White Paper

Designing recyclability into fibre-based packaging using fully soluble bio - digestible barrier systems

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Designing recyclability into fibre-based packaging using fully soluble bio-digestible barrier systems

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The move to replace conventional, hard to recycle and single use plastics to meet recyclability targets, has resulted in a wide variety of fibre-based packaging formats combined with alternative functional barriers being introduced into the recovered paper recycling streams. The need for barrier functionality has meant that it has not generally been practicable to remove conventional plastics altogether, and for regulators to seek to set rules around plastic content and fibre recovery to ensure that recycling mills can collect quality fibre. Maximising fibre recovery rates is clearly the goal of a circular economy approach and the designing of recyclability in packaging should focus on the practicalities of fibre recovery in the mill and aim at eliminating all elements contained in packaging such as adhesives and conventional plastics, which impact on fibre dispersion and recovery, generating biproducts which have to be removed and disposed of, by the mill.

In this work undertaken by Aquapak Polymers Ltd, laboratory and commercially prepared extrusion and adhesive paper-polymer laminates were constructed with the aim of identifying 'fit for purpose' packaging materials which are compatible with the paper recycling process. The work focused on Hydropol[1], a commercially available fully soluble, biodigestible barrier polymer, which can be adhesive or extrusion coated onto paper and brings a plurality of benefits to fibre-based packaging, including oil and grease resistance together with a high gas barrier. Hydropol has also been shown to increase some paper strength properties (tear, burst, puncture and tensile strength), allowing laminated papers to be heat-sealed for 'form, fill and seal' fibre packaging applications. Hydropol is designed to solublise at the typical re-pulping temperatures and durations used by high volume recycling mills allowing fibre to be dispersed to make new paper. Tests reveal that once solubilised, Hydropol doesn't appear to impact sheet properties, even when Hydropol coated paper forms 20% of the fibre furnish, and is biodegraded in the mills' anaerobic digestion and aerobic activated sludge treatments as part of its intended use. Hydropol is non-toxic and biodegradable in the marine environment should it be littered, forming no microplastics in the environment.

The work identified that Hydropol, as an extrusion coating onto paper facilitated complete fibre release and dispersion during repulpabilty tests. The work also identified that care needs to be taken when selecting adhesives to laminate barrier substrates to paper. Whilst some repulpable adhesives were identified, others were found to lock in valuable fibre and/or generate unwanted stickies.

The work illustrates the importance of designing-in and testing fibre-based packaging to confirm recyclability under the repulping conditions used by high volume recycling mills. In addition, the work demonstrates that 'recycle-ready' packaging adhesives and fully soluble, bio-digestible barrier systems are available to designers to manufacture recyclable fibre-based packaging.

Introduction

New recycled fibre sources

There has been heightened interest and usage of fibre-based packaging to replace non-recycled single use flexible plastic packaging in primary packaging and e-commerce packaging[2]. This interest is a direct consequence of the absence of a recycling infrastructure to collect and reprocess flexible plastic packaging at scale, pollution to terrestrial and aquatic environments and the unfortunate generation of microplastics which can enter food chains. The transition to fibre-based packaging is being driven by producers wanting to meet their extended producer responsibility requirements for increased recycling as well an expectation from consumers, brands and retailers that the packaging they use is recyclable.

4evergreen[3] suggest that there is potential to 'mine' fibre-based packaging resources more extensively and increase the rate of recycling from 84.6%[4] to reach a 90% recycling rate for fibre-based packaging by 2030 by focusing on the collection, sorting and recycling from household, out-of-home and on-the-go consumption. Whilst considered a valuable source of 'once-used' virgin fibre, these 'Group 5 paper grades'[3] are challenging to recycle as they often combine paper with other materials, such as plastic, to increase barrier resistance to moisture, oil and grease, gas ingress/egress and to improve puncture, tear and cushioning properties. In addition, these packs are designed for easy filling and sealing in-line, include patched-in windows to view the contents and offer openability and re-sealability features for consumers. This has resulted in a huge variety of fibre-based

Figure 1 Plastic-rich pulper rejects and ejected plastic-fibre 'bundle'

packaging formats, using many fibre types in multi-material constructions with plastic films, including other non-fibre components (such as adhesives), which are a source of plastic rejects and problematic sticky deposits at high volume recycling papermills. Additionally, valuable cellulose fibre becomes entrained with the plastic waste which reduces fibre yield whilst adding to disposal costs (*Figure 1*).

