# Falling impact as an isolated disintegration mechanism in drum pulping for packaging board

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**ABSTRACT:** Falling impact is one of the main mechanisms in the disintegration of packaging board in a drum pulper. In this study, the disintegration effect of falling impact was studied and evaluated with three different materials. Impact disintegration was isolated with a designed device that simulates falling in drum pulping. The falling heights studied were 2.75 m and 3.75 m. Repeated impacts from both of the studied distances were found to be similarly efficient at disintegrating a weaker material, such as testliner. This kind of behavior proposed that every material has an optimal falling height, from an energy consumption perspective.

Another way to increase falling impact is to increase the mass of falling pulp. It was found that it is possible to increase the efficiency of the disintegration of stronger materials, such as kraftliner, with an increased falling mass. It was also noticed that motion after impact is important for disintegration as well.

The number of impacts needed to disintegrate packaging board was found to be high. This raised the question of whether or not the falling of pulp is the only method for disintegrating packaging board. The results suggest that impacts by falling alone are not enough for the thorough disintegration of packaging board material; rather, other mechanisms are also involved.

***Application:*** Mills seeking fundamental knowledge about drum pulping to optimize their pulping process will find this study helpful.

Packaging board is one of the most commonly recycled raw materials, with a recycling rate of 74% on average in Europe, but the rate can be as high as 80% in some countries, as in Belgium [1,2]. The first unit process in the fiber line is pulping, where recovered paper or board fed as bales are disintegrated into a pumpable suspension and coarse contaminants are removed. Currently, two principles are used to pulp packaging board. One is continuous low-consistency (LC) vat pulping based on a rotor that produces high shear forces, which disintegrate board into a fiber suspension. The other is a rotating drum, where board is disintegrated at high consistency (HC) by impacts due to the repeated lifting and falling of the material. A drum pulper is an innovation that is newer than traditional pulping in the vat. The first patent to present some principles of drum pulping was granted in 1982 [3]. The use of a drum pulper has gained popularity since the 1980s due to its continuous operation, easy separation of large coarse contaminants, and energy efficiency [4].

A drum pulper normally consists of two sections. The first section of the drum is used to disintegrate packaging board, and the second section is used as a screen to separate a disintegrated-pulp suspension from coarse contaminants and flakes. Consistency in the disintegration section is 14%–20 %, and in the separation section, it is lowered to 3%–5 % in order to achieve efficient screening. In the disintegration section, lifters are used to elevate the pulp until it reaches a point where it falls onto the bottom of the drum. The impact energy is dependent on the height of the fall and on the amount of pulp on a lifter, i.e., potential energy. The falling height is determined by the diameter of the drum but also by the falling point that depends on the drum rotation speed. Usually, the drum rotation speed is adjusted so that the pulp falls from "11 o'clock" to "5 o'clock." The drum speed cannot exceed the critical speed because if the rotation speed is too high, the pulp does not fall from the lifters. The number of lifters affects the falling frequency and the amount of pulp to fall from one lifter [5].

Besides the impact energy by falling, the retention time of the pulp determines the energy applied in pulp disintegration, i.e., number of impacts during the pulping process. The retention time depends on the length, angle of tilt, and diameter of the drum, as well as the rotation speed [6]. An increased diameter and angle of tilt and decreased length reduce the pulp retention time in the drum, thus reducing the total energy applied to the pulp. An increased falling height, which depends on the drum diameter and rotation speed, also decreases the retention time of the pulp due to the distance the pulp advances in the drum during one rotation. The effect of falling height on the total applied energy is not straightforward, however, because shortening the retention time due to an increased height also increases the impact energy.

