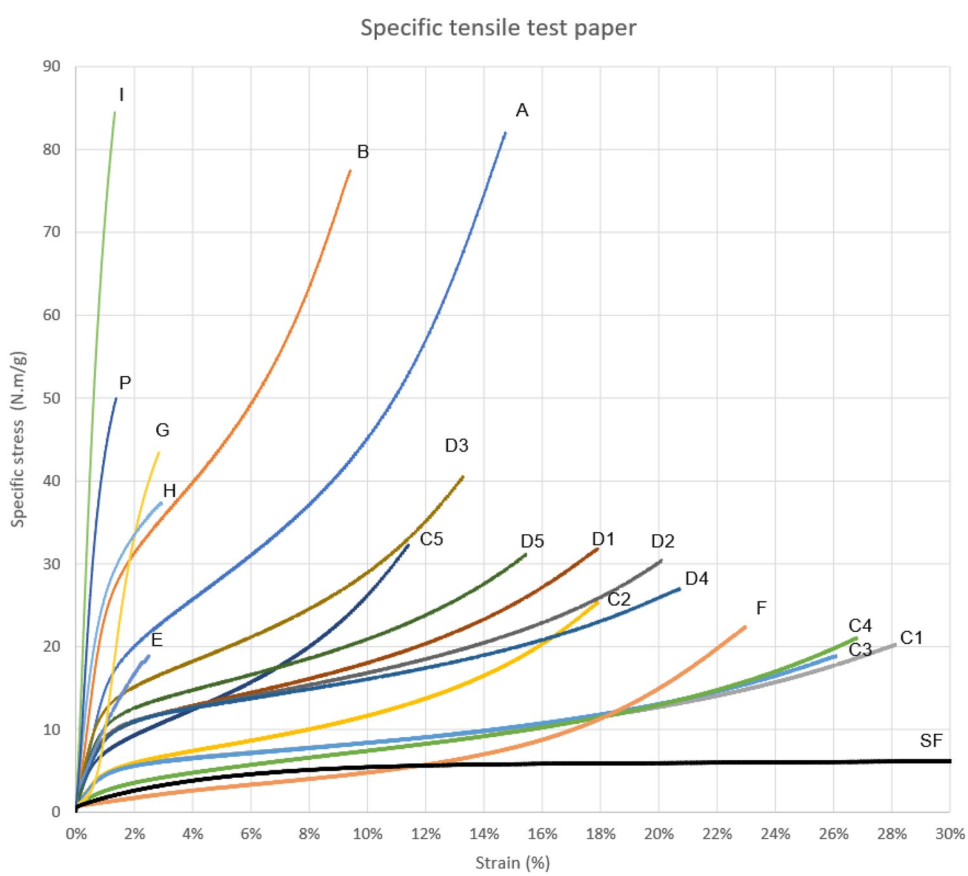


Table 2 Summary of results of tensile tests

Paper type	Area density	Elongation		Breaking load		Specific breaking stress		Breaking strain
		Average	Std. deviation	Average	Std. deviation	Average	Std. deviation	Average
	g/m^2	Mm	Mm	N	N	Nm/g	Nm/g	%
A	100	26,32	0,57	122,66	4,89	81,77	3,26	14,6
B	99	16,71	0,82	113,07	7,97	76,14	5,37	9,3
C1	117	50,32	1,43	35,44	2,05	20,27	1,17	28,0
C2	107	32,77	0,91	39,62	2,76	24,78	1,73	18,2
C3	116	47,29	1,84	32,01	1,84	18,44	1,06	26,3
C4	114	48,80	2,39	35,51	3,04	20,83	1,78	27,1
C5	99	20,35	0,87	47,72	3,90	32,27	2,64	11,3
D1	202	31,83	2,28	95,51	10,15	31,53	3,35	17,7
D2	218	36,28	1,22	100,16	6,46	30,64	1,98	20,2
D3	195	23,88	0,77	117,58	6,46	40,13	2,21	13,3
D4	221	37,31	1,40	90,99	4,29	27,39	1,29	20,7
D5	201	27,87	1,25	95,69	6,64	31,78	2,20	15,5
E	35	4,64	0,26	9,86	0,62	19,05	1,20	2,6
F	94	41,32	2,93	31,97	3,85	22,63	2,73	23,0
G	79	5,15	0,64	50,25	4,91	42,24	4,13	2,9
H	90	5,42	1,13	50,96	3,85	37,82	2,86	3,0
I	58	2,34	0,17	72,62	5,07	83,16	5,81	1,3
P	52	2,63	0,17	61,65	3,30	50,63	2,71	1,5

Table 3 Averaged results of elastic contraction tests following a force of 30 N

Paper type	Elongation			Strain = elongation/sample length			Type of strain distribution	
	Total elongation (mm)	Permanent elongation (mm)	Elastic elongation (mm)	Total strain (%)	Permanent strain (%)	Elastic strain (%)	Perman (% of total strain)	Elastic (% of total strain)
A	3,60	2,18	1,43	2,00	1,21	0,79	60,42	39,58
B	1,68	0,69	0,99	0,93	0,38	0,55	40,90	59,10
C1	46,16	42,63	3,53	25,64	23,68	1,96	92,35	7,65
C2	28,48	25,57	2,91	15,82	14,21	1,62	89,78	10,22
C3	45,89	42,23	3,66	25,49	23,46	2,03	92,02	7,98
C4	43,99	40,53	3,46	24,44	22,52	1,92	92,13	7,87
C5	15,08	12,70	2,38	8,38	7,06	1,32	84,22	15,78
D1	5,66	4,27	1,39	3,15	2,37	0,77	75,40	24,60
D2	5,47	3,99	1,48	3,04	2,22	0,82	72,94	27,06
D3	2,42	1,37	1,05	1,34	0,76	0,58	56,69	43,31
D4	5,65	4,03	1,62	3,14	2,24	0,90	71,34	28,66
D5	3,72	2,45	1,27	2,07	1,36	0,71	65,86	34,14

columns are calculated values. Figure 8 illustrates the split into permanent and elastic elongation.

Based on these results, the preferred paper grade could be C which shows the highest elastic elongation. Figure 7, however, shows that a tension force of 30 N comes close to the tensile strength of paper C with the risk of the paper tearing at the time of impact loading or even during winding. Therefore, an alternative split between permanent and elastic elongation at a tension force of 50% of the tensile strength has been made, as shown in Table 4.

A graphical representation of these data can be found in Fig. 9.

The elastic elongation available to absorb vibrations and impact forces is now comparable for paper grades C

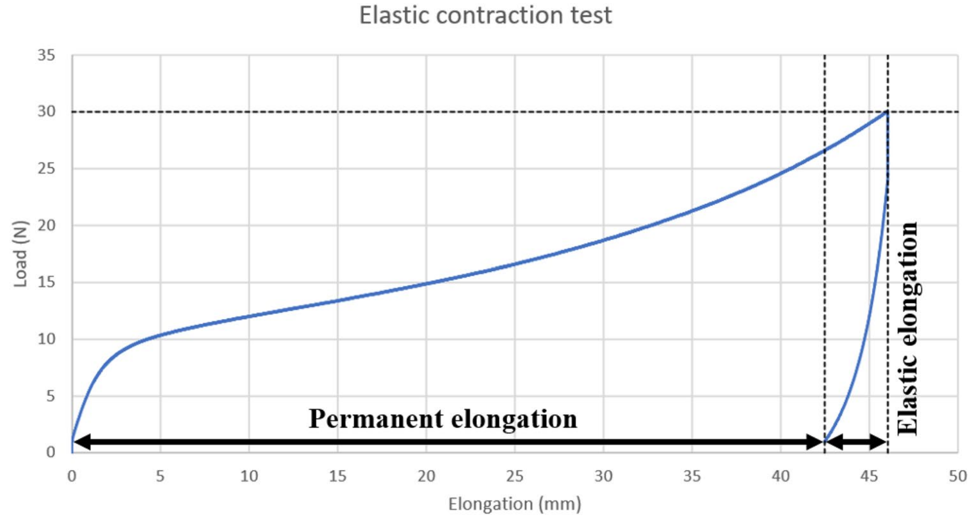


Fig. 8 Permanent and elastic elongation

Table 4 Averaged results of elastic contraction tests following a force of 50% of ultimate force