Addressing these issues, 4evergreen identified the importance of designing-in and testing fibre-based packaging to confirm recyclability under the repulping conditions used by high volume recycling mills. Recent CPI guidance[5] recognises that it is not yet practicable to eliminate plastics altogether from some fibre based barrier packaging, but encourages specifiers and designers to minimise plastic content to not more than 5% of pack weight on single sided laminates and that '*The development of fully soluble, bio-digestible barrier systems would be welcomed*'. CEPI's Paperbased Packaging Recyclability Guidelines[6] notes that the '*design phase should consider the intended purpose and end of life stage of the packaging in order to optimise the recycling of paper packaging*'. Regarding paper-plastic laminates and new alternative barriers, the guidance recommends packaging designers:

- *Optimise the adhesion between the laminate side and the board to facilitate separation*
- *Ensure that the paper fraction of the packaging breaks down into single fibres when pulped within a specified timeframe*
- *Give preference to polymers and other sealing agents that can be dealt with efficiently by the papermill process and effluent water systems and do not compromise the finished product, the production process or the environment whilst being recycled.*

Scope of work

Hydropol extrusion laminated papers were prepared on 85gsm Recycled liner (DS Smith) using Aquapak's pilot-scale extrusion coater. Laboratory-made Hydropol adhesive laminated papers were prepared using 85gsm Recycled liner to identify laminating adhesives which facilitate Hydropol solubility and fibre dispersion during repulping. Commercial adhesive paper-polymer laminates were made to examine the impacts of full-scale preparation and adhesive curing on Hydropol solubility and fibre dispersion during repulping. These constructions combined a range of low grammage papers which would find applications across food packaging and potentially lightweight e-commerce packaging applications. Laminate constructions consisted of paper and:

- Hydropol/PE coex film which combines the moisture barrier of polyethylene, and the gas, grease and oil barriers of Hydropol to meet industry regulatory guidance for <5% w/w insoluble plastic content
- Hydropol/Biopolymer coex film to provide a fully biodegradable pack which offers moisture, oil, grease and gas barrier that meets industry regulatory guidance for <5% insoluble plastic content
- Hydropol coex structures made up of different Hydropol grades with different solubility rates providing increased water resistance
- Mono Hydropol film laminated to papers such as 40gsm Newsprint to provide light weight but strong packaging that is suitable for e-commerce.

Laboratory scale repulpability and fractionation tests were carried out to identify the impacts of the various pack components on the extent of fibre dispersion, coarse reject generation and potential to be recycled into new paper products end-of-life.

Materials and methods

Laboratory prepared adhesive paper-polymer laminates

Adhesives were wet laid onto Recycled liner 85gsm (DS Smith plc) using a RK hand coater No 3 bar depositing ~18µm adhesive. As required, Hydropol film was bonded to the adhesive coated paper using a manually operated laminating roller (*Figure 2* and *Table 1*). Both coated papers and laminated structures were dried or cured in line with guidance supplied by the adhesive manufacturers.

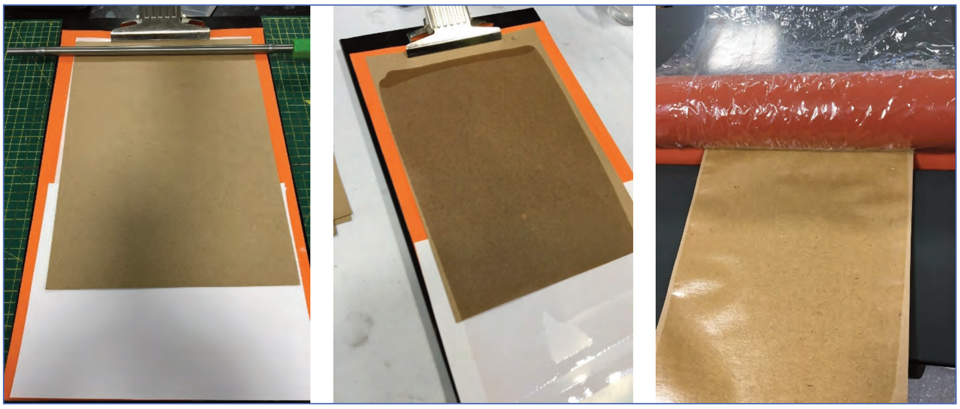

Figure 2 Laboratory drawdown: RK coating bar No3 depositing 18µm wet film onto DS Smith Recycled liner 85gsm paper (left and middle). Hydropol film being adhered to paper using a laboratory roller (right)

