Point load measurements on paperboard packages and bulging

CAMILLA PERSSON, PATRIK KARLSSON, ANDERS BIEL, ULF STIGH, CHRISTOPHE BARBIER, MIKAEL NYGÅRDS, JOHAN TRYDING, HANNES VOMHOFF, AND CHRISTER KORIN

ABSTRACT: Paperboard packaging is made by processing board materials into sheets or rolls and shaping them through creasing, cutting, folding, and erecting. The conversion process generates residual moments at the folds that cause panel bulging. This study experimentally investigates how the bulging introduced during the converting processes influence the mechanical response of paperboard packages during point load testing within the elastic deformation range.

The study shows that panel bulging may significantly affect packaging performance as-perceived strength and stiffness. Bulging, influenced by the board's basis weight, can affect the package performance even more than packaging stiffness. Point load tests in the elastic region were performed on empty packages (78 mm × 50 mm × 110 mm) with force applied at specific points along their long sides. The packages evaluated in this study were made of two identically processed materials of different grammages. The heavier material showed more pronounced bulging than the lighter one, leading to overlapping force-displacement curves for the packages, and to that, a lower force and stiffness may be measured at a certain indentation depth for the package of heavier material. This complicates material choice according to functional requirements.

The results show that a highly bulged package might resemble one with less bulging of another material. According to the results, it is not certain that a higher grammage package shows a higher indentation force and stiffness than a lower grammage package when measured at a certain indentation. This indicates that optimizing the creasing and folding processes can be a way to enhance performance rather than simply increasing board weight. The study underscores the importance of controlling converting parameters, especially creasing and folding behavior. Well-performed creasing and folding gives a low residual momentum, little bulging, and a high stiffness and compression strength at point loading in the elastic region. Proper optimization can improve packaging performance and manual handling user-friendliness.

Application: The results from this study are of significant importance for the package industry, especially in package design, as the results show that a lower grammage may give a higher stiffness, depending on loading position.

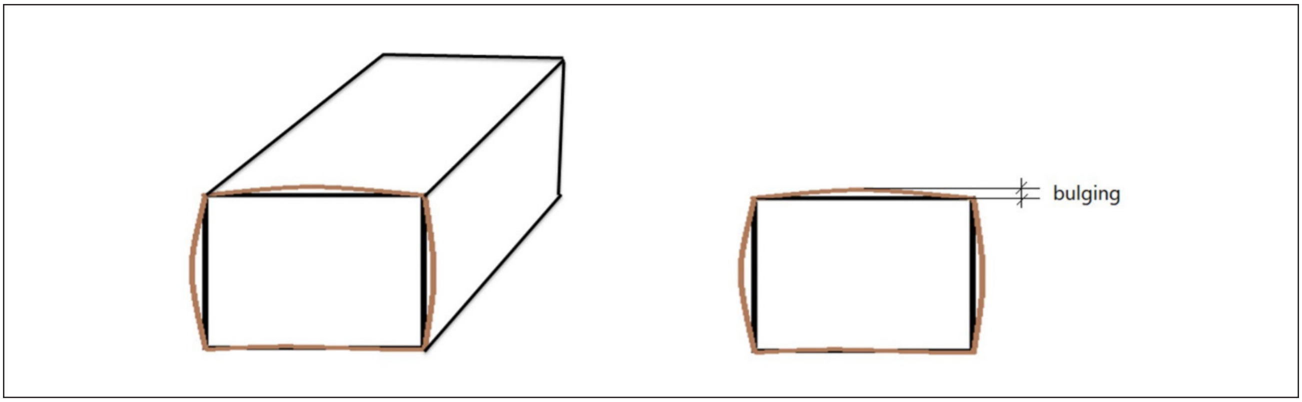
Paperboard packages protect the contained product from external damage. At the same time, this functions as a marketing tool for the product [1]. The latter role makes it essential for the packaging to convey the appropriate quality of the product. For instance, stiffer packaging is typically associated with luxury products, whereas flimsier packaging is used for lower-priced items [2]. Moreover, consumers often reject products in damaged packaging, even if the products themselves remain intact [2]. Beyond protection and marketing, packaging also contributes to user-friendliness. Flimsy packaging, for example, may lead to excessive application of pressure, potentially causing spillage of the contents, which can negatively impact both repurchase behavior and environmental sustainability [2,3].

For these reasons, understanding the influence of packaging conversion on packaging performance is critical. This paper investigates the response of paperboard packages to point load and the differences that occur depending on bulging and the placement of the point load.

Paperboard packaging is produced from single- or multilayer board materials converted into sheets or rolls. The converting process continues with creasing, cutting, folding, and erecting to form the packaging, which can be filled and used by the consumer.

Creasing is a folding guide where the material is intentionally deformed and damaged to reduce bending resistance. The paperboard is compressed by a creasing tool against a matrix. Depending on the creasing parameters (e.g., matrix dimensions), in relation to the paperboard thickness, varying residual moments arise during folding, resulting in different degrees of panel bulging. A high residual moment is associated with significant bulging, as the residual moment forces the packaging panels to bulge outward, as seen in **Fig. 1**.

Point load measurement is a conventional method to evaluate packaging properties, generating force-displacement diagrams that provide insights into material and packaging characteristics, such as stiffness and compression strength.



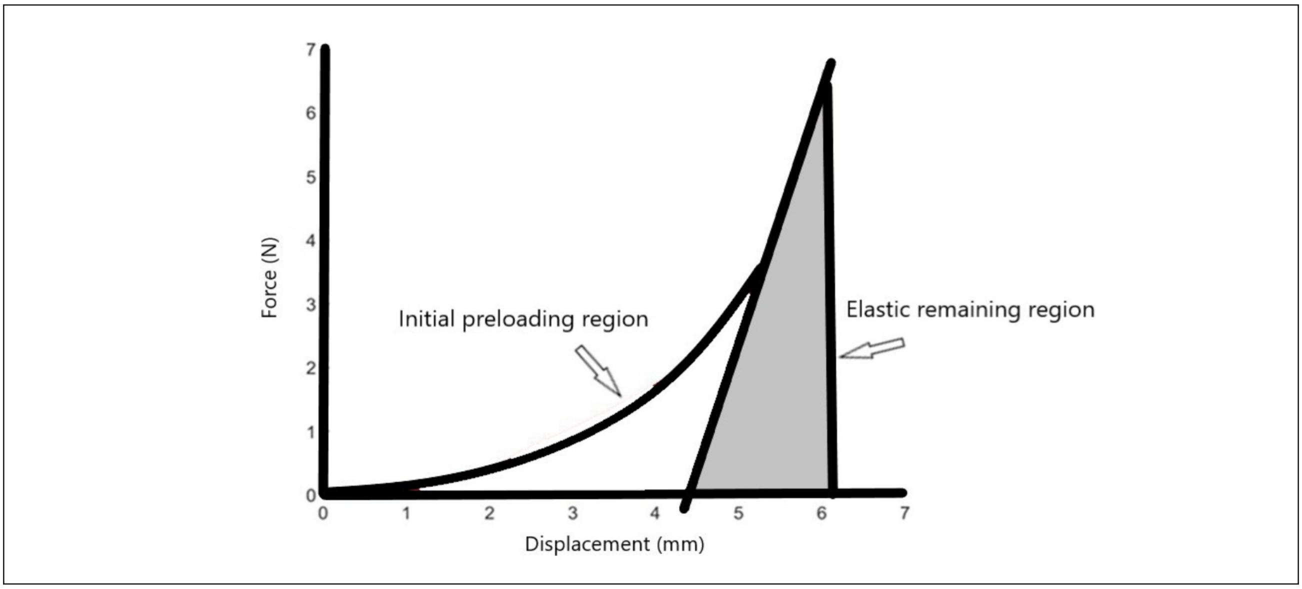
1. Bulging of a package cross-section; deviation from the ideal rectangular shape.

