Improved properties of recycled fibre packages

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The challenge

Recycled fibre is an important raw material for containerboard (liner and fluting papers used to manufacture corrugated board) and other boards and packaging papers, but it also poses a considerable challenge to the quality of paper packaging. Papers made from recycled fibres lose strength and stiffness compared to papers made from virgin fibres. Problems become worse at very low or high humidity. Brittleness increases at low humidity making the paper less resistant to damage, and both stiffness and strength decrease at high humidity.

The most important function for the produced paper is to give the finished box enough strength to withstand transport and handling while protecting the goods. Bending stiffness and compression strength in the plane of the paper are the most important properties for box strength. To protect the goods from impact, e.g. when the box is dropped, good damage resistance is also needed and thus brittleness should be avoided.

The paper must also resist damages when converting it to a box. Damages occurring in converting will reduce the strength of the box and may also damage barriers protecting the goods or preventing leakage of liquid content. The surface layers of the cartonboard (also known as paperboard or boxboard) or corrugated board are severely strained during creasing and folding operations, so low strain at break and brittleness could lead to serious problems.

The current situation

The repulpability and recyclability of products are key to reaching high circularity. Ensuring this is becoming more and more important not only for the producers using recycled fibre but also for the users of virgin fibre who increasingly need to prove that their products can be recycled. About 80% of paper can be recovered and be a part of the circular flow of paper and board. To reach that level of circularity, all parts of the circle must be improved. A significant challenge is to maintain good performance of recycled fibre packages.

The increase in packaging paper production and paper recovery rates pose challenges to the quality of recycled fibre as more and more recovered paper is used as raw material during production. Legislation around the world and especially in the EU demand increased recovery of materials. However, easily available sources such as clippings from converting and supermarket packaging are already exploited, and a further increase in the recycling rate can mainly come from increased post-consumer recovery. The increased recovery rates and demand for recycled paper will, due to the increased post-consumer recovery, lead to more non-fibre material together with the recovered fibre material. This will lower the end-product quality and/or increase handling and production cost. The increase in contaminant levels will result in lower yield in the mills.
and increased costs. The yield of paper for recycling as raw material in packaging papers is today 90–95%.

One consequence of increased recovery and utilization is that the fibres will be reused more times. According to the Monitoring report 2018 by the European Paper Recycling Council [1], the average number of times a fibre is used today is 3.5 times in Europe and 2.4 times for the rest of the world. Although the fibres, even after several cycles, will be good enough for papermaking, the handling e.g. slushing, pumping etc. will create fine material reducing both pulp strength and yield for each cycle.

Another trend affecting the recycled raw material for packaging is the continued reduction of, in absolute tons, graphic paper production, but more importantly in percentage of total paper and board production. This results in less virgin fibres entering the market; thereby driving up the price of recovered fibre and compelling the use of lower quality fibres to reduce production cost.

The production of packaging paper and board as well as tissue and speciality papers have grown by about 3% per annum between 2010 and 2018 while graphic papers have decreased about 3% per annum. Packaging grades represented 52% of all paper and board production in 2018. Today, 53% of the fibre raw material used for papermaking comes from recycled paper compared to 40% in 1991 (refer Figure 1) [2]. For packaging grades, 74% is produced from recycled raw material.

![Figure 1 CEPI Raw materials consumption](image)

About 70% of the recovered paper used for packaging paper are old corrugated containers (OCC) and other packaging papers and board. The rest is mostly mixed paper and board grades.

The recycled fibre quality determines the paper quality to a large extent. Due to the wide range of paper properties that can be obtained, different paper quality grades based on recycled fibres have been defined. Corrugated board is built up of liner and corrugated
medium. The liner produced from recycled fibre is denoted testliner and divided into four grades [3], with testliner 1 having the highest quality and testliner 4 the lowest. The grades are determined by reaching minimum requirements on either burst index or SCT index. For testliner 1, these requirements are almost as high as for virgin fibre based kraftliner. The specifications for grammages below 200 g/m² are shown in Figure 2. Similar criteria exist for different grades of recycled fluting and the corrugated medium made from it [3]. All requirements on mechanical properties for the grades are for strength measures at standard laboratory climate. They do not consider high or low humidity, or other measures that also have large impact on performance, like stiffness.