Sample ref.	Paper	Film	Adhesive	Primer
1 (control)	Recycled liner 85gsm	None	None	No
2	Recycled liner 85gsm	None	None	Yes
3	Recycled liner 85gsm	None	PSA	No
4	Recycled liner 85gsm	Hydropol	PSA	No
5	Recycled liner 85gsm	None	Solvent-free (1)	No
6	Recycled liner 85gsm	Hydropol	Solvent-free (1)	No
7	Recycled liner 85gsm	None	Solvent	No
8	Recycled liner 85gsm	Hydropol	Solvent	No
9	Recycled liner 85gsm	None	Water-based repulpable	No
10	Recycled liner 85gsm	Hydropol	Water-based repulpable (low coat weight)	No
11	Recycled liner 85gsm	Hydropol	Water-based repulpable (high coat weight)	No
Extrusion coating	Recycled liner 85gsm	Hydropol	None	No

Table 1 Composition of laboratory prepared adhesive paper-polymer laminates. The composition of the Hydropol-extrusion coated paper is also shown

Sample ref.	Paper	Film	Adhesive
12 (control)	DS Smith White Top	None	None
13	DS Smith White Top	Hydropol	Water based / repulpable
14	DS Smith White Top	PE/Hydropol	Water based / repulpable
15	100gsm Kraft	Hydropol	Solvent free (1)
16	50gsm Kraft	Hydropol	Water based PSA
17	40gsm Kraft Convertor A – Brand A	Hydropol	Solvent free (2)
18	40gsm Newsprint	Hydropol	Solvent
19	100gsm Kraft Convertor A	Hydropol/PE laminate	Solvent free (2)
20	40gsm Kraft Convertor A – Brand A	WWH	Solvent free (2)
21	40gsm Kraft Convertor A – Brand A	Biopolymer/Hydropol	Solvent free (2)
Extrusion coating	Recycled liner 85gsm	Hydropol	None

Table 2 Composition of commercially prepared adhesive paper-polymer laminates. The composition of the Hydropol-extrusion coated paper is also shown

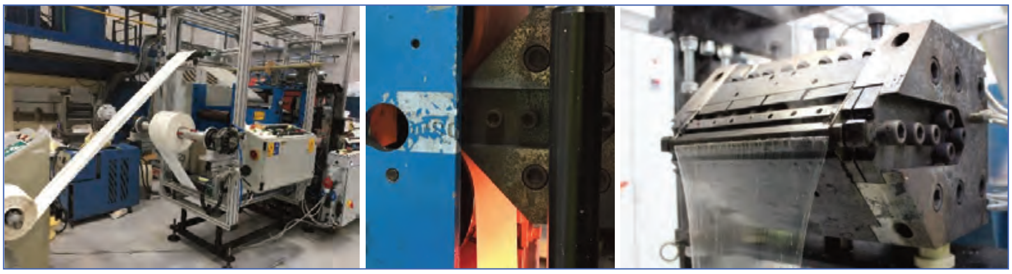

Figure 3 Pilot extrusion coating line showing base-paper unwind and coated paper rewind (left), extrusion die applying a Hydropol polymer to paper (middle) and extrusion die extruding Hydropol polymer curtain (right)

Preparation of commercial adhesive paper-polymer laminates

Adhesive paper-polymer laminates were prepared by four UK specialist coaters using commercially available solvent-free and solvent-based laminating adhesives. Paper-polymer laminates were also constructed using a new water-based 're-pulpable' laminating adhesive. In all cases, adhesive was applied to polymer as a film of thickness ~4µm prior to adhesion to the paper (*Table 2*).