In addition, the point load situation can be said to constitute a first approximation of how a package is mechanically affected during handling. People use several different types of grips combined in movement patterns to gather information about the packages they handle [4,5]. Point load measurement is a way of approximating how a package is mechanically affected in a grip situation. The point load is thought to be exerted by a finger pressing against the package while the package has a counter-hold on the other side [4].

In this study, packaging stiffness is measured to gain knowledge of factors that may influence the perceived stiffness, or in other words, grip stiffness, of the package for the studied load case. From here on in this study, packaging stiffness and grip stiffness will be used interchangeably as synonyms.

Figure 2 illustrates a typical force-displacement curve for packaging subjected to point load testing in the elastic region. The area under this curve can be divided into two energy regions: the initial preloading region and the elastic remaining region (in the same way as performed for another situation of loading [6]). Initially, the curve exhibits a shallower slope in the initial preloading region as the sample begins to experience load. It then transitions to a steeper slope in the elastic remaining region. When the package is loaded within the elastic region, it deforms but returns to its original shape upon unloading. If the package had been loaded beyond the elastic region, the slope of the force-displacement curve would have decreased, and yielding and plastic deformation would have occurred, which would result in material hardening, irreversible geometrical changes, and residual deformation after unloading.

The present study involves point load measurements on paperboard packaging within the initial preloading region and elastic remaining region, terminating the test before plastic deformation occurs. These regions are the most interesting to study in order to understand the first packaging experience during handling, describing how the package



2. A typical force-displacement curve of a package point loaded within the elastic region with two energy areas under the curve showing the initial preloading region (white) and the elastic remaining region (light grey).

Position of Load Point		Material in the Package, g/m²	Material Thickness, µm	Number of Experiments
C1A	15 mm	315	455	11
C2A	15 mm	340	505	11
C1B	30 mm	315	455	11
C2B	30 mm	340	505	10

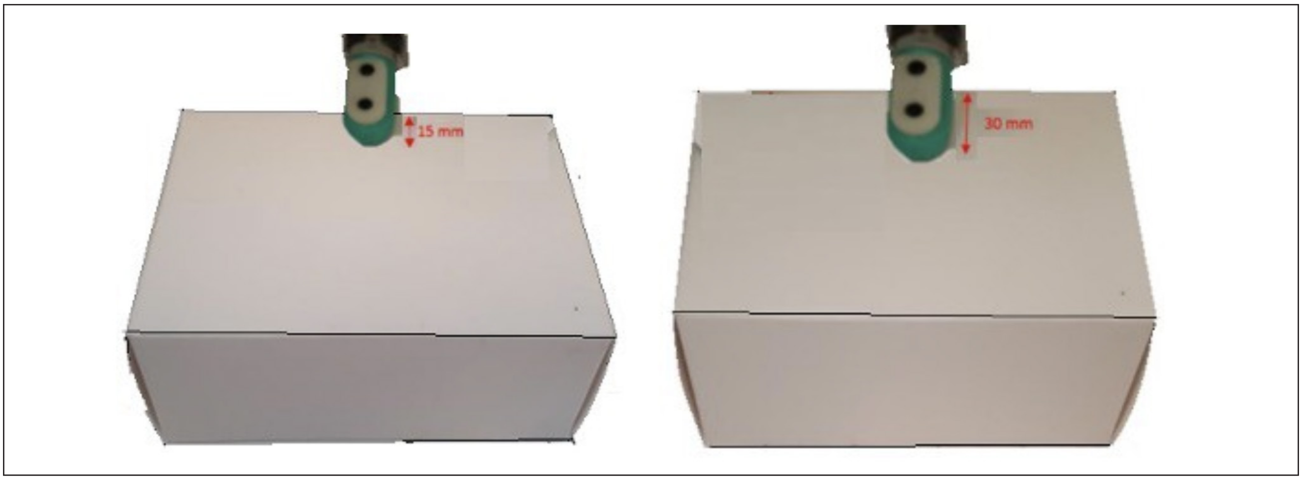
I. Test setup for the measurements.

is perceived when it comes to grip stiffness [7,8]. The aim of this study is to provide examples of how mechanical properties can be objectively measured using point load testing and how bulging for a packaging design can influence the interpretation of the results. Additionally, the study demonstrates the impact of bulging on the outcomes of point load measurements of paperboard packaging.

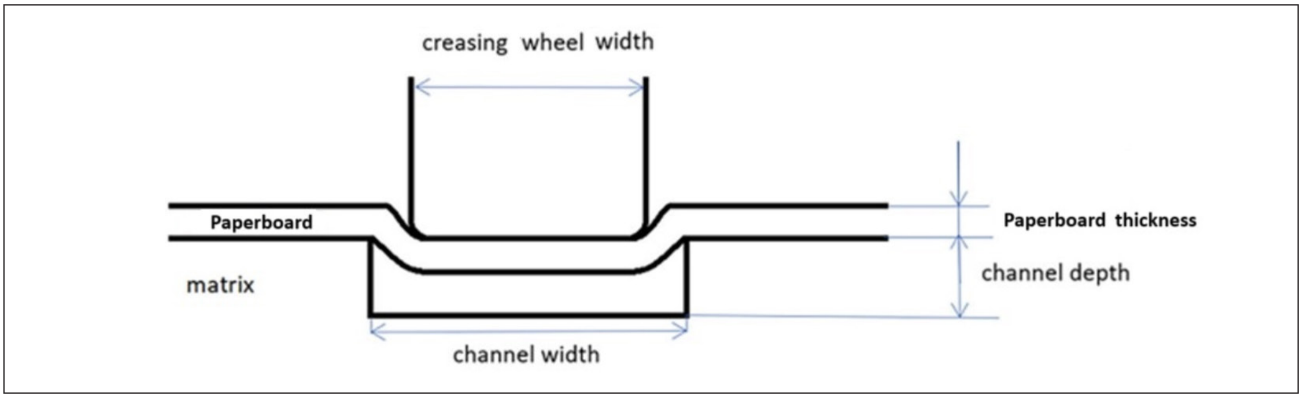
MATERIALS AND METHODS

This study investigates point load measurements within the elastic region on several seemingly geometrically identical paperboard packages. These packages were produced using the same process, with the intended geometry of rectangular blocks measuring 78 mm x 50 mm x 110 mm, but made from paperboard materials with two different grammages, as shown in **Table I**. The loading and measurements were performed in the same location at the midpoint of the long side of the empty packages, 15 mm and 30 mm inwards from the long edge, as illustrated in **Fig. 3**. Two different distances from the edge were chosen in order to study the influence of the distance to the edge.