Paper type	Elongation			Strain = elongation/sample length			Type of strain distribution	
	Total elongation (mm)	Permanent elongation (mm)	Elastic elongation (mm)	Total strain (%)	Permanent strain (%)	Elastic strain (%)	Perman (% of total strain)	Elastic (% of total strain)
A	14,14	11,88	2,25	7,85	6,60	1,25	84,07	15,93
B	6,91	4,99	1,92	3,84	2,77	1,07	72,19	27,81
C1	26,05	22,39	3,66	14,47	12,44	2,03	85,96	14,04
C2	20,48	17,29	3,19	11,38	9,61	1,77	84,42	15,58
C3	22,99	19,44	3,55	12,77	10,80	1,97	84,56	15,44
C4	27,79	23,91	3,88	15,44	13,28	2,15	86,05	13,95
C5	7,09	4,74	2,35	3,94	2,63	1,31	66,84	33,16
D1	8,91	5,79	3,12	4,95	3,22	1,73	65,00	35,00
D2	15,46	11,88	3,58	8,59	6,60	1,99	76,85	23,15
D3	9,67	7,03	2,64	5,37	3,91	1,47	72,72	27,28
D4	13,69	10,19	3,49	7,60	5,66	1,94	74,47	25,53
D5	9,57	6,71	2,86	5,32	3,73	1,59	70,12	29,88

and D and slightly greater than for paper grades A and B. The additional permanent elongation is greater for paper grades C. The post-treatments and coatings have a clear added value, as can be seen from the comparison between C1-C4 on the one hand and C5 on the other.

The results of the tear tests are summarized in Table 5. At this stage of the investigation, the tear tests are limited to paper grades A, B and C1. Grades A and B are selected because of their high tensile strength, C1 is the paper type with the highest elastic stretchability.

The tear test curves averaged over the 10 test specimen can found in Figs. 10, 11, 12.

The decrease in strength as a function of the misalignment angle θ is graphically represented in Fig. 13.

Figure 13 shows that the strength of papers A and B is more subject to "misalignment" than the strength of paper C1, which could perhaps be expected based on the greater stretchability of paper C.

5 5. Observations, conclusions, further research

5.1 Observations

The 5 requirements set at the start of the investigation for paper to qualify as a wrapping material for suspension packaging are evaluated:

Fig. 9 Elongation for each paper at 50% of their breaking load

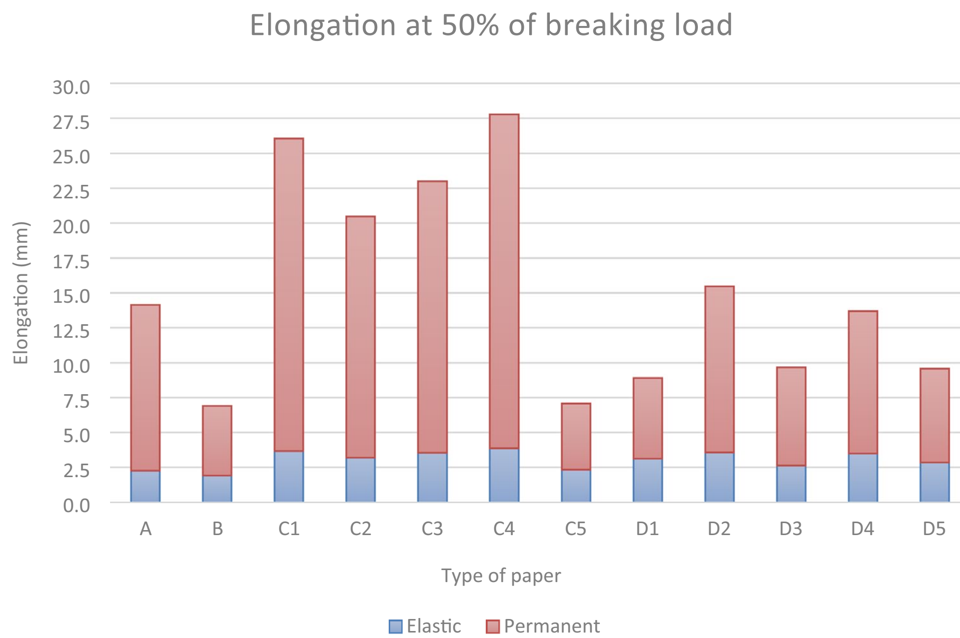


Table 5 Averaged results of tear tests

Paper	Misalignment distance a	Misalignment angle θ	Max force (N)		Difference with zero misalignment		Max elongation (mm)	
	Mm	degrees	Avg	St.dev	±	%	mm	St.dev.
A	0	0,00	122,68	4,89	−0	−0%	26,34	0,57
	15	4,76	123,85	7,94	+1,2	+1%	24,51	0,83
	25	7,91	111,86	6,66	−10,8	−9%	23,88	1,02
	35	11,00	87,29	6,81	−35,4	−29%	20,78	1,49
	45	14,04	78,95	7,42	−43,7	−36%	19,76	1,97
	55	16,99	65,04	4,30	−57,6	−47%	17,28	1,45
B	0	0,00	113,07	7,97	−0	−0%	16,71	0,82
	15	4,76	108,50	8,02	−4,6	−4%	15,70	1,12
	25	7,91	94,98	3,87	−18,1	−16%	14,91	0,68
	35	11,00	76,64	4,12	−36,4	−32%	11,98	0,76
	45	14,04	65,41	4,65	−47,7	−42%	9,70	1,10
	55	16,99	44,44	13,74	−68,6	−61%	6,91	2,03
C1	0	0,00	35,44	2,05	−0	−0%	50,32	1,43
	15	4,76	30,53	2,49	−4,9	−13%	47,53	1,78
	25	7,91	31,01	3,33	−4,4	−12%	49,08	3,13
	35	11,00	28,62	1,82	−6,8	−18%	47,90	1,89
	45	14,04	24,99	1,70	−10,4	−27%	44,57	2,21
	55	16,99	22,60	2,65	−12,8	−33%	44,61	2,65

1. Ssignificant elongation in the longitudinal direction (machine direction): the elongation at break is 9% or more for paper types A, B, C and D.
2. Part of the elongation is elastic: the elastic elongation after loading up to 50% of the tensile strength is 1 to 2% for paper types A, B, C and D.
3. A higher breaking strain may be advantageous: grades A, B and I score best on this criterion
4. Resists tensile forces in combination with smaller transverse forces: in absolute values A and B score best, but C1 scores best in proportion to its tensile strength
5. Is coated or can be coated so that its mechanical properties are preserved during transport in damp conditions: according to the suppliers, A, B and C1 meet this criterion.