Preparation of Hydropol extrusion coated papers

Hydropol was extrusion coated directly onto paper (85gsm Recycled liner) using Aquapak's pilot extrusion coater. The coater is equipped with a die which delivers a coat width of 200mm (*Figure 3*).

Repulping and fractionation

Repulping tests were carried out in a standard laboratory disintegrator (*Figure 4*) using procedures described in *ISO 5263-1:2004*[7]. Samples were repulped at a consistency of 1.5%w/w, 40°C, pH 7.0 and for 50,000 stirrer revolutions for a duration ~ 17 minutes.

Each pulper sample was fractionated using a Bauer McNett fractionator according to methods described in *TAPPI T233 cm-15*[8] (*Figure 4*) equipped with 8/16/50 and 100 mesh screens (aperture – 2.38mm/1.19mm/0.297mm and 0.149mm respectively). The weight of material retained by each screen was measured.

Figure 4 Standard laboratory disintegrator and Bauer McNett fractionator

Mesh	Aperture (mm)	Target fraction
8	2.38	Coarse rejects
16	1.19	Undispersed fibre bundles/flakes and smaller contraries
50	0.297	Softwood fibre
100	0.149	Hardwood fibre
>100	<0.149	Material passing to Dissolved Air Flotation and effluent plant eg cellulose fines, filler and dissolved coating residues

Table 3 Bauer McNett Mesh aperture sizes and target fractions

Results

The results of the repulpabilty tests can be summarised as follows:

- Thermally bonded Hydropol to paper, as an extrusion coating, facilitated complete fibre release and dispersion
- Selected water-based and some solvent-free repulpable laminating adhesives used to combine paper with Hydropol facilitated complete fibre release and dispersion
- Novel fibre/coex constructions comprising White Top paper, a water based repulpable adhesive and a polyethylene/Hydropol coextrusion facilitated complete fibre release and dispersion and also meets industry regulatory guidance for <5% w/w insoluble plastic
- Selected solvent and solvent-free laminating adhesives 'locked-in' fibre preventing fibre release and dispersion. 'Locked in' fibre would be screened out and ejected with

plastic pulper/screen rejects; reducing fibre yield and increasing disposal costs

- Selected PSA laminating adhesives generated 'stickies' during the repulping process. These stickies could cause 'sticky paper breaks' and could accumulate on paper making machinery.

These results are discussed in detail below.

Uncoated papers, paper with primer coating and Hydropol extrusion coated paper

Excellent fibre dispersion was noted for the uncoated paper controls (85gsm Recycled liner and White Top), 85gsm Recycled liner paper with primer coating and Hydropol extrusion coated Recycled liner. In these cases, very low percentages of undispersed fibre/coating were retained by the 2.38mm Mesh 8 screen indicating that the fibre had dispersed during the repulping process. There was an absence of fibre flakes/bundles. No adhesiveness was noted to be associated with the recovered fibre (*Tables 4* and *5* – sample ref. 1, 2, 10 and extrusion coating; *Figure 5*).

Adhesive laminates using water based repulpable adhesives

Excellent fibre dispersion was noted for water-based repulpable adhesives used in the following constructions:

- Recycled liner coated with water-based repulpable adhesive (sample ref. 9)
- Recycled liner coated with water-based adhesive at low and high coat weight together Hydropol film (sample ref. 10 and 11)
- White Top coated with water-based repulpable adhesive and Hydropol film (sample ref. 13)
- White Top coated with water-based repulpable adhesive and polyethylene (10µm)/Hydropol (15µm) coextrusion (sample ref. 14).

In the latter case, a relatively clean fibre free polyethylene film fraction was recovered by the mesh 8 filter. Visual assessments suggested as absence of polyethylene on the Mesh 16, 50 and 100 filters (*Figure 6*).

Infra-red analysis of non-filtrable solids arising during the repulping and fractionation of sample ref. 14 – White Top/water based repulpable adhesive and Hydropol/polyethylene coextrusion

IR analysis was carried out on small sections of the non-filtrable solids which were retained on Mesh 8, 16, 50 and 100 filters, using a Thermoscientific Nicolet iS5 FT-IR spectrometer with ATR iD7 attachment. These analyses were carried out in triplicate/filter paper. Polyethylene was detected on the Mesh 8 filter only which retains course rejects >2.38mm confirming visual assessments (*Figure 7*). The filtrable solids retained in mesh 16, 50 and 100 showed spectral characteristics of an 'intermolecular alcohol' such as cellulose.