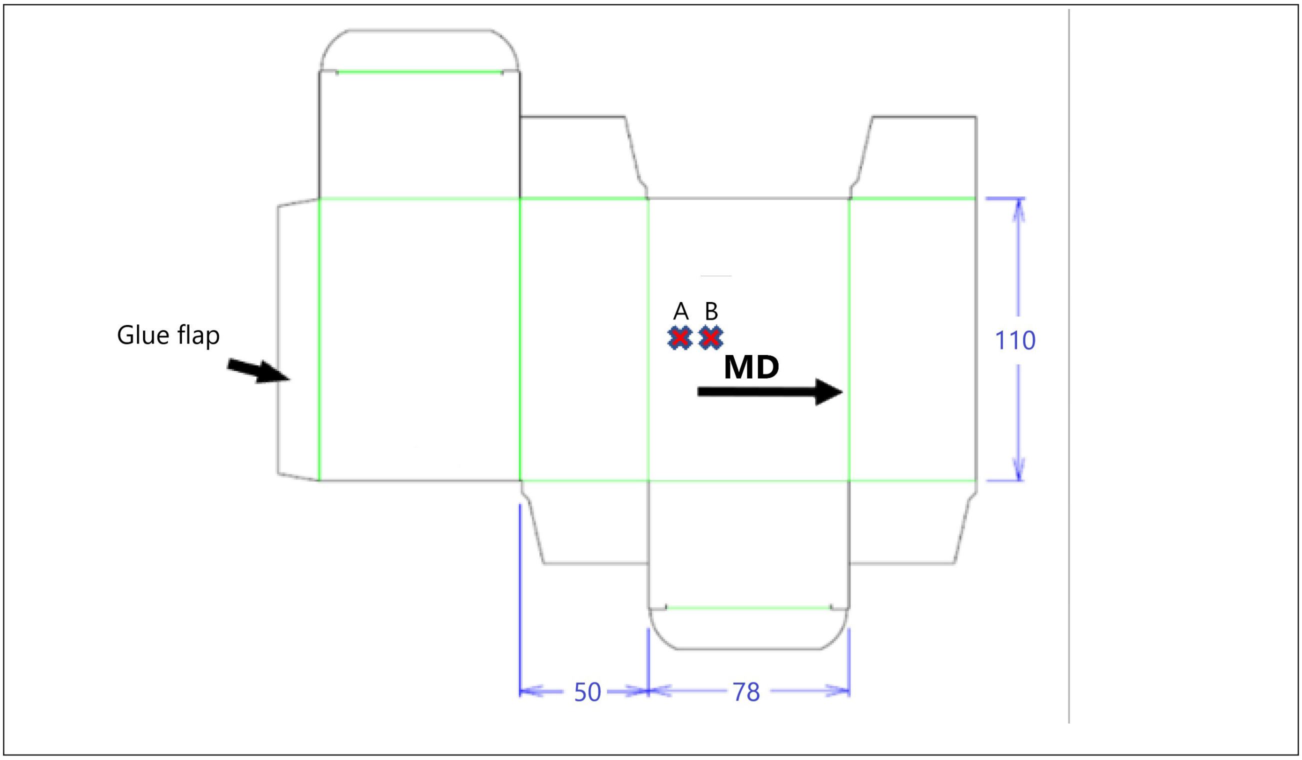
The paperboard used in this study is commonly made as



3. Positions of point loading on the package. This figure illustrates the positions at (a) 15 mm and (b) 30 mm where point load measurements were applied to the pack.



4. Schematic representation of the components of the creasing process.



5. The blank of the packages shows the placement of double-sided adhesive tape on the glue flap. Position A and Position B, where the loads are applied in the measurements, are shown with the two red "X" labels.

packaging material for luxury products, including cosmetics, chocolate, and pharmaceuticals. It is a four-ply board, with the plies bonded together through couching. The outer plies are composed of chemical pulp, while the inner plies consist of chemithermomechanical pulp (CTMP) and broke. The paperboard is coated with clay coating on both sides.

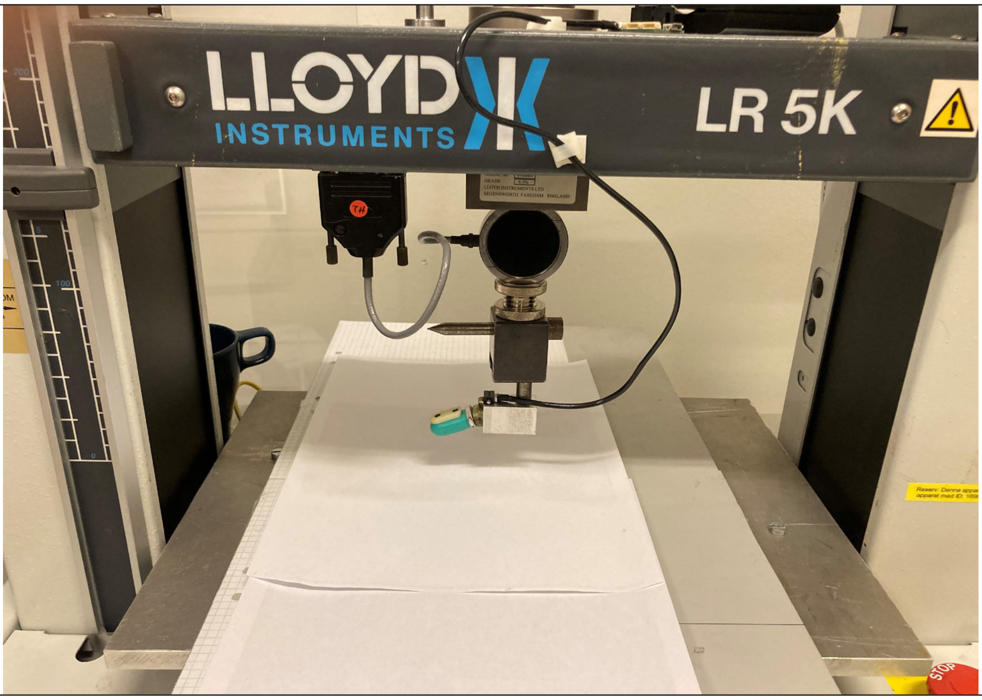
The paperboard packages were produced in a climate-controlled environment with temperature of 23°C and relative humidity of 50% using a Kongsberg Esko CAM table (Kongsberg Precision Cutting Systems; Ghent, Belgium) for creasing and cutting. **Figure 4** illustrates the various components of the creasing process that have an influence on the outcome of the creasing [9]. To achieve a channel depth greater than the thickness of the creased paperboard, a matrix made of the same paperboard material but with a higher grammage was used as a creasing matrix, and the matrix width was 1.6 mm for creasing 315 g/m^2 and 1.7 mm for creasing 340 g/m^2 paperboard. Creasing was performed using a two-point (0.71 mm) creasing wheel before the blank was cut.