Fig. 10 Tear test curves of paper A per misalignment

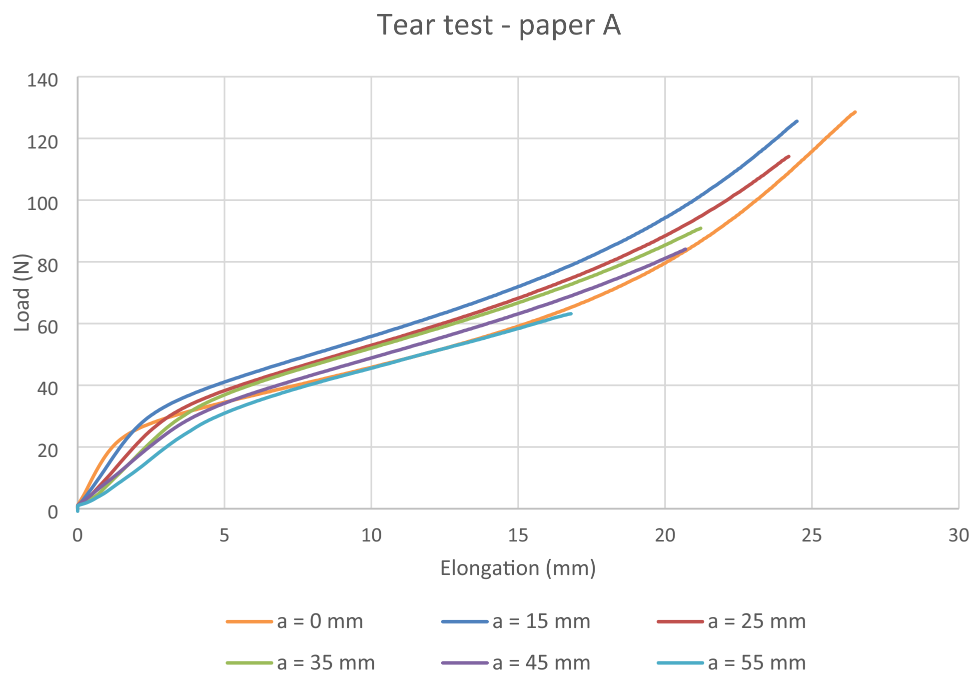
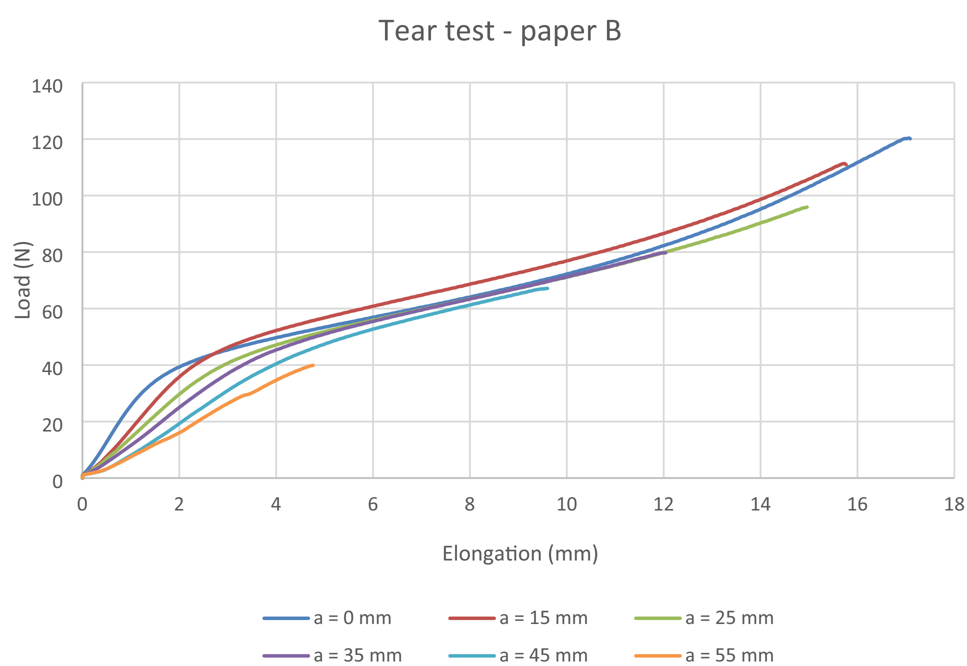


Fig. 11 Tear test curves of paper B per misalignment



5.2 Conclusion

Based on the material tests carried out, it is not possible to conclude with certainty that plastic stretch film can be replaced by commercial paper as winding material for suspension packaging. The tensile curves of plastic stretch film types and so-called stretchable paper types can hardly be compared:

- The total stretch ability of paper is far below the stretch ability of plastic stretch film
- The paper tensile curves do not show a flat zone that would allow easy wrapping
- The elastic part of the elongation of paper is very low and may be critical

Since this elastic elongation at 50% of the tensile strength is the highest for paper type C (with small differences between

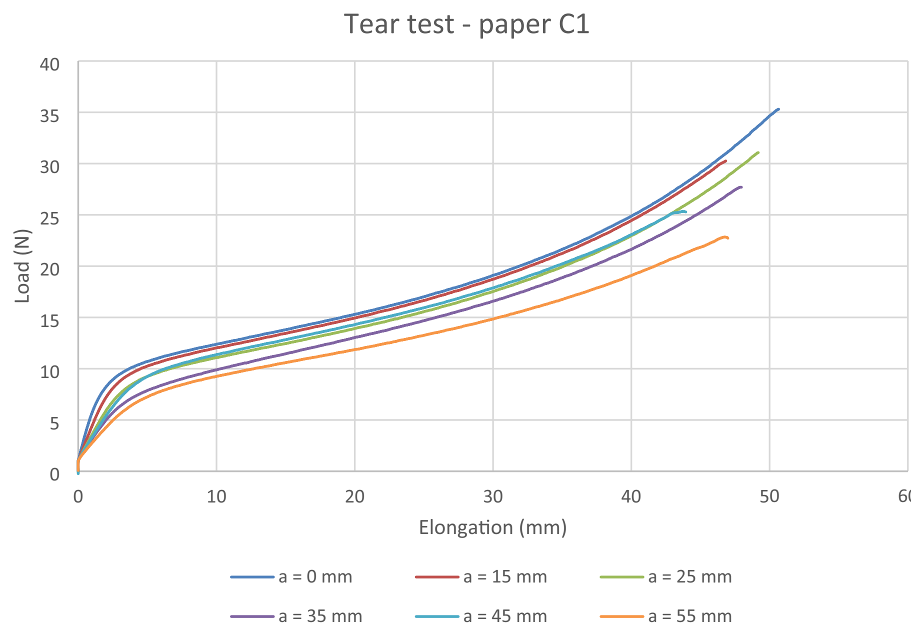


Fig. 12 Tear test curves of paper C1 per misalignment

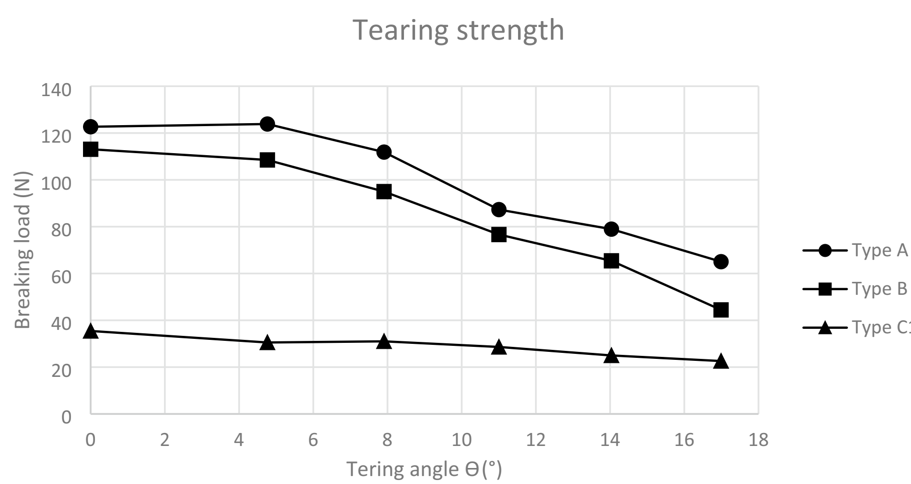


Fig. 13 Breaking load as a function of tearing angle θ

C1, C3 and C4), the conclusion of this research is that paper C may be indicated as a test material in further research.