Adhesive laminates using solvent-free adhesive

Recycled liner paper coated with solvent-free adhesive (1) alone or combined with Hydropol film as a laminate structure fully repulped as evidenced by fibre dispersion and low coarse rejects detected in mesh 8 filter (sample ref. 5 and 6). A similar result was obtained in the case of a commercial laminate made from kraft paper (100gsm) and Hydropol film using solvent-free adhesive 1 (Sample ref. 15), *Tables 4* and *5*; *Figure 8*).

Figure 5 Non filtrable solids retained for Recycled liner (sample ref. 1 top left), White Top (sample ref. 12 – top right), Recycled liner plus primer (sample ref.2 - bottom left) and Hydropol extrusion coated Recycled liner (bottom right). Each picture shows retained solids by mesh 8 (top left), mesh 16 (top right), mesh 50 (bottom left) and mesh 100 (bottom right)

Figure 6 Non filtrable solids retained for White Top (sample ref. 12 – top left), White Top/water-based repulpable adhesive/Hydropol film (sample ref. 13 – top right), White Top/water-based repulpable adhesive and Hydropol/polyethylene coextrusion film (sample ref. 14 – bottom left) and mesh 8 non- filtrable solids showing high quantities of retained PE. Each picture shows retained solids by mesh 8 (top left), mesh 16 (top right), mesh 50 (bottom left) and mesh 100 (bottom right)