The blanks were allowed to rest for at least 4 h before the packages were folded and manually erected. To minimize variations, the same procedure was followed for each package. Double-sided tape was applied to the glued flap along the long side to seal the box longitudinally. The position and size of the double-sided tape were the same in all experiments. **Figure 5** illustrates the package blank and the taping process.

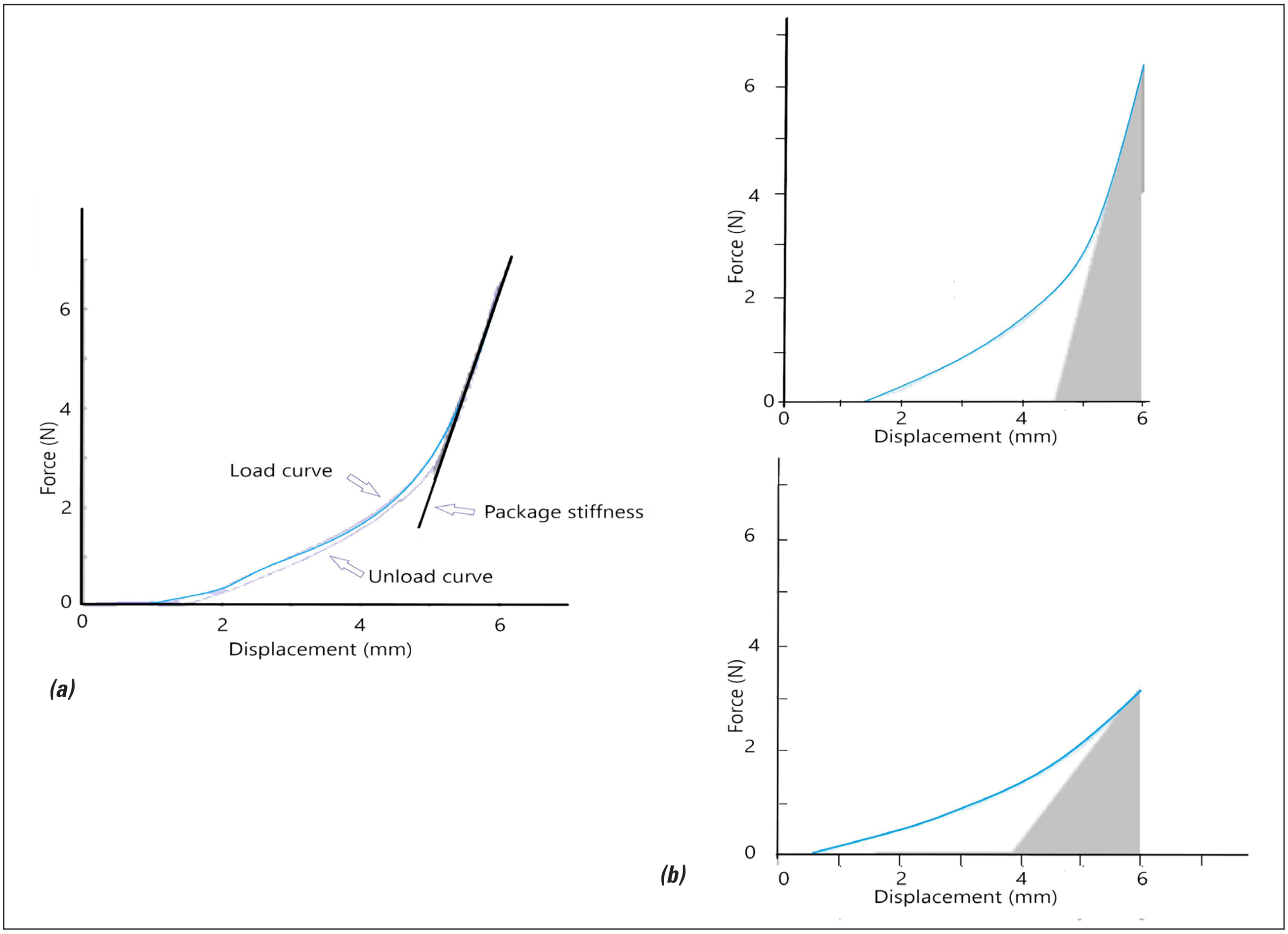
The paperboard packages were subjected to point loading within the elastic range while the force-displacement curve was recorded. The temperature was 21°C–22.5°C during measurement and the relative humidity was 31%–39%. A uniaxial testing machine, a Lloyd LR5K compression tester (AMETEK Sensors & Fluid Management Systems; Wilmington, MA, USA), was used for the point load and is show in **Fig. 6**. The used indenter was a Biotac tactile sensor (Syntouch Inc., Montrose, CA, USA). A more comprehensive description of the test equipment is given in Eriksson et al. [10]. To ensure that the measurements were performed solely within the elastic range, a downward displacement of approximately 5 mm was selected. A package was placed on the testing table to achieve this, and the indenter was lowered onto the paperboard until a force of 0.02 N was registered. The indenter was then raised 1 mm, and the position of the indentation was zeroed. The test was initiated from this level for all packages, and the indenter was lowered to 6 mm at a constant speed of 60 mm/min. A total of approximately 10 paperboard packages were tested for each testing situation. Figure 3 and Fig. 5 show the different positions of point loading on the package. Each force-displacement curve was analyzed individually and then in groups.

RESULTS AND DISCUSSION

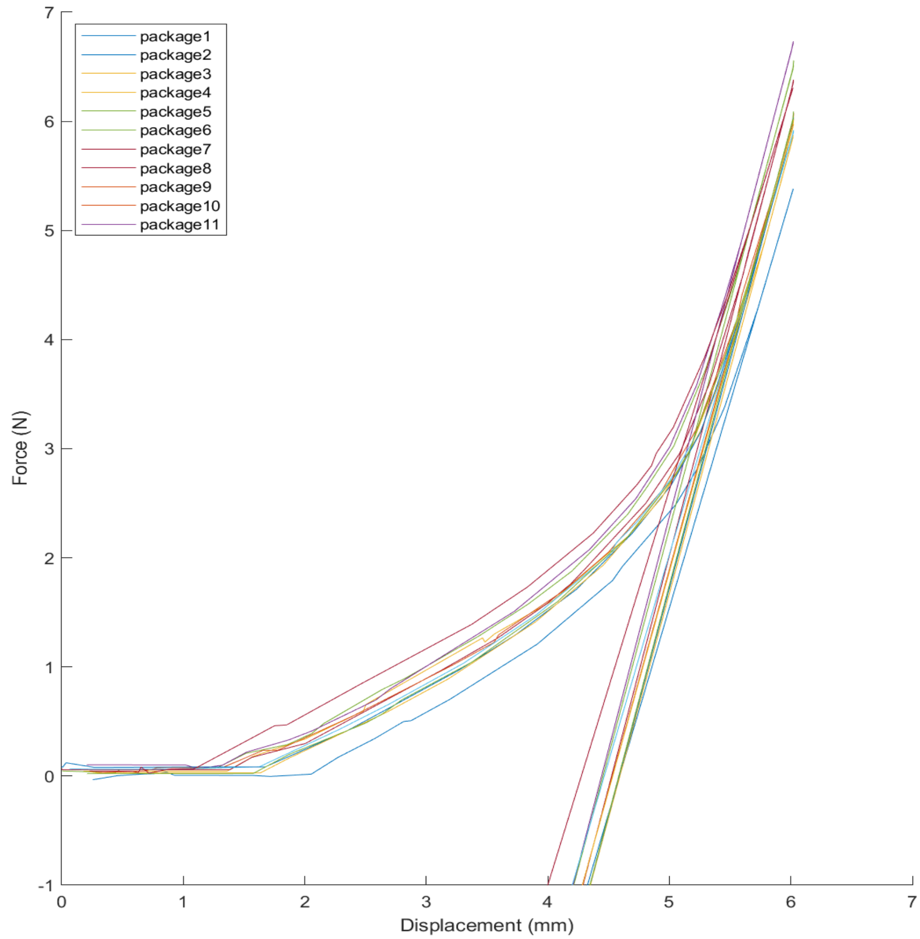
Figure 7a presents a typical force-displacement curve obtained from the measurements. The force increases after