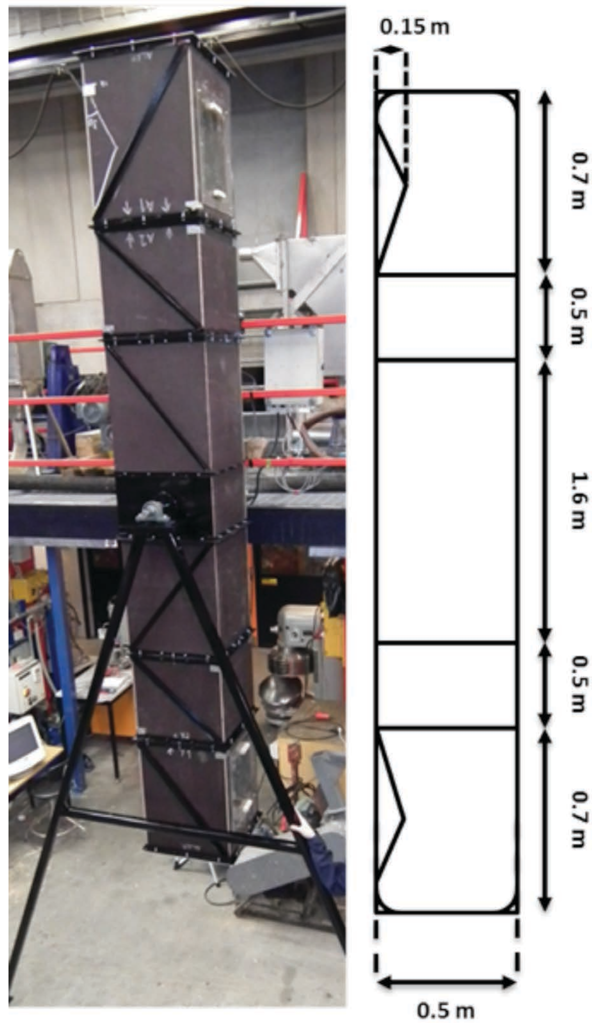
The target of pulping is to achieve high material efficiency by avoiding fiber losses due to the rejection of non-disintegrated fiber material, i.e., flakes. However, the kinetics and mechanisms of drum pulping, especially in the case of packaging board, are mostly unknown. Quite a few studies regarding drum pulping have been published [6]. The lack of knowledge may sometimes lead to the over-dimensioning of pulpers, which causes unnecessary monetary investment and energy costs for recycled fiber mills.

This study aims to reveal the role of impact energy in the disintegration of various boards in drum pulping. A device was designed to study impact energy by falling, in a controlled way. Board disintegration kinetics due to impacts were monitored by measuring the flake and pulp suspension amounts during pulping.

## MATERIALS AND METHODS

Materials used in these studies were virgin and recycled pulp containing linerboard and old corrugated container (OCC) material obtained from a Nordic board mill. **Table I** summarizes the specifications of materials used in this study. Ash content was analyzed with PrepASH (Precisa, PrepASH129; Dietikon, Switzerland) according to the TAPPI Standard Method T21 om-02 "Ash in wood, pulp, paper, and paperboard: Combustion at 525°C." The tensile strength of materials was tested with an Instron 5544 (Instron; Norwood, MA, USA) that was equipped with a 100 N load cell using the TAPPI Standard Method T 456 om-03 "Tensile breaking strength of water-saturated paper and paperboard." The OCC material used in this study came from a Nordic board factory before being converted. The OCC material consisted of surface layers made from kraftliner with a grammage of 200 g/m². The corrugated layer was a fluting made from semi-chemical pulp with a grammage of 130 g/m².

The material for the study was cut into 20 cm x 30 cm specimens. The specimens were stored for two days in a humidity of 50% and a temperature of 23°C. Impacts by




*1. Designed device for falling-impact experiments. Device was controlled with designed automation configuration. Rotation direction changes every half revolution so that pulp falls to bottom of drum instead of lifter. Device was made from five modules so that it is possible to remove two modules in order to decrease falling height from 3.75 m to 2.75 m.*

| Material | Ash Content 525°C, % | Tensile Index, kNm/kg | Wet Tensile Index, kNm/kg | Grammage, g/m² |
|---|---|---|---|---|
| Kraftliner | 1.2 | 131.7 | 13.0 (9.8 % wet/dry) | 120 |
| Testliner | 11.9 | 64.0 | 3.3 (5.2 % wet/dry) | 125 |
| OCC | 4.6 | n.a. | n.a. | 200 + 130 +200 |

*I. Properties of materials used in this study. Testliner and kraftliner materials were obtained from a Nordic board mill, and OCC material was obtained from a boxboard converting factory.*

falling were studied in a device designed to simulate the falling of pulp in a drum pulper. The device is specified and illustrated in **Fig. 1**. The device was constructed from wood panels, and the bottom was made from a 5 mm aluminum plate that was coated with a hydrophobic resin in order to reduce the adhesion of the pulp suspension to the plate. Wood panels were reinforced with a steel frame. The device was sealed with silicone to make it waterproof. The rotation of the device was cyclic, and the direction of the rotation was changed every half revolution. In this way, pulp was enabled to fall to the bottom of the tower instead of onto the other lifter. The rotation was powered with a 0.75 kW motor, and the motion was controlled with a designed automation system.