5.3 Further research

The final conclusion regarding the use of paper as a wrapping material in suspension packaging will have to be based on drop tests of parcels with suspension packaging. In order to be able to perform relevant drop tests, a wrapping machine that is able to control the tension in the strip of paper being wrapped must be developed. The tensile curves and the tear test curves described above can serve as a starting point to choose the setpoints for the tension in the wrapping paper. Further research is needed as well to find an appropriate connection method for both ends of the paper strips on the base plate and to choose an appropriate coating for the wrapping paper.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Human or animal rights This research does not contain any studies with human participants or animals performed by any of the authors.

Informed concent Informed consent was obtained from all individual participants included in the study.

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Appendix 1

See Figs. 14,15,16,17,18,19,20,21,22,23.

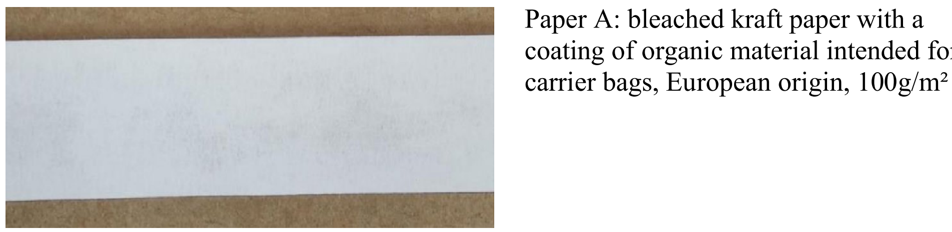

Fig. 14 15 mm wide sample of paper A

Fig. 15 15 mm wide sample of paper B

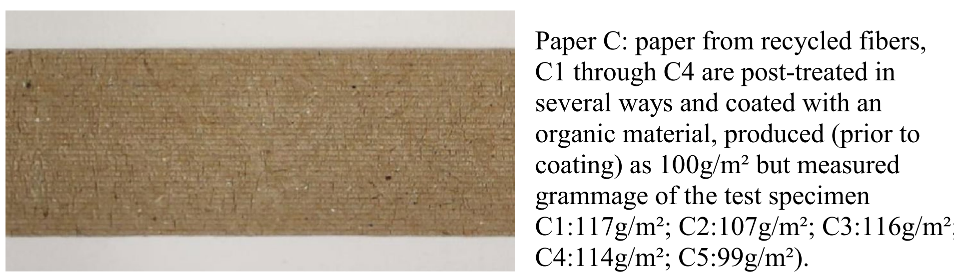

Fig. 16 15 mm wide sample of paper C

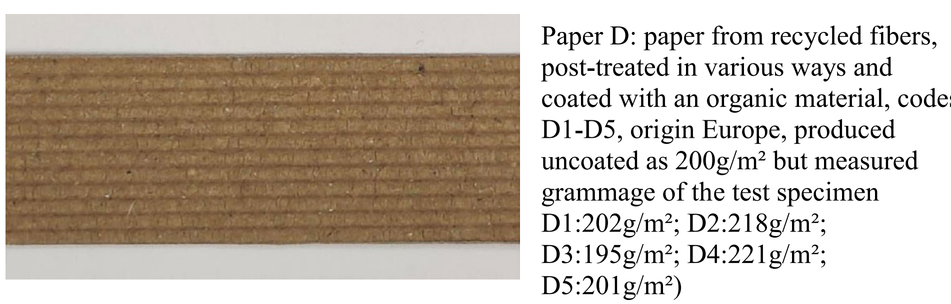

Fig. 17 15 mm wide sample of paper D

Fig. 18 15 mm wide sample of paper E

Fig. 19 15 mm wide sample of paper F

Fig. 20 15 mm wide sample of paper G

Fig. 21 15 mm wide sample of paper H

Fig. 22 15 mm wide sample of paper I

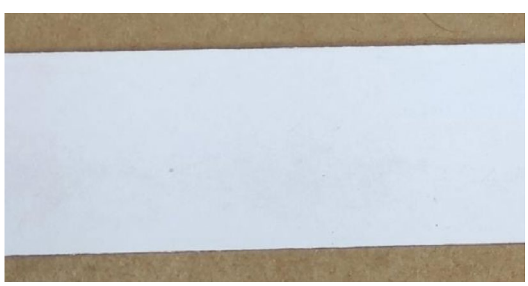

Fig. 23 15 mm wide sample of paper P

Appendix 2

See Figs. 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41.