6. The uniaxial compression test machine used.



7. (a) A typical force-displacement curve obtained from the measurements. (b) Force-displacement curves for a package loaded in test setup C1A, respectively, in test setup C1B. See Table I for description of test setups.



8. Loading curves (i.e., up to the maximum displacement) and packaging stiffness tangents drawn in the same color for all packages in test setup C1A.

approximately 1 mm of displacement as the measurement probe contacts the packaging. The measurement remains within the elastic region as the force increases during loading and then decreases back to zero similarly. Thus, it is confirmed that all measurements fall within the elastic region. The force-displacement curve shows two slopes along its trajectory, which aligns with an initial preloading region and an elastic remaining region, as illustrated in Fig. 2.

In Fig. 7b, two force displacement curves are presented. The white areas under the beginning of the force-displacement curves represent the initial preloading region, while the light grey areas represent the elastic remaining region. The initial preloading region is estimated to primarily reflect the deformation of the tactile sensor and tensioning of the panel bulging. If the bulging is large (i.e., the creased and folded paperboard exhibit significant spring-back), the indenter will hit the package early during down movement from the fixed-in-space position. The elastic remaining region is primarily estimated to reflect the packaging stiffness where the influence of the material's bending stiffness is reduced, and the compression of the side panel has a more significant impact. At this indentation depth, the rear part of the sensor near the standing panel takes load, suggesting that the standing panel has significant influence [10].

Figure 8 presents the force-displacement curves for all packages during test setup C1A loading. It is observed that the force begins to increase (i.e., the indenter contacts the top surface of the package) at different displacements for the various packages. This can indicate variations in bulging and potential variations in the thickness between the packages. However, in this case, only one type of paperboard was used (i.e., the paperboard thickness remains constant). The force-displacement curve consists of measurement points recorded at intervals of 0.01 mm. **Table II** presents the displacement values for all packages in test setup C1A, at which the force increases by at least 0.1 N, representing an approximate displacement at which the indenter starts to take load, thereby indicating the top surface level of the package. The difference in displacement at this force level is observed to be up to approximately 0.9 mm.

Another way to assess the initial contact, referred to as bulging, is to examine where the tangent representing the

Package	Paperboard Surface Level, mm	Packaging Stiffness, N/mm	Indentation Distance of the Initial Preloading Region, mm
1	1.88	3.77	2.71
2	1.34	4.11	3.25
3	1.40	4.15	3.05
4	1.56	4.25	2.96
5	1.17	4.04	3.36
6	1.30	4.26	3.15
7	1.72	3.79	2.74
8	1.89	4.17	2.69
9	1.60	4.02	2.93
10	1.54	4.20	3.05
11	1.00	3.62	3.28

II. Estimation of the paperboard surface level (displacement at 0.1 N force; a low value represents contact with the package surface earlier and thus more bulging than a high value); packaging stiffness; and distance between where the stiffness tangent intersects the displacement axis and where 0.1 N force is registered (the force has started to increase) for each package in test setup C1A.

stiffness intersects the displacement axis, as illustrated in Fig. 8. The distance between the point where the indenter starts to take load and the intersection of the stiffness tangent with the horizontal axis gives the indentation distance of the initial preloading region.

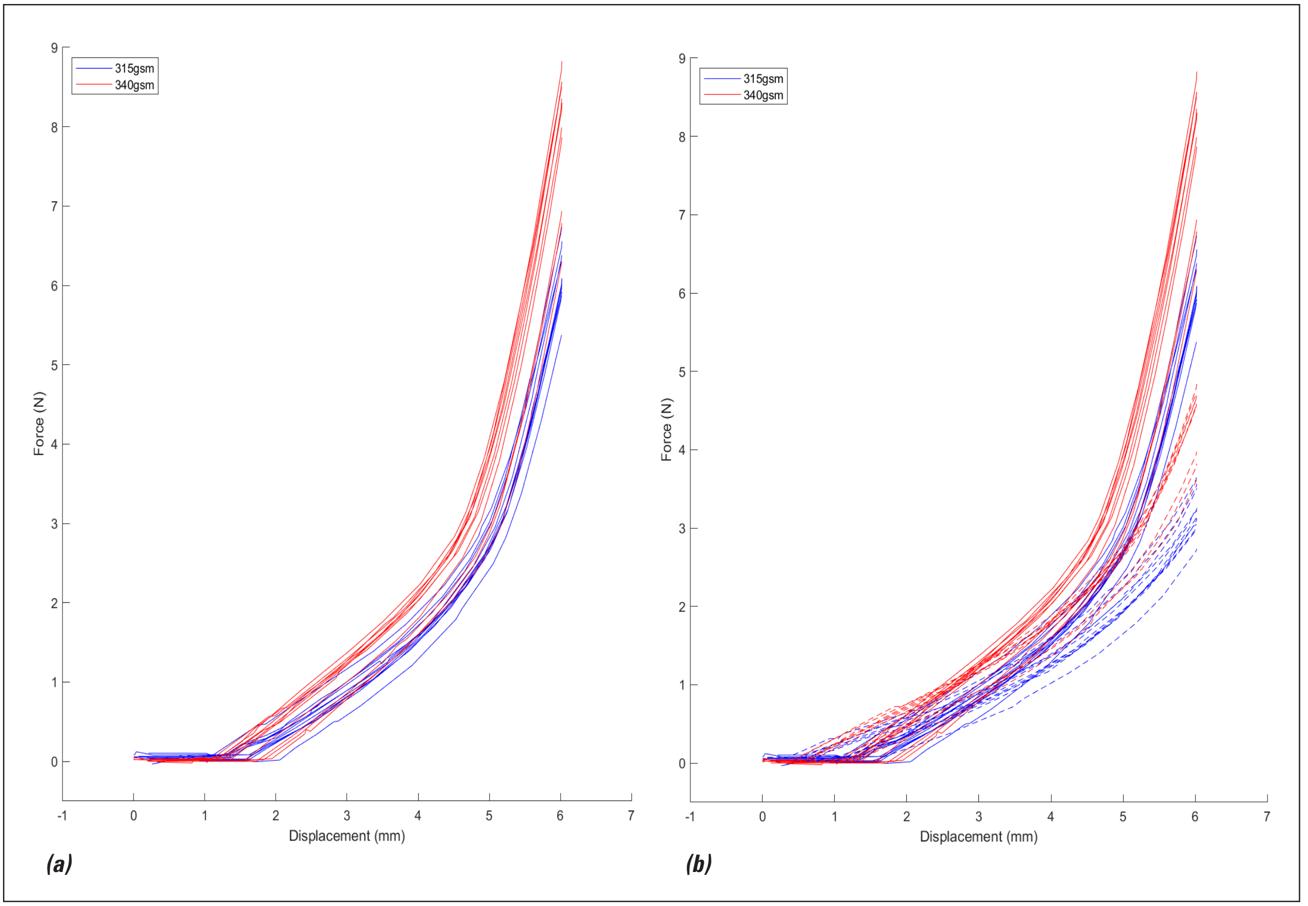
Table II presents each package's packaging stiffness and bulging related values. The packaging stiffness was calculated as the slope of the last 25 data points (approximately 0.25 mm) preceding the maximum load recorded during the measurement for each package. Because the measurement was conducted within the elastic region, the packaging stiffness, characterized by the most significant slope, was observed immediately before the maximum registered force.