The batch size was varied in different tests, but the maximum batch size with a 4 m drum was 13 kg, and with a 3 m drum, it was 17.3 kg due to the motor's torsion limitations. The temperature at the beginning of pulping was adjusted to 43°C. During the 300 fallings, the temperature decreased to 28°C degrees due to the cooling in falling and the transportation of heat from the structure.

The disintegration rate was studied by the flake content of the pulp. It was analyzed according to TAPPI Standard Method T 275 sp-02 "Screening of pulp (Somerville type of equipment)." For screening, a 40 g sample (of dry matter content) was taken, and the flake content was calculated as the mass of the retained pulp on the screen compared to the mass of the feed sample.

Various tests were carried out in order to study the role of falling impact in the disintegration of boards. First, pulp disintegration at two consistencies, 15% and 19%, was investigated. A test was also carried out where the specimen was in a large wire bag, with the assumption that falling would be more controlled and impact more focused. Next, the effect of material strength on disintegration by impacts was studied. Three materials with a consistency of 15% were tested to study the number of impacts needed from a 3.75 m height to disintegrate the material. The batch size in the tests varied from 6.6–17.3 kg.

The impact energy of pulp was estimated using the potential energy equation (Eq. [1]). The effect of mass factor was studied at 2.75 m and 3.75 m heights and with testliner and kraftliner materials. Consistency in the tests was adjusted to 15%. The second factor that could be affected was height, and it was studied with kraftliner and testliner materials. The disintegration of both materials was evaluated with the total energy applied and the impact number. **Table II** lists all of the parameters used in the experiments.

| Figure | Material | Consistency, % | Height, m | Mass of Batch, kg | Mass of Oven Dry Packaging Board, kg | Impact Energy/Fall, J | Energy/Mass, J/kg |
|---|---|---|---|---|---|---|---|
| 2 | OCC | 15 | 3.75 | 13 | 1.95 | 478.2 | 36.8 |
| 2 | OCC | 19 | 3.75 | 13 | 2.47 | 478.2 | 36.8 |
| 2 | OCC | 15 | 3.75 | 13 | 1.55 | 478.2 | 36.8 |
| 3 | Testliner | 15 | 3.75 | 10.3 | 1.55 | 378.9 | 36.8 |
| 3 | Kraftliner | 15 | 3.75 | 10.3 | 1.55 | 378.9 | 36.8 |
| 3 | OCC | 15 | 3.75 | 10.3 | 1.55 | 378.9 | 36.8 |
| 4A | Kraftliner | 15 | 3.75 | 6.6 | 0.99 | 242.8 | 36.8 |
| 4A | Kraftliner | 15 | 3.75 | 10.3 | 1.55 | 378.9 | 36.8 |
| 4A | Kraftliner | 15 | 3.75 | 13 | 1.95 | 478.2 | 36.8 |
| 4B | Testliner | 15 | 2.75 | 10.3 | 1.55 | 277.9 | 27.0 |
| 4B | Testliner | 15 | 2.75 | 13 | 1.95 | 350.7 | 27.0 |
| 4B | Testliner | 15 | 2.75 | 17.3 | 2.6 | 466.7 | 27.0 |
| 5AB | Testliner | 15 | 3.75 | 10.3 | 1.55 | 378.9 | 36.8 |
| 5AB | Testliner | 15 | 2.75 | 10.3 | 1.55 | 277.9 | 27.0 |
| 5CD | Kraftliner | 15 | 3.75 | 10.3 | 1.55 | 378.9 | 36.8 |
| 5CD | Kraftliner | 15 | 2.75 | 10.3 | 1.55 | 277.9 | 27.0 |

***II. Parameters for each study.***

$$E_{potential} = E_{kinetic} = mgh = \tfrac{1}{2}mv^2 = E_{impact} \quad (1)$$

where

E = energy, J
m = mass of falling pulp, kg
g = gravitational coefficient, m/s$^2$
h = falling height, m