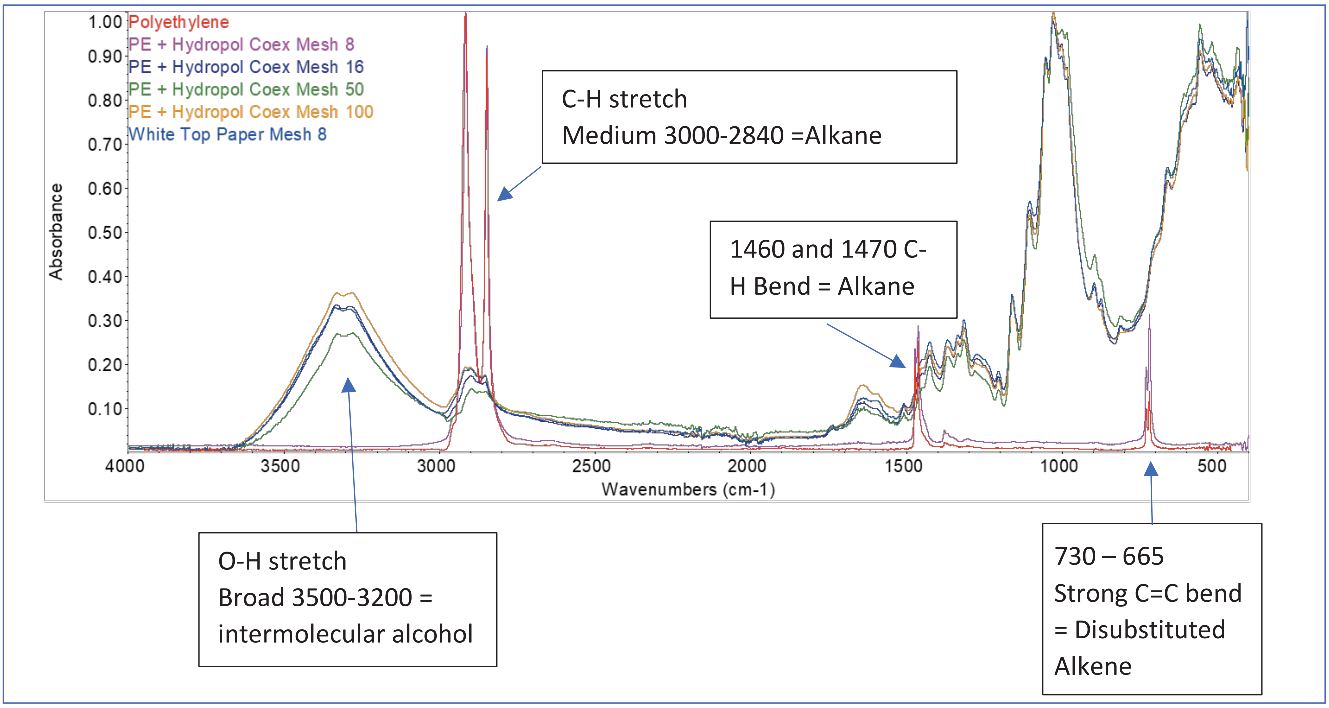

Figure 7 FTIR analysis of non filtrable solids on Mesh 8, 16, 50 and 100 filters. A reference spectrum for polyethylene is shown for comparison

Figure 8 Non filtrable solids retained for Recycled liner with solvent free adhesive (1) (sample ref. 5 – left), Recycled liner with solvent free adhesive (1) and Hydropol film (sample ref. 6 – middle) and kraft (100gsm) with solvent free adhesive (1) and Hydropol film (sample ref. 15 – right). Each picture shows retained solids by mesh 8 (top left), mesh 16 (top right), mesh 50 (bottom left) and mesh 100 (bottom right)

The extent of fibre dispersion from a range of commercially made adhesive laminates with solvent- free adhesive (2) was also evaluated (sample ref. 17; 19 and 20). In these cases, high levels of non-dispersed fibre and plastic bundles (16.2% and 27.6%) were retained by the 2.38mm Mesh 8 screen, *Table 5* and *Figure 9*. It is unclear if this result was due to the kraft paper grade itself (unlikely) or an incompatibility with the adhesive used, but it does show that both the paper grade and solvent free adhesive need testing to ensure they are compatible with the repulping process. Repulpability tests carried out on the Hydropol/Biopolymer coex film (sample ref. 21) were terminated during the repulping stage due to the generation of 'strings' which wrapped around the pulper impeller and caused excessive losses from the pulper.

Adhesive laminates using solvent-based adhesives

High quantities of non-dispersed fibre (9.7% and 19.9%) was noted to be retained by Mesh 8 for Recycled liner coated with solvent-based adhesive (sample ref. 7) or solvent-based adhesive with Hydropol film (sample ref. 8) in laboratory made paper-laminates (*Table 4*, *Figure 10*). 27.4% of the original paper construction was retained when a solvent-based adhesive was used

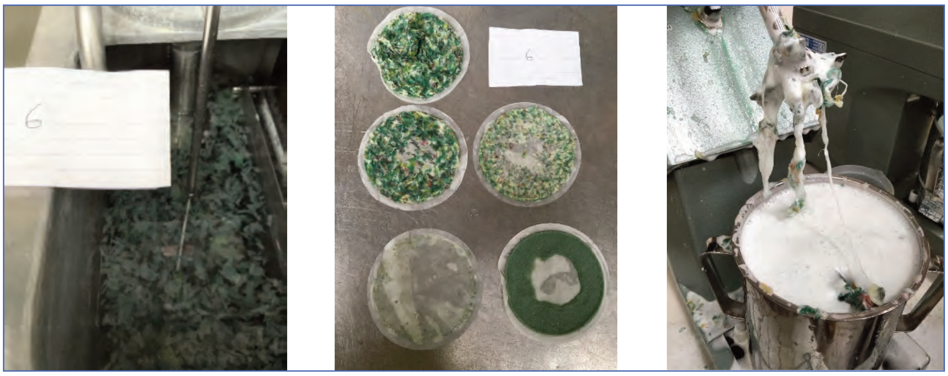

Figure 9 Sample ref. 17 High solids (27.6%) > 2.38mm retained by Mesh 8 filter in Bauer McNett (left) and recovered on Mesh 8 filters (middle – top left). Sample 21 – trial discontinued due to presence of non-repulpable 'strings' on impeller and excessive pulper losses (right)

Figure 10 Non-filtrable solids retained for Recycled liner with – left), Recycled liner with solvent based adhesive and Hydropol film (sample ref. 8 – middle) and newsprint (40 gsm) with solvent based adhesive and Hydropol film (sample ref. 18 – right). Each picture shows retained solids by mesh 8 (top left), mesh 16 (top right), mesh 50 (bottom left) and mesh 100 (bottom right)