The two force-displacement curves in Fig. 7b are from measurements on a 315 g/m^2 (low grammage) package at the two specific studied distances from the long-side fold. These graphs illustrate two different looks of the force-displacement graph. The package has a larger bulging in Position B as indicated by the displacements at which the indenter starts to take load (at 1.56 mm indentation in Position A and at 0.87 mm indentation in Position B for the studied package). As the indenter hits the package earlier in Position B, the bulging is greater there than in the A position. The indentation distance of the initial preloading region, measured as the distance between the indenter loading start and the stiffness tangent intersection of the displacement axis, is roughly the same in this case (2.96 mm in Position A and 2.98 mm in Position B). The initial preloading region and the elastic remaining region, however, differs (initial preloading region 4.90 Nmm in Position A and 4.37 Nmm in Position B; remaining elastic region 6.07 Nmm in Position A and 4.31 Nmm in Position B).

The packaging stiffness and indentation distance within the elastic remaining region have a dominant influence on the force required during point loading, as seen in Fig. 7b and Fig. 8. If the package is loaded more in the elastic remaining region than in the initial preloading region (i.e., to a deep depth), the loading force and strength in the test will increase.

The distance indented depends on the indentation distance set for the measurement and from which point the indentation distance is set — a fixed point in space or relative to the package surface. For measurements relative to the packaging surface, a large bulging may underestimate the stiffness. Low bulging leads to a higher final force, and significant bulging leads to a low final force within the measurement.

The advantage of conducting measurements within the elastic region is that multiple tests can be performed on the same package. However, when different packages with the same geometry are used, varying creasing and folding results can lead to differences in bulging. If multiple measurements are averaged, inconsistent bulging can introduce measurement errors. When calculating an average from multiple measurements, variations in bulging must be carefully considered, as different values may be achieved depending on how the average stiffness is derived. Additionally, if packages made from materials with different grammages have varying levels of bulging, this can create the appearance that packaging stiffness values originate from the same measurement, even when significant differences in grammage exist between the measurement situa-



9. (a) Force-displacement curves for the two different materials, i.e., test setup C1A and C2A. The red curve represents the material with the highest grammage (340 g/m²), while the blue curve corresponds to the material with lower grammage (315 g/m²). (b) Force-displacement curves for two different measurement positions: C1A and C2A (closest to the crease, 15 mm, represented by solid lines), and C1B and C2B (furthest from the crease, 30 mm, represented by dashed lines). Different colors distinguish different material types.

tions. Depending on where the package is loaded, the bulging differs at the loading place. If point load measurements on the packages are compared, neglecting where the loading places are the influence of the bulging differences might be misinterpreted as the packages originating from the same grammage, as demonstrated in **Fig. 9**.

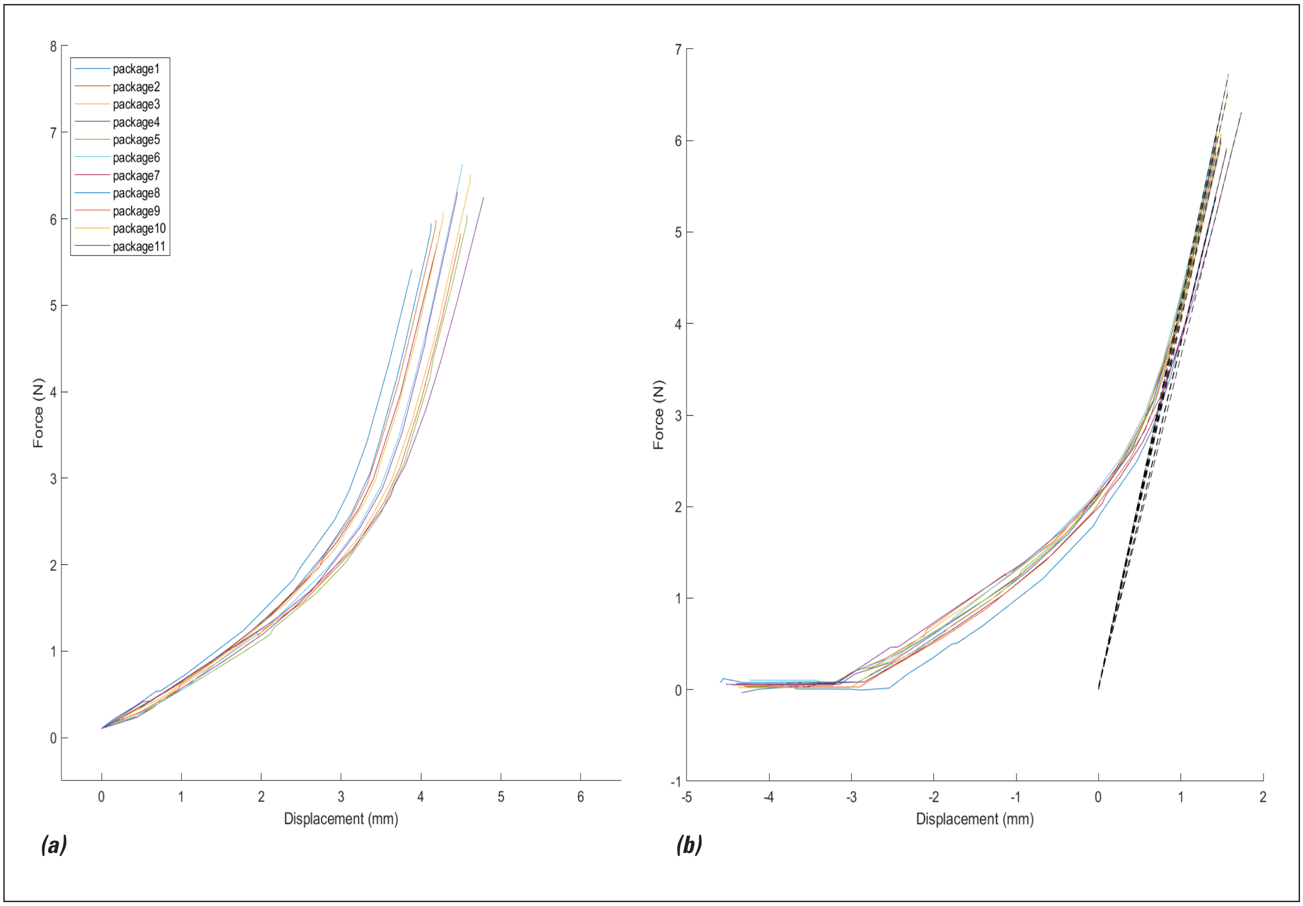
Figure 9a illustrates that the stiffness of the higher grammage packages is larger than that of the lower grammage packages, and that during the indentation, a higher force is reached for the packages of the stiffer material during the point load measurements. To the right (in Fig. 9b), force displacement curves are shown for the two studied distances from the long-side fold and its standing panel. The impact of bulging becomes more pronounced further from the fold, as the edge panel begins to carry the load close to it. The solid blue curve in Fig. 9b, Position B, could be misinterpreted as corresponding to the dashed red curve at Position A.