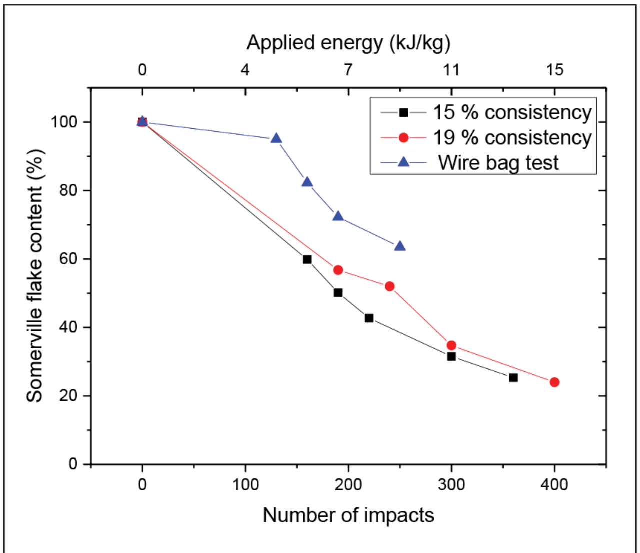
## RESULTS

In the first tests, the effect of consistency was studied. **Fig. 2** illustrates the disintegration rate at two pulping consistencies. Disintegration was found to be faster at a consistency of 15% than at a consistency of 19 % when the same impact energy was used.

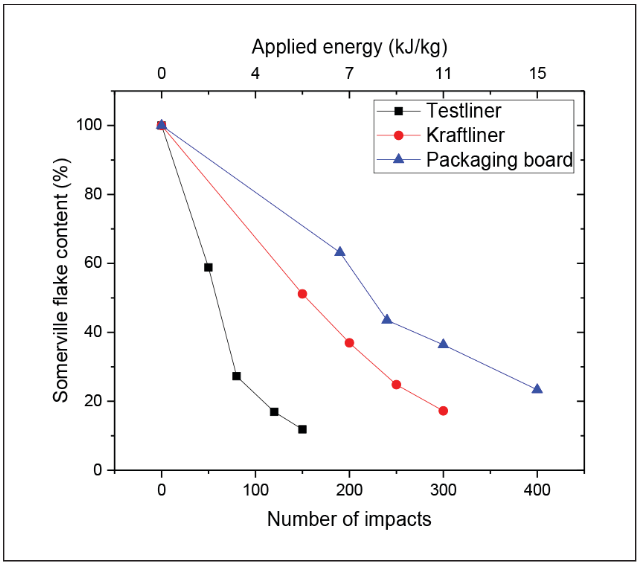
Material disintegration in the wire bag at a consistency of 15% was shown to be much slower, especially at the beginning of pulping.

**Fig. 3** illustrates the role of material strength in the disintegration rate by falling impacts. As expected, testliner, which was the weakest material, disintegrated at the fastest rate, while multilayer OCC disintegrated at the slowest rate. Testliner required 150 impacts in order to achieve a Somerville flake content of 10%. Kraftliner required approximately 300 falls to achieve a 20% flake content. OCC needed 400 impacts in order to achieve a flake content of 25%.

The effect of batch size was tested in the falling tests. **Fig. 4** illustrates the results from those experiments, and Table II presents the impact energies for each fall in those experiments. Fig. 4A presents a 3.75 m fall with kraftliner material with different batch sizes. Fig. 4B presents a 2.75 m fall with testliner material with different batch sizes. The results in Fig. 4B were quite similar to each other, and no differences can be seen from the results. With a stronger material (testliner) and higher falling height, a difference can be seen in the batch sizes (Fig. 4A). The 13 kg batch size disintegrated slightly faster than the smaller batch sizes did. The impact energies varied from 242–478 kJ, which can be seen in Table II for each case.




*2. Effect of falling impact on disintegration rate with two different consistencies and wire bag test at consistency of 15%. All tests were done with OCC material and 13 kg batch, and temperature at the beginning was adjusted to 43ºC.*