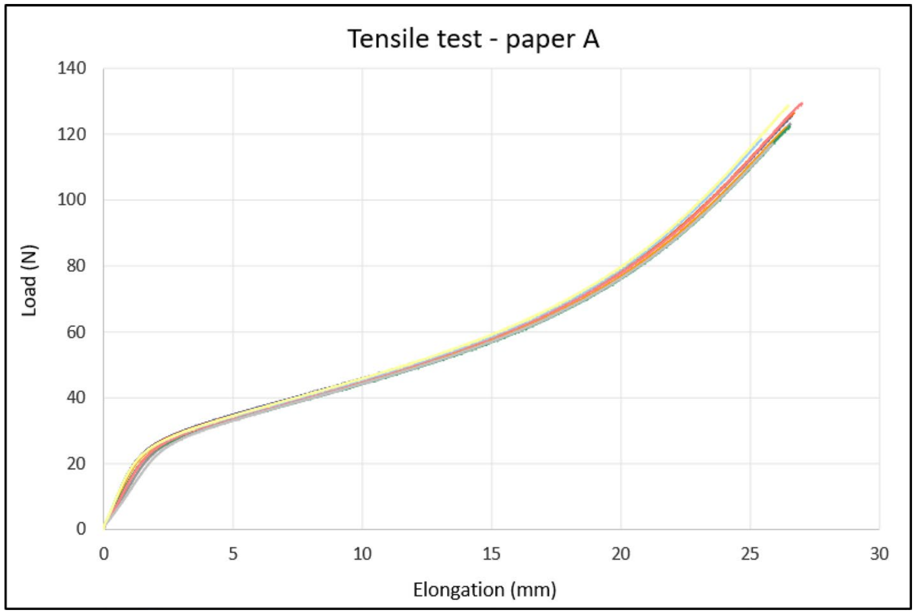

Fig. 24 Force elongation curves of individual specimen of paper A

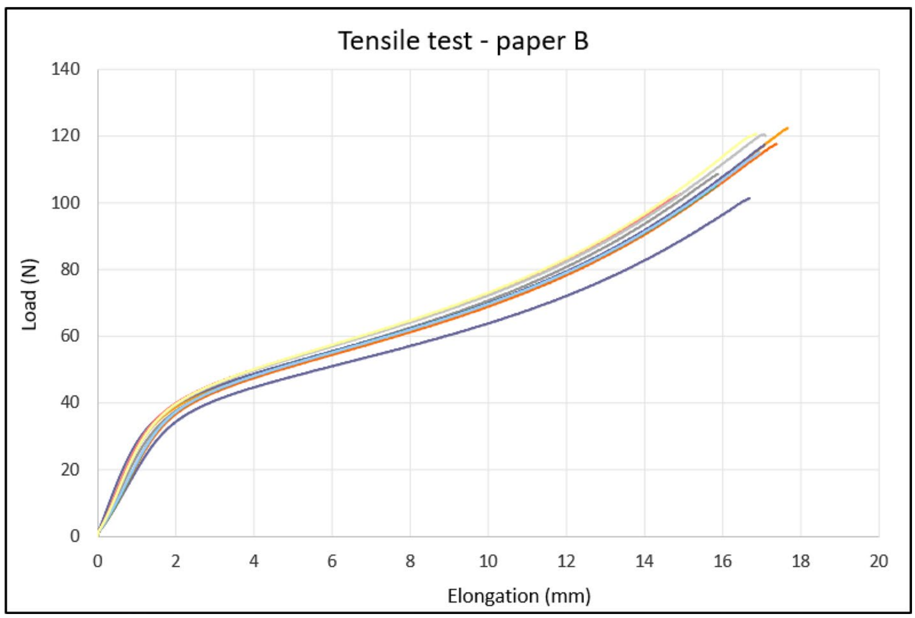

Fig. 25 Force elongation curves of individual specimen of paper B

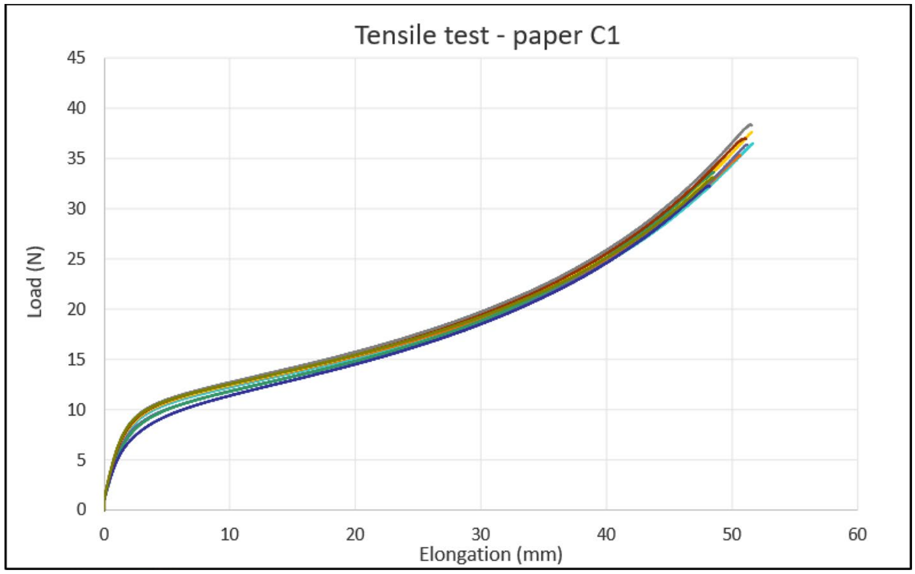

Fig. 26 Force elongation curves of individual specimen of paper C1

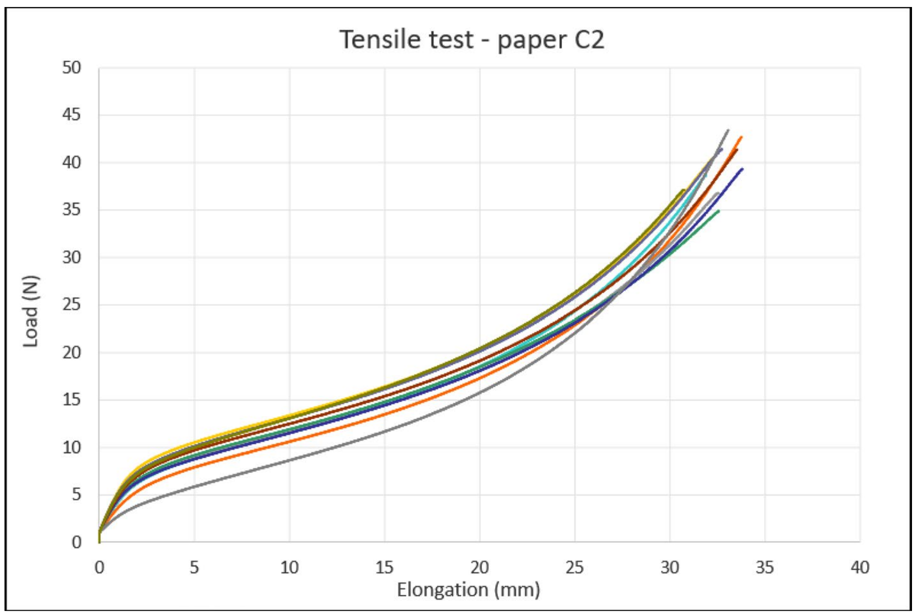

Fig. 27 Force elongation curves of individual specimen of paper C2

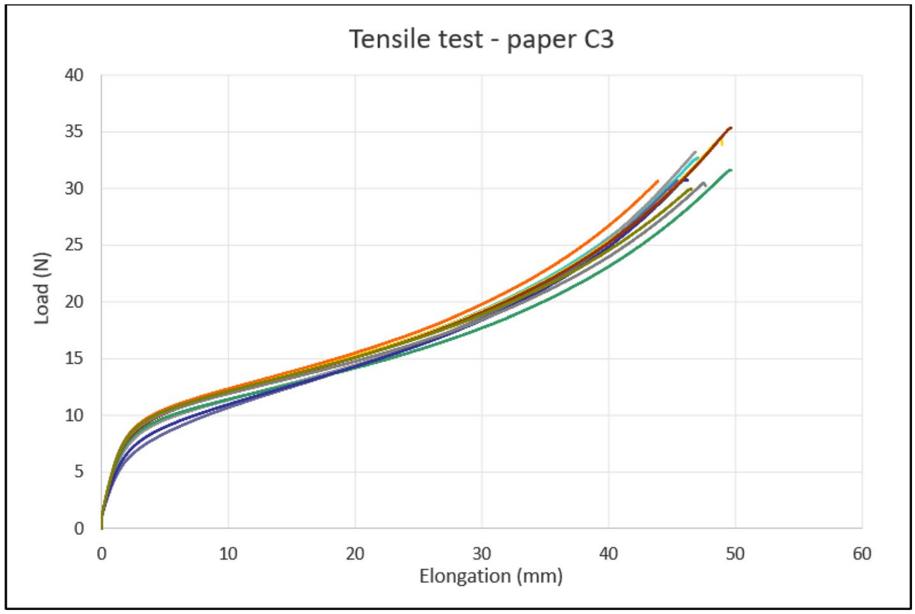