A usual approach for assessing packaging is to present measurement results as averages, which may involve adjusting the curves in various ways to enable the presentation of average curves. Questions that arise in this case are: should the average be taken for the same place in room coordinates, or should it be taken for the same indentation depth from the top surface of the package, or for the same beginning of the remaining elastic region? In the way these measurements have been performed, the latter alternatives involve adjustment of the curves to enable averaging.

Figure 10a shows how the force-displacement curves of the packages differ when adjusted to start taking load at the same point, and Fig. 10b how they differ when adjusted so that the elastic remaining region in the force-displacement curve starts at the same point.

Figure 11 presents the averaged curves as follows: (a) without adjustments; (b) adjusted to start at zero indentation scale when the indenter contacts the top surface of the paperboard and starts to take load; and (c) adjusted so that the elastic remaining region starts in the same point. The measured packaging stiffness for each package in test situation C1A is shown in Table II.

Table III shows the stiffness differences that can be seen in different mean value formation with the setup de-



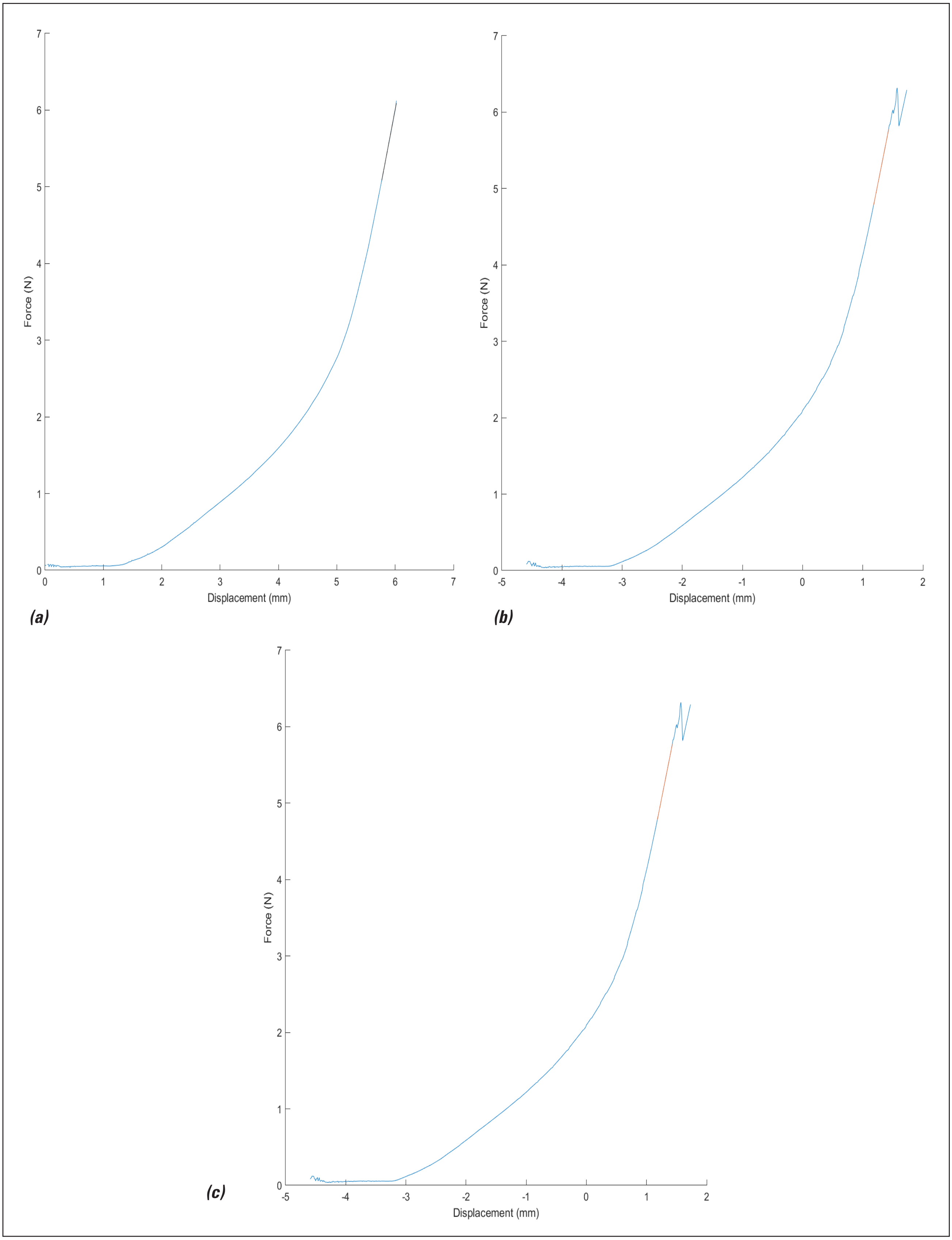
10. (a) Force-displacement curves adjusted along the displacement axis so that all curves begin to rise at 0.1 N of force at zero displacement. (b) Force-displacement curves, when adjusted so that the elastic region under the force-displacement curve starts at the same displacement.

scribed in this work. The stiffness has been calculated within the area marked in the graphs, which accommodate all loaded packaging. It becomes evident that if average value computation is performed before calculating the stiffness average, the results show significant differences depending on how the averaging process is conducted. Extracting the stiffness values for each individual package and averaging them is considered to give the most relevant results. It also enables the calculation of dispersion measures, such as standard deviation.

For the previously-noted reasons, **Table IV** was generated by calculating the stiffness values for all measurements and then averaging the stiffness. Additionally, related average bulging and energy region characteristics are given in **Table V**. According to Table IV, it becomes evident that the impact of bulging results in significant stiffness differences, where significantly lower stiffness is obtained where a more pronounced bulging is present at Position B than in Position A. Thus, if measurements are conducted at the lower grammage in Position A, they will result in a higher

Description	Packaging Stiffness, N/mm
Based on each curve individually	4.03
Based on the average of curves (no adjustment)	4.03
Based on the average of the loading curves adjusted to start at 0.1 N load	3.09
Based on the average of the loading curves adjusted so that the elastic region starts at the same point	3.97

III. Average stiffness based on various curve analyses. The material used was 315 g/m², with the position at 15 mm.



11. Averaged curves without and with different adjustments: (a) without adjustments; (b) adjustments to start in zero; and (c) adjustments to same point of tangent intersection.