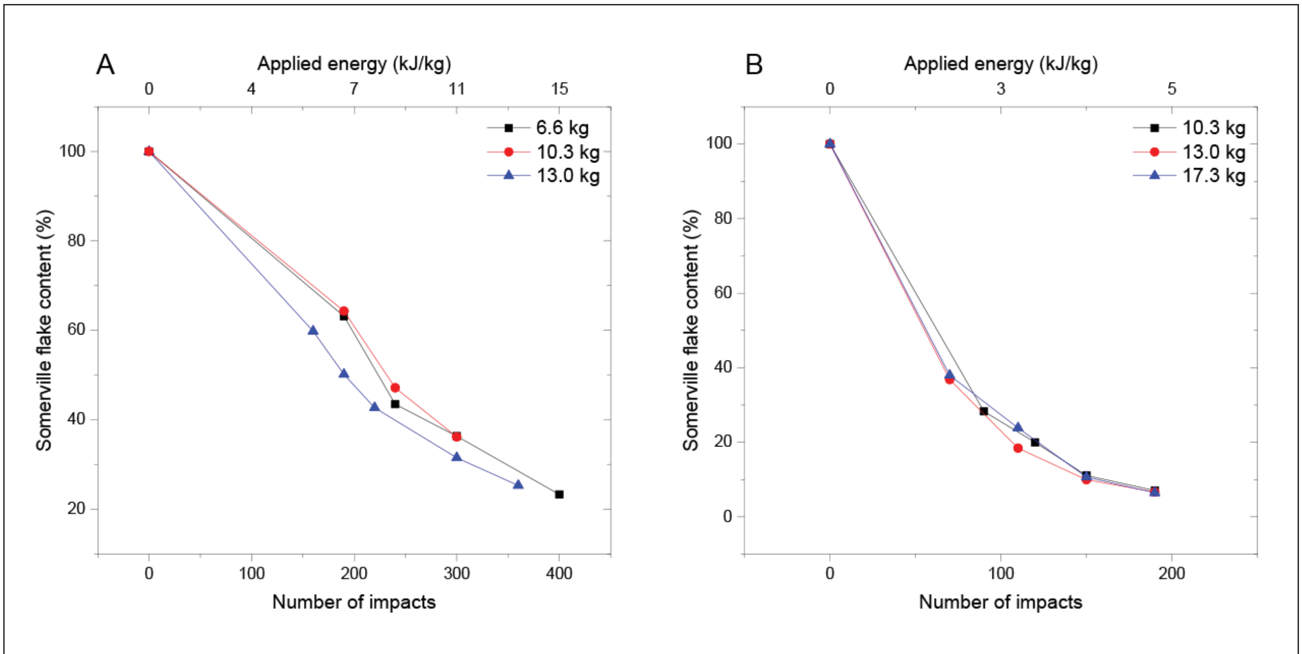



*3. Effect of falling impact on different materials. All tests were done with 10.33 kg batch at 15% consistency, and temperature was adjusted to 43ºC.*

**Fig. 5** illustrates the effect of falling height on two different materials. Fig. 5A illustrates the disintegration of testliner with a different number of falls. According to the results, the disintegration of testliner at a 2.75 m fall is kinetically as fast as it is from 3.75 m. Fig. 5B presents the same experiment, but the number of falls has been changed to present the total energy applied to the mass. When the total energy applied (Fig. 5B) is compared in these cases, better efficiency is achieved with a 2.75 m fall. The same experiment with kraftliner material is presented in Fig. 5C (number of falls) and Fig. 5D (total energy applied). In this case, better efficiency is achieved with a longer falling height. The impact energy for testliner and kraftliner materials from a 2.75 m height was 277.9 J, and from a 3.75 m height, it was 378.9 J.

## DISCUSSION

Disintegration in drum pulping is proposed to occur due to the impacts of falling pulp. The effect of falling impacts in a drum pulper is quite difficult to study in detail because the effect cannot be controlled well enough. Thus, in the present study, a rotating tower with an adjustable falling height was designed, where it was possible to solely investigate the role of falling impact in the disintegration rate of the batches of board materials.