Fig. 28 Force elongation curves of individual specimen of paper C3

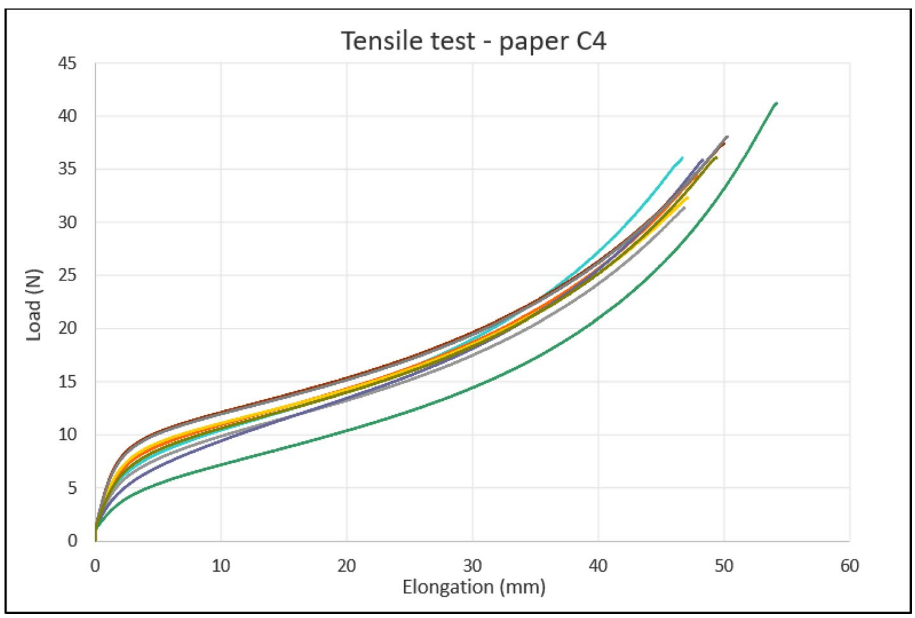

Fig. 29 Force elongation curves of individual specimen of paper C4

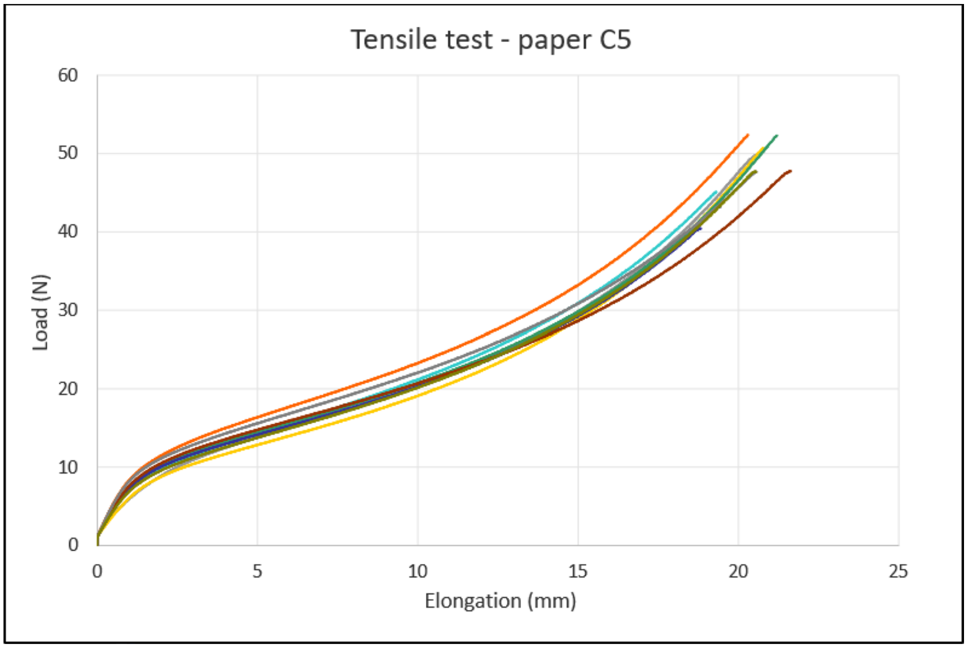

Fig. 30 Force elongation curves of individual specimen of paper C5

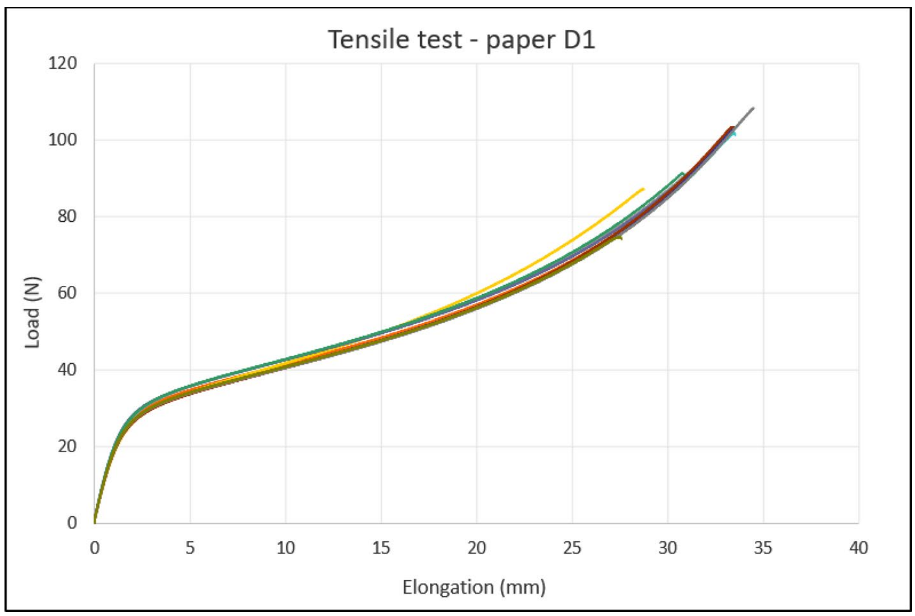

Fig. 31 Force elongation curves of individual specimen of paper D1

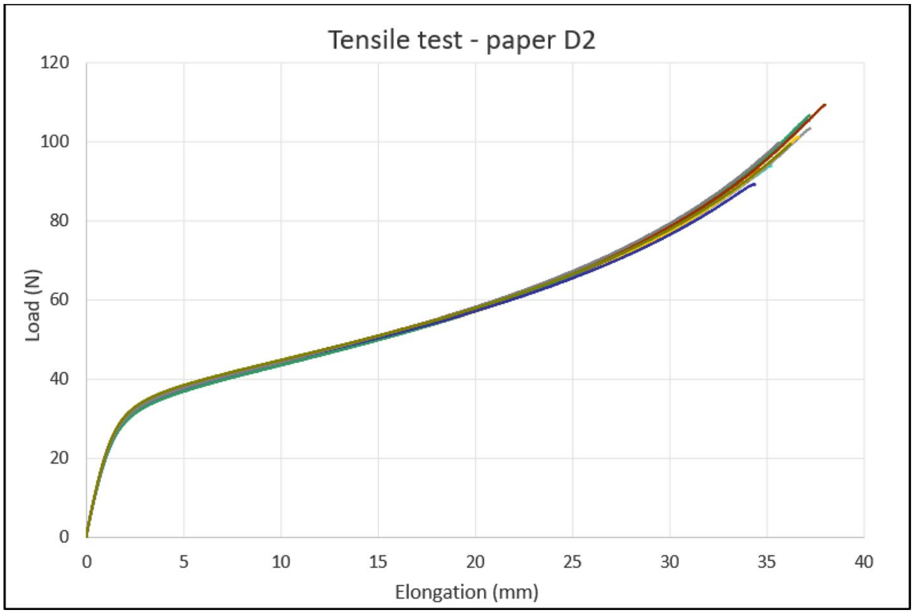

Fig. 32 Force elongation curves of individual specimen of paper D2

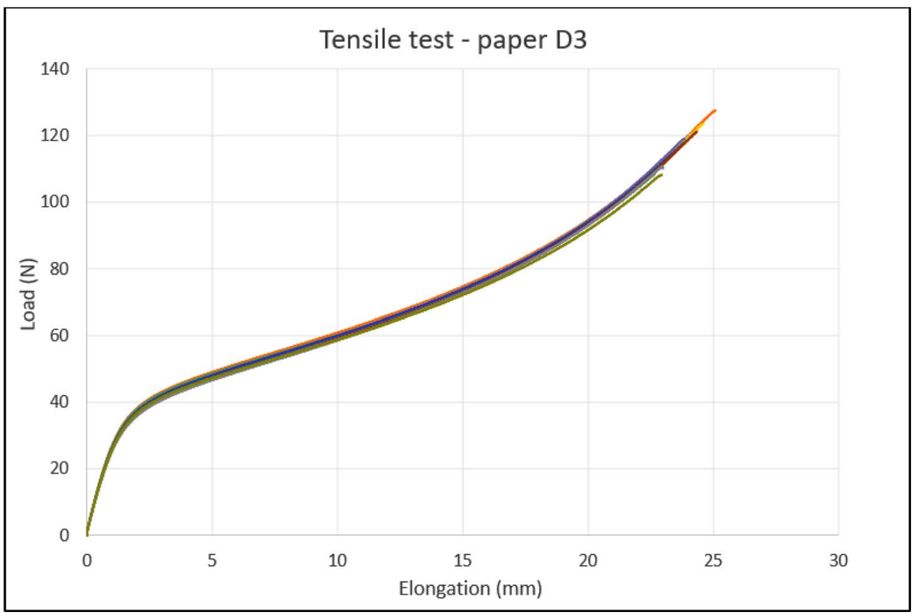