Figure 11 Sample ref 5 - sticky threads > 2.38mm retained by Mesh 8 filter in Bauer McNett (top left) and adhering to mesh 8 screen (top middle). Stickies retained on Mesh 8 filter paper (top right). Sample ref 16 – sticky threads retained by mesh 8 filter in Bauer Mc-Nett (bottom left) and presence of stickies on mesh 8 filter paper (bottom middle and right)

Sample ref.	Paper	Film	Adhesive	Primer	Dispersion temp °C	Dispersion counts k	Mesh					
							8	16	50	100	>100	
							Fraction					
							1	2	3	4		
							Percent Retained					Stickies Yes/No
1 (control)	Recycled liner 85gsm	None	None	No	40	5	0.6	16.6	3.5	25.3	58.3	No
2	Recycled liner 85gsm	None	None	Yes	40	5	1.1	22.8	3.8	28.1	52.9	No
3	Recycled liner 85gsm	None	PSA	No	40	5	6.5	22.7	3.4	12.1	63.9	Yes
4	Recycled liner 85gsm	Hydropol	PSA	No	40	5	6.0	15.5	3.2	6.2	69.3	Yes
5	Recycled liner 85gsm	None	Solvent-free (1)	No	40	5	1.1	14.5	3.8	22.3	67.0	No
6	Recycled liner 85gsm	Hydropol	Solvent-free (1)	No	40	5	0.2	9.0	3.1	13.5	82.9	No
7	Recycled liner 85gsm	None	Solvent	No	40	5	9.7	25.6	3.5	16.8	53.1	No
8	Recycled liner 85gsm	Hydropol	Solvent	No	40	5	19.9	5.5	1.8	1.9	79.7	No
9	Recycled liner 85gsm	None	Water-based repulpable	No	40	5	0.3	14.1	0.2	8.3	85.9	No
10	Recycled liner 85gsm	Hydropol	Water-based repulpable (low coat weight)	No	40	5	0.1	6.7	6.2	9.2	86.5	No
11	Recycled liner 85gsm	Hydropol	Water-based repulpable (high coat weight)	No	40	5	0.1	7.3	3.2	13.3	84.7	No
Extrusion coating	Recycled liner 85gsm	Hydropol	None	No	40	5	0.1	10.5	3.2	22.4	63.8	No

Table 4 Repulpability assessments of laboratory prepared adhesive paper-polymer laminates. Undispersed fibre/coating > 2.38mm is retained by mesh 8 screen. The presence/absence of stickies is indicated. Repulpability assessments for a Hydropol extrusion coated paper are shown for comparison

Sample ref.	Paper	Film	Adhesive	Dispersion temperatur	Dispersion counts	Mesh					Stickies Yes / No
						8	16	50	100	>100	
						Fraction					
						1	2	3	4		
				°C	No. K	Percent Retained					
12 (control)	DS Smith White Top	None	None	40	5	0.8	17.2	2.8	38.2	41.0	No
13	DS Smith White Top	Hydropol	Water based / repulpable	40	5	0.3	12.6	3.1	30.7	53.4	No
14	DS Smith White Top	PE/Hydropol	Water based / repulpable	40	5	3.8	13.6	3.3	30.1	49.2	No
15	100gsm Kraft	Hydropol	Solvent free (1)	40	5	2.3	8.6	1.9	8.9	78.8	No
16	50gsm Kraft	Hydropol	Water based PSA	40	5	12.8	11.9	1.6	17.8	56.0	Yes
17	40gsm Kraft Convertor A – Brand A	Hydropol	Solvent free (2)	40	5	27.6	2.3	0.0	3.8	66.3	No
18	40gsm Newsprint	Hydropol	Solvent	40	5	27.4	4.2	1.6	10.0	56.7	No
19	100gsm Kraft Convertor A	Hydropol/PE laminate	Solvent free (2)	40	5	16.2	15.7	2.6	21.5	36.0	Yes
20a	40gsm Kraft Convertor A – Brand A	WWH	Solvent free (2)	40	5	24.5	4.3	0.5	4.3	66.3	No
20b	40gsm Kraft Convertor A – Brand A	WWH	Solvent free (2)	65	5	20.7	4.2	0.3	2.7	72.1	No
21	40gsm Kraft Convertor A – Brand A	Biopolymer/Hydropol	Solvent free (2)	40	0.68	Trial discontinued					Not tested
Extrusion coating	Recycled liner 85gsm	Hydropol	None	40	5	0.1	10.5	3.2	22.4	63.8	No