![Figure 2 Comparison of specifications for virgin fibre brown kraftliner and testliner with decreasing properties from grade 1-4.](image)

The incoming paper raw material is reslushed and treated in a stock preparation process before going to the paper machine where new paper is produced. The produced paper is then printed and converted before being used as packages. The design of packages should keep the packaged goods safe but at the same time the package should use as little material as possible and be easy and efficient to transport.

Recycled pulp raw material for packaging is a very heterogenous material consisting of fibres with different origin, both with regard to fibre species and how the fibres have been processed into pulp. The way the papers that are being recycled have been produced and converted also add to the variation, introducing materials such as fillers (mostly referred to as ash), printing inks, glues etc.

To get the desired strength, the paper that are to be converted into packages need to meet the mechanical properties necessary. With a novel approach to the utilization of the recovered material and smart design of the paper, the packaging product could be given the needed mechanical strength.
The most important function for the produced paper is to give the finished box enough strength to withstand transport and handling while protecting the goods. Bending resistance and resistance to cracking during converting as well as the capability to keep the shape of the box when subjected to forces, for example when boxes are stacked on top of each other, are some of the functions that must be ensured.

Functional paper properties can be linked to important end-use properties. The most common box test is the box compression test (BCT) which estimates stacking strength. The compressive strength of the box has been linked to the compressive strength and bending properties of the cartonboard or corrugated board [4, 5, 6], which are also linked to the common paper properties as illustrated for corrugated board in Figure 3.

The short span compression test (SCT) is typically used to measure the compressive strength for cartonboard as well as liner and fluting. For corrugated board, the edge crush test (ECT) is used to measure the compression strength directly, but this strength is also linked to the SCT values of the papers used in the board. Bending stiffness can be measured directly using a bending test or can be calculated from tensile stiffness measured in the tensile test. Because of their importance for package performance, both the SCT value and tensile stiffness are very common in paper and board specifications. These are usually lower for papers made of recycled fibres than for paper made from virgin fibres. The differences increase at higher humidity.

To convert paper to boxes, creasing, cutting, and folding are required. During these operations the surfaces of the materials are severely strained and might crack as a result. Examples of cracks that may occur in cartonboard and corrugated board are shown in Figure 4. The loading situation during creasing has been analysed for both cartonboard [7] and corrugated board [8]. The analyses indicate that high strain levels will be critical for cartonboard and containerboard with low strain at break and high brittleness. These
properties are worse for papers made from recycled fibres than for papers made from virgin fibres, and the difference increases at lower humidity.

![Figure 4 Crease cracks in cartonboard and corrugated board.](image)

The strength of the paper depends on the strength of the fibres as well as the strength of the bonds connecting them. By utilizing the fibres to their best potential and ensuring good bonding between them, the paper strength can be optimized. The increasing ash content found in recovered paper further lowers the strength as ash is detrimental for the bonding between fibres. The paper sheet structure is another important component to reach the best possible product performance. Designing the paper in the z-direction can improve converting and stacking strength of the packaging box.

### Improving the properties

To maintain good recycled fibre packaging performance, the paper and packaging production and performance from sorting of the recycled paper to the logistics, handling and distribution of the packages must be addressed. By evaluating the different additives and design strategies used in the papermaking, containerboard and cartonboard properties can be improved for better performance, both during converting processes and use of the packages.

The recovered paper is reslushed in a pulper to separate the particles in the paper from each other. After reslushing and deflaking there is a mixture of individual particles, fibres, fines, filler and small contaminants. By fractionating the recycled pulp material into more homogenous fractions, the different fractions can be treated individually utilizing each fraction to their best potential.