Fig. 33 Force elongation curves of individual specimen of paper D3

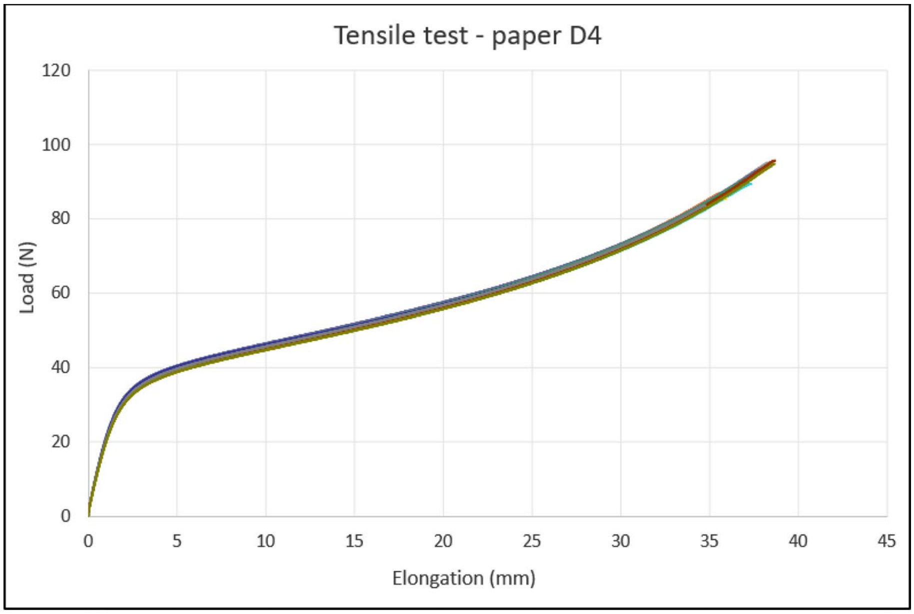

Fig. 34 Force elongation curves of individual specimen of paper D4

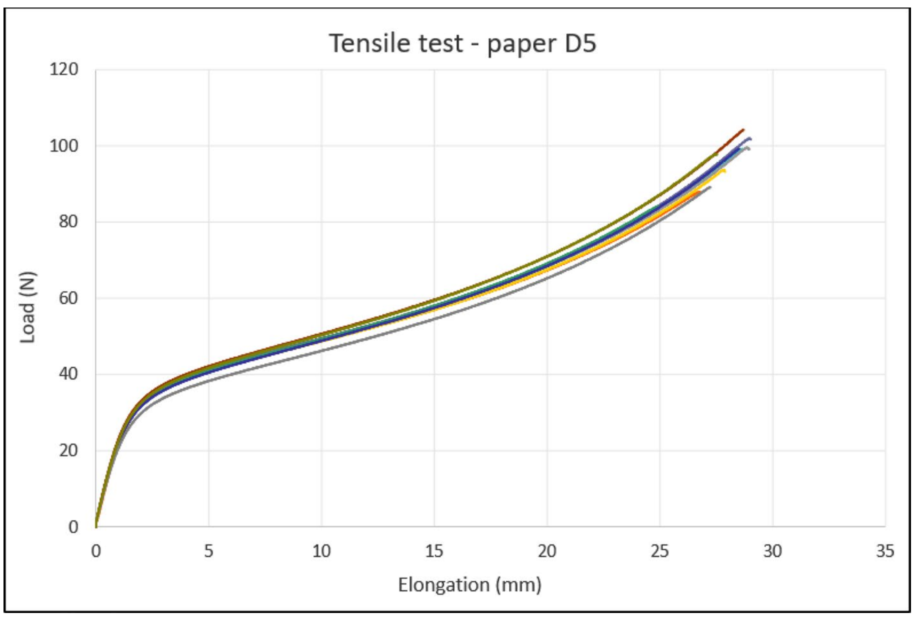

Fig. 35 Force elongation curves of individual specimen of paper D5

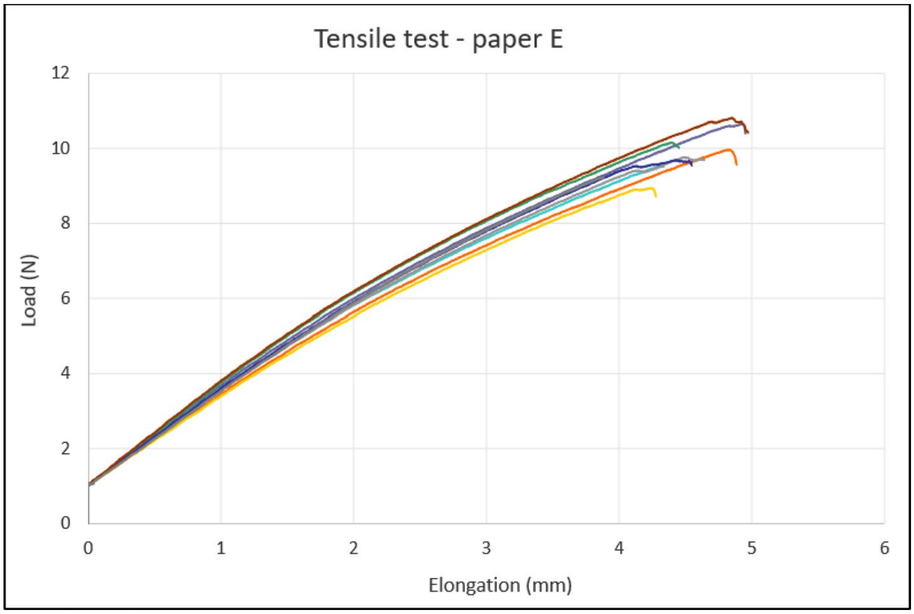

Fig. 36 Force elongation curves of individual specimen of paper E

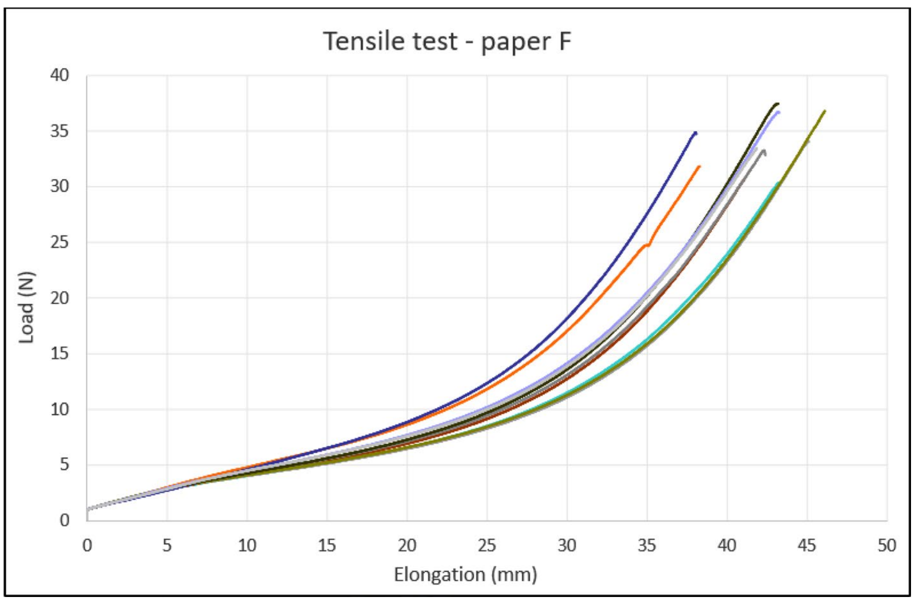

Fig. 37 Force elongation curves of individual specimen of paper F