Table 5 Repulpability assessments of commercially prepared adhesive paper-polymer laminates. Undispersed fibre/coating > 2.38mm is retained by mesh 8 screen. The presence/absence of stickies is indicated. Repulpability assessments for a Hydropol extrusion coated paper are shown for comparison

to adhere Hydropol to 40gsm Newsprint (sample ref 18; *Table 5, Figure 10*).

Adhesive laminates using water-based Pressure Sensitive Adhesives

High quantities of non-dispersed fibre was noted to be retained by Mesh 8 for laboratory coated Recycled liner paper and PSA adhesive (sample ref. 3) and PSA adhesive with Hydropol film (sample ref. 4) –*Table 4, Figure 11*, and also commercially prepared 50gsm kraft papers (sample ref 16) –*Table 5* and *Figure 11*. In all case, high quantities of 'stickies' were observed to be associated with fibre retained on Mesh 8, 16, 50 and 100 filters. Sticky threads were also noted to bind to mesh screens (*Figure 11*).

Conclusions

A range of different adhesive chemistries are used to bond polymers to paper for numerous fibre-based packaging applications. Laminating adhesives are typically applied at <1% w/w of overall pack weight and might be assumed to not impact fibre dispersion and/or pack recyclability. The results of this study suggest that laminating adhesives can be critical in the recycling loop; they can 'lock-in' valuable fibre and, in some cases, as this testing has shown, result in more than a quarter of fibre associated with some adhesive laminated packs being lost from the paper recycling process. Using non-repulpable laminating adhesives could consign paper and board packaging to the ***'Don't Recycle'*** category under the OPRL labelling scheme.[9]

A water based/repulpable adhesive was evaluated and found to facilitate complete fibre dispersion as were some solvent-free laminating adhesives. Compatible adhesive technologies should be tested and adopted by designers so that fibre-based packaging can be recycled in high volume recycling mills. Extrusion coating is the most direct method of combining Hydropol to paper. The thermal bonding of Hydropol to paper facilitated complete fibre dispersion and would be the preferred route to simplify package manufacture, reduce pack weight and eliminate potential deleterious impacts from non-repulpable laminating adhesives. Such an extrusion coated fibre-based pack would qualify for the OPRL '***Recycle***' label.

CPI Guidance recognises that it not practicable to eliminate plastics altogether from barrier packs which require moisture barrier and have set an 'aspirational' target of <5% of pack weight on single sided laminates. In this study, a fibre/'coex' construction was designed and manufactured commercially which combined the moisture barrier of polyethylene with Hydropol – a fully soluble bio-digestible, oil, grease and gas barrier. This construction comprised 3.2% w/w polyethylene yet provided a 'fit for purpose' repulpable barrier pack to meet current CPI targets. Importantly, the 10µm polyethylene appeared to remain intact during repulping and was captured by the 2.38mm screen and would be ejected from the papermaking process. Polyethylene was not detected in the fibre solids retained by mesh 16, 50 and 100 screens which suggests an absence of microplastics >0.149mm which might pass through stock preparation and into the paper sheet.

The paper industry has witnessed heightened interest and usage of fibre-based packaging to replace non recycled single use plastic packaging in primary and e-commerce packaging applications. 4evergreen suggest that there is potential to increase the recycling rate of paper and board used from packaging from 86.4% to 90% by 2030 with focus on the collection and reprocessing of fibre-based packaging, out of home and on-the-go consumption. Such an initiative would increase the rate of paper recycling in Europe which has stagnated over recent years. The current study provides evidence which attests 4evergreen's position that fibre-based packaging needs to be designed and tested to ensure recyclability within high volume recycling mills. This work does, however, demonstrate that 'recycle ready' adhesives and fully soluble bio-digestible barriers are available to designers to manufacture functional fibre-based packaging which can be recycled by high volume recycling mills.

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