Recycled fibre quality can be improved by the separation of fibres with low bonding ability from those with good bonding ability. Fibres with low bonding capability can then be treated to improve the strength properties. Furthermore, removal of ash not only improves the strength qualities of recycled paper (as well as quality of recycled pulp) but
also provides ash as a by-product that can be utilised elsewhere. These processes serve to improve the mechanical performance of the packaging product produced from recycled fibres.

Through fractionation with screens and hydrocyclones, the pulp material can be divided into different fractions [9]. In Figure 5, the pulp was first screen fractionated with microholes into a short fraction containing mostly fines and filler particles and a long fibre fraction. The short fraction was then hydrocyclone fractionated into a short fine fraction consisting of fibrillar fines and small filler particles and a coarse short fraction containing filler aggregates, flaky fines and short fibre fragments. Hydrocyclone fractionation of the long fibre fraction resulted in a fine fibre fraction with easily collapsed, well bonding fibres and a poorly bonding coarse fibre fraction.

Figure 5 Fractionation of a recycled pulp from OCC/Mixed waste.

By refining the coarse fibre fraction only, the pulp strength can be developed with less detrimental effect on dewatering compared to refining the whole pulp. In Figure 6, it is shown how both SCT and tensile stiffness increased by 20% (as compared to the feed) by refining the coarse fraction. 75 kWh/t was added to the coarse fraction (pulp stream 7 in Figure 6). Since this fraction was one third of the total pulp, the total specific energy consumption was limited to as little as 25 kWh/t. The strain at break is also improved by mechanical treatment of low bonding fibres together with other mechanical properties such as SCT and tensile stiffness.
By also removing some of the ash concentrated in pulp stream 5, the SCT and tensile stiffness was increased by about 30% (as compared to the feed).

Addition of strength additives, both fibre-based and chemical, is another route for improvement. By combining the mechanical treatment with strength additives, the mechanical properties can be further improved.

At RISE, studies have shown that a combination of strength additives enhance the effect (refer Figure 7) [10]. The fibre-based strength additive will, besides the primary effect of increased bonding, also provide additional surface and charge to the pulp, thereby facilitating increased use of chemical additives.

For cartonboard and to some extent also containerboard, design of the z-profile could be beneficial. This allows a design strategy which utilises different recycled fibre fractions.
in the best possible way. By making the plies at the surfaces stiff and strong, high bending stiffness can be obtained and the risk of surface cracking during converting can be decreased. Moreover, by further designing plies and ply interfaces in the z-direction, bulk which contributes to bending stiffness can be obtained without compromising compressive strength (SCT). The behaviour during creasing, cutting and folding can also be steered towards controlled delamination that will decrease the strains at the surface during these operations with minimal loss of integrity of the material.

By combining strategies for raw material utilisation, addition of fibre-based and chemical strength additives and demonstrating this in paper produced at RISE pilot paper machine, packages with better mechanical properties can be developed.

To find the strategies suitable for each individual mill, a systematic approach is needed (refer Figure 8). The best strategy to use is individual to each mill depending on the existing conditions and limitations.

Figure 8 Combining strategies to reach desired goal.
Towards improved recycled fibre packages

There are several strategies that can be used to improve the mechanical properties of recycled fibre packages:

- By separating the pulp into different fractions, low bonding fibres can be mechanically or chemically treated, inactive fines can be activated, and ash can be removed to increase strength.

- By combining chemical and fibre-based additives, further strength improvement can be achieved. Fibre-based additives facilitate the possibility to add more chemicals by increasing both charge and the available surface.

- By engineering the z-profile, high bending stiffness and good resistance to surface cracking can be obtained without compromising the compressive strength. The z-profile can also ensure well controlled creasing and folding properties giving consistent converting without loss of material integrity.

Different parts and combinations of these strategies can be used to upgrade recycled fibres and improve properties of the recycled fibre packaging. The most efficient combinations may vary between mills and products, and suitable strategies must thus be selected and customised to fit different cases.
References