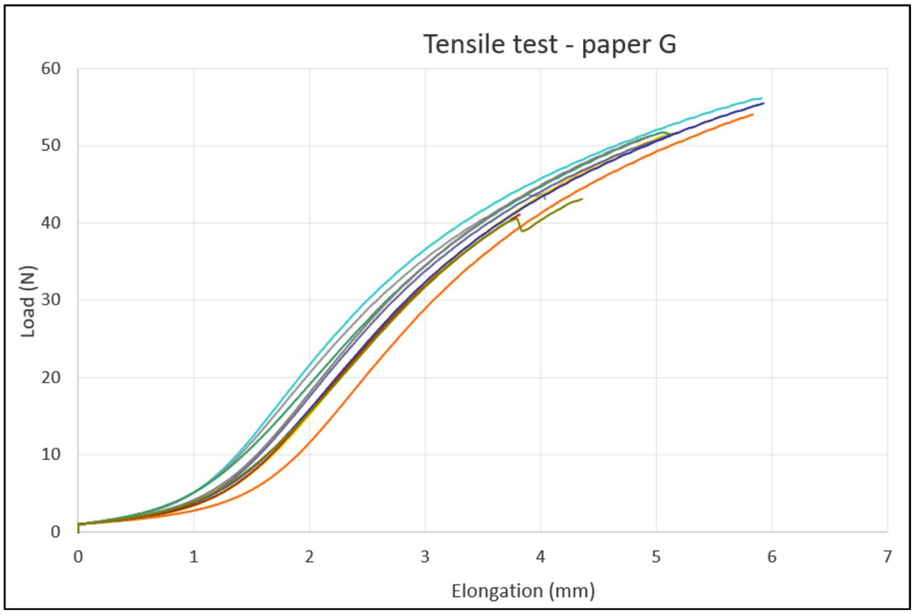

Fig. 38 Force elongation curves of individual specimen of paper G

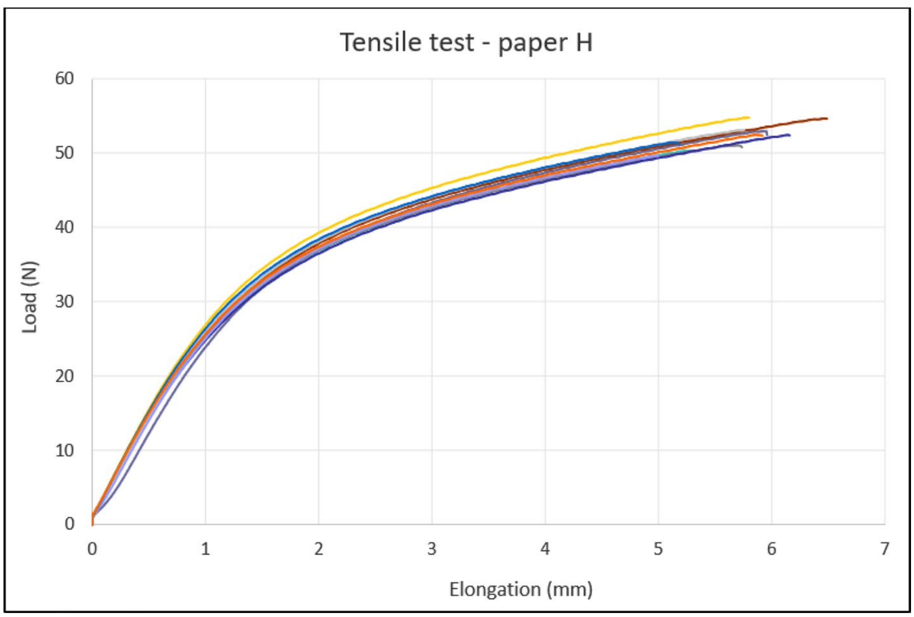

Fig. 39 Force elongation curves of individual specimen of paper H

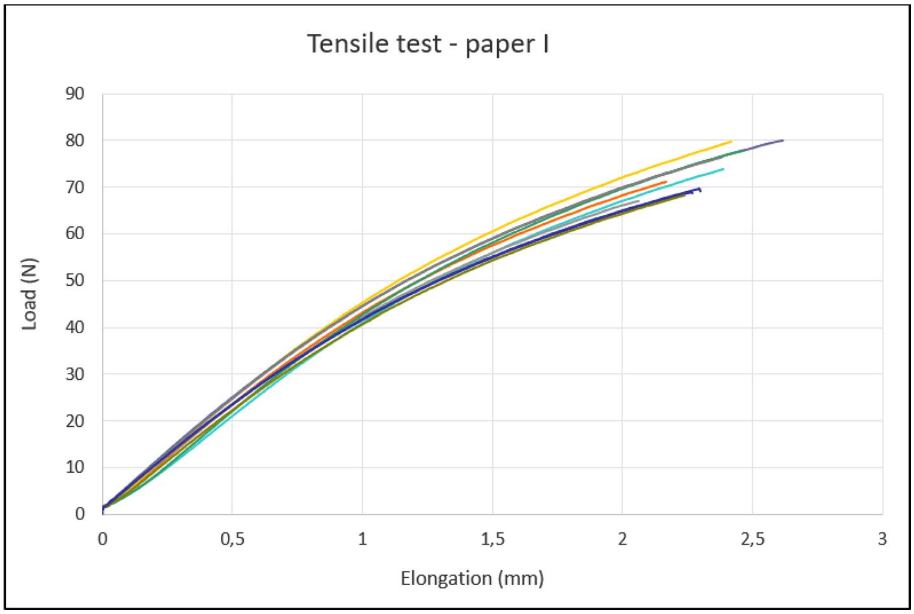

Fig. 40 Force elongation curves of individual specimen of paper I

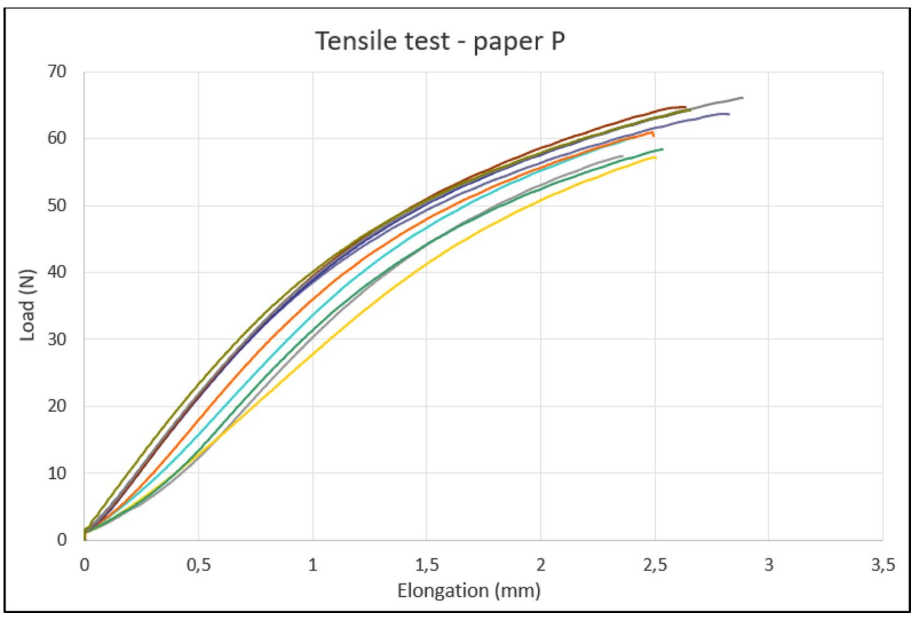

Fig. 41 Force elongation curves of individual specimen of paper P

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