Test Setup	Packaging Stiffness, N/mm	Standard Deviation, N/mm	MaximumValue, N/mm	Minimum Value, N/mm
C1A	4.03	0.22	4.26	3.62
C2A	5.18	0.32	5.64	4.67
C1B	1.41	0.23	1.87	1.15
C2B	2.35	0.23	2.69	1.96

IV. Average stiffness values, standard deviation, and maximum and minimum values for both materials at the two different positions.

Test Setup	Paperboard Surface Level, mm indentation	Indentation Distance of the Initial Preloading Region, mm	Initial Preloading Region, Nmm	Remaining Elastic Region, Nmm
C1A	1.48	3.02	3.80	4.62
C2A	1.38	3.12	4.63	5.93
C1B	0.89	2.83	2.66	3.66
C2B	0.79	3.36	4.12	4.12

V. Average bulging characteristics and initial preloading region and remaining elastic region for the different measurements

stiffness value compared to measurements for the higher grammage at Position B. In addition to changing the material on a package, one way to affect the perceived stiffness and strength of the packaging can be to influence where the packaging is loaded during handling. Consumers may perceive different grip stiffness of the package depending on where they touch the package.

The results from the present study are of significant importance for the package industry and especially in package design, as the results show that a lower grammage may give a higher stiffness, depending on loading position.

CONCLUSION

When measuring point load within the elastic region, it is essential to account for bulging and to recognize its impact on measurement results and their interpretation, particularly when averaging multiple measurements. Bulging can be illustrated by the point at which the indenter takes load and the force begins to increase on the force-displacement curve or by the distance from this point to where the stiffness tangent intersects the displacement axis. Differences in bulging are more pronounced when point load measurements are taken further from package folds where standing panels take load. All samples in this study have been creased, folded, and erected using the same process. The force-displacement curves exhibited such variability depending on measurement position that the experimental results for packages of different materials overlapped. Consequently, it is not always possible to determine the material of a paperboard package based solely on a single force-displacement curve from a point load measurement. More information as measurement position is needed. A package with significant bulging can exhibit similar properties to a package made of another paperboard material with less bulging, depending on loading place.

When evaluating packaging stiffness, it matters whether the stiffness is calculated individually for each package and then averaged or whether the force-displacement curves are averaged before determining stiffness. In this study, the difference in measured stiffness depends on the method employed and is comparable in magnitude to the stiffness differences between materials.

ACKNOWLEDGMENTS

This study is part of the research project Characterisation of Paperboard for Creasing and Folding (CPCF) financed in part by the Knowledge Foundation, Sweden, Tetra Pak Packaging Solutions AB, Billerud Sweden AB, and Holmen Iggesund Paperboard AB. The CPCF is a joint project involving Örebro University, Karlstad University, and the industrial partners. Support from all partners is gratefully acknowledged. The authors would also like to express gratitude to Ahmed Abdulkareem and Omar Al-Radi for their valuable contributions to the execution of the laboratory measurements.

LITERATURE CITED

1. Judd, D., Aalders, B., and Melis, T., *The Silent Salesman – Primer on Design, Production and Marketing of Finished Package Goods*, Continental Press, Singapore, 1989.
2. Löfgren, M. and Witell, L., *QMJ* 12(3): 7(2005). https://doi.org/10.1080/10686967.2005.11919257.
3. Kano, N., "Life cycle and creation of attractive quality," *4th Int. QMOD Conf.*, Linköping University, Linköping, Sweden, 2001, p. 18.
4. Eriksson, D., Loeb, G.E., Persson, C., et al., *Nord. Pulp Pap. Res. J.* 35(3): 362(2020). https://doi.org/10.1515/npprj-2019-0086.
5. Eriksson, D., "Getting to grips with cartons," Ph.D. thesis, Department of Mechanical Engineering, Örebro University, Örebro, Sweden, 2021.
6. Korin, C., Lestelius, M., Tryding, J., et al., *J. Adhes. Sci. Technol.* 21(2): 197(2007). https://doi.org/10.1163/156856107780437426.
7. Srinivasan, M.A. and LaMotte, R.H., *J. Neurophysiol.* 73(1): 88(1995). https://doi.org/10.1152/jn.1995.73.1.88.
8. Bergmann Tiest, W.M. and Kappers, A., "Kinaesthetic and cutaneous contributions to the perception of compressibility," in *Haptics: Perception, Devices and Scenarios, EuroHaptics 2008, Lecture Notes in Computer Science* (M. Ferre, Ed.), Vol. 5024, Springer, Berlin, Heidelberg, 2008. https://doi.org/10.1007/978-3-540-69057-3_30.
9. Persson, C., Eriksson, H., and Korin, C., *Nord. Pulp Pap. Res. J.* 38(3): 491(2023). https://doi.org/10.1515/npprj-2023-0021.
10. Eriksson, D., Persson, C., Eriksson, H., et al., *Nord. Pulp Pap. Res. J.* 36(1): 91(2021). https://doi.org/10.1515/npprj-2020-0070.

ABOUT THIS PAPER

Cite this article as:
Persson, C., Karlsson, P., Biel, A., et al., *TAPPI J.* 25(3): 192(2026). https://doi.org/10.32964/TJ25.3.192

DOI: https://doi.org/10.32964/TJ25.3.192

ISSN: 0734-1415

Publisher: TAPPI Press

About this journal

ABOUT THE AUTHORS

This study is part of continuous work to understand the user perspective regarding packages. There has been a long ongoing discussion on how to present data measured on bulging packages, and clarification on how to handle this was needed.

It was surprising to discover that a lower grammage may give a higher stiffness depending on loading position. It was also interesting to find that package designers have the potential to influence the perceived stiffness and strength of a package by where they design the places for customers to grasp it. These findings allow manufacturers to better fulfill customer demands.

In the future, research concerning creasing and folding will continue within the ongoing Knowledge Foundation project in Sweden.

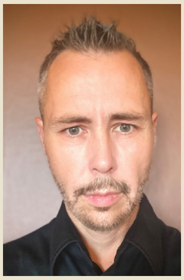
Persson, Karlsson, and Korin are senior lecturers at Örebro University in Örebro, Sweden. Biel is associate professor and Stigh is professor at Karlstad University in Karlstad, Sweden. Barbier is senior manager, Research & Specialists, for Billerud AB in Grums, Sweden. Nygårds is senior specialist, Packaging Performance, at Billerud AB in Stockholm. Tryding is retired senior specialist from Tetra Pak Packaging Solutions AB, Malmo, Sweden. Vomhoff is senior development engineer at Holmen Iggesund Paperboard AB in Iggesund, Sweden. Email Persson at Camilla.Persson@oru.se.

Persson

Karlsson

Biel

Stigh



Barbier

Nygårds