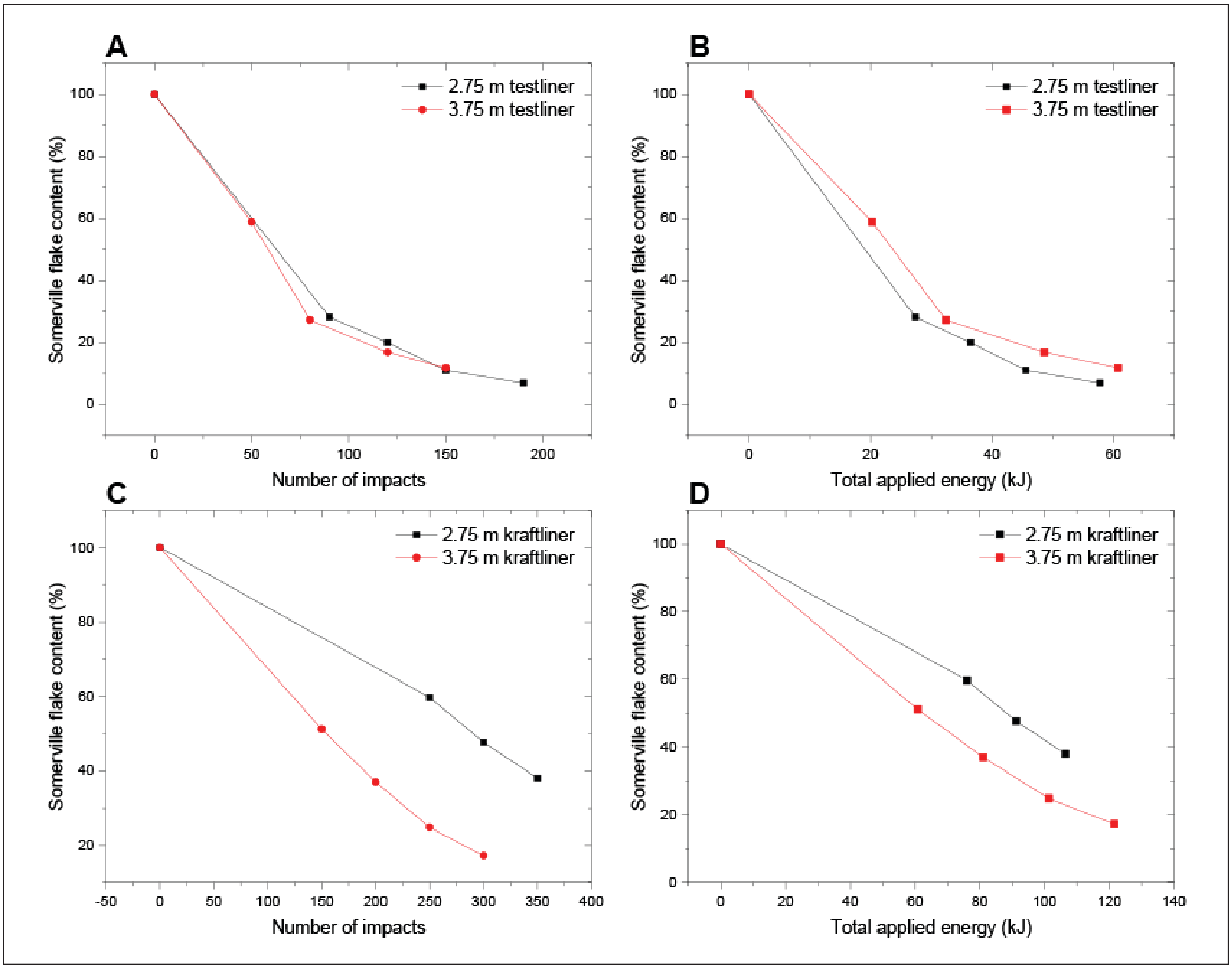

***4. Effect of batch size on disintegration kinetics. Graph A on left illustrates kraftliner disintegration kinetics with various batch sizes for a 3.75 m fall. Graph B illustrates testliner disintegration kinetics with various batch sizes for a 2.75 m fall. Consistency in tests was 15%, and temperature was adjusted to 43ºC.***

Fabry introduced the concept of impact energy [6], which is basically defined as potential energy per mass of pulp suspension (J/kg), for describing the disintegration rate in drum pulping. With this definition, the impact energy in drum pulping fundamentally depends on the diameter of the drum and the mass of the falling pulp if the rotation speed of the drum is assumed to be optimal. Impact alone is not enough for efficient disintegration, however, as shear forces are also needed. This could be seen in our test with the wire bag (Fig. 2). If material could not "flow" freely after an impact, the disintegration slowed down considerably because energy was channeled to the wall instead of to the disintegration of the flakes. Thus, the concept of impact energy should also include mechanical forces due to the deformation, compression, and spreading (flowing) of a pulp batch during an impact.

In this study, two falling heights were tested with two materials: testliner and kraftliner. In the case of testliner, the disintegration rate was not increased, although the falling height was increased from 2.75 m to 3.75 m. In the case of kraftliner, a considerable improvement in the disintegration rate was achieved with the same change in the falling height. In other words, a lower amount of energy was needed to achieve a given flake content. The reason may be related to inefficient wetting in the beginning of pulping as well as the wet strength of materials. By increasing the falling height, the increased impact force may enhance water penetration into board material in the beginning of pulping, leading to a faster disintegration rate. This effect can be seen when kraftliner does not wet as easily as testliner does, as seen earlier [7]. Testliner is probably wetted so fast that disintegration cannot be sped up by increasing the impact force. Similarly, when pulping proceeds and the material has been wetted, the impact energy has to overcome the wet strength of the material [8]. If the impact energy is not high enough, the disintegration rate of the flakes decreases. On the other hand, if the impact energy considerably exceeds the material wet strength, an advantage in the disintegration rate can no longer be seen, as was the case for testliner. The material effect can also be seen in Fig. 3, where in identical conditions, the disintegration rate was about two times faster for testliner than for kraftliner. For three-layer OCC material, the disintegration rate was clearly the slowest—about four times slower than that of testliner.

With kraftliner, the disintegration rate was slightly increased with an increasing batch size, but with testliner, there was no effect (Fig 4). The reason may be related to wetting and the wet strength of materials, similar to the case of falling height. However, the effect of batch size on the disintegration rate was found to be much smaller than on the falling height.

The disintegration consistency was found to have a slight effect on the disintegration rate. At a consistency of 15%, the rate was faster than at a consistency of 19%. The finding agrees with those of Kankaanpää [5] and Fabry [6]. The reason might be due to faster wetting of the multiplied OCC but also due to the more advantageous rheology of pulp. At a lower consistency, mechanical forces might disintegrate the material more effectively during the deformation and spreading of the pulp batch during an impact. It is worth noticing, however, that




***5. The charts illustrate the effect of falling height on disintegration kinetics with two different materials. Batch size in tests was 10.33 kg, consistency in tests was 15%, and temperature was adjusted to 43°C.***

although the batch sizes of the suspension were the same in our experiments, the amount of OCC as a dry mass was about 20% less at a consistency of 15% than at a consistency of 19%. Thus, energy consumption per kg of OCC was higher at a lower consistency at the same flake content level.

The findings of the study have important implications for dimensioning and developing more efficient drum pulpers. The results suggest that in the dimensioning of drums, specific impact energy should be related to both the material wetting rate and the wet strength that disintegration forces have to overcome. By increasing the impact energy, the rate of disintegration increases until the limit. After the limit, use of excess specific impact energy by increasing the drum diameter or batch size do not increase disintegration rate. In other words, an optimal drum diameter may be found depending on the material wet strength properties. However, in the case of strong board grades, the optimal diameter may be way over a practical limit.

Falling numbers in this study were quite high, but residual flake content was still high. If the results in this study would be scaled according to the calculations by Fabry [6], the pulper would be 40 m long (300 falls) with a 1° drum angle. This indicates that falling impact alone is not enough to disintegrate board material. This means that in a drum pulper, some shear forces occur during lifting and rolling, which may play a role in disintegration. This depends, however, on the filling level of the drum pulper. It has been proposed that at a high filling level, excess pulp mass falls down before reaching the optimal falling point and generates a slushing effect, which disintegrates material [9]. These shear forces might play a more important role than earlier recognized.

## CONCLUSIONS

The disintegration of packaging board material due to the impacts of falling in drum pulping was studied. The stronger the material, the more important is falling height, i.e., the potential energy to be converted to disintegration forces by an impact. However, the excess impact energy does not increase the disintegration rate in drum pulping after a given threshold value related to material strength. The results also suggest that impacts by falling alone are not enough for the thorough disintegration of packaging board material, as other mechanisms are also involved. **TJ**

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We chose this topic because pulping is one of the most energy consuming unit operations in the OCC recycling process, and there are very few publications about OCC pulping, especially drum pulping. It has been said that falling impact is the major disintegration mechanism in drum pulping, but there have not been any studies where this disintegration mechanism was isolated. Previous studies have primarily shown the important parameters in pulping efficiency during drum pulping.

The most difficult aspect in this study was the isolation process for falling impact as a disintegration mechanism. It took a few months to come up with a workable solution for problems in design of the falling device.

The most interesting part of this research was the force and sound that the falling pulp has during impact. Personally, it was surprising to find out how big the difference was between disintegration kinetics with different materials. This aspect provides possibilities, but at the same time it is troubling since the best fibers are found in the strongest materials.

The results of this study provide some basic knowledge about drum pulping and some new ideas for next generation drum pulpers that work more efficiently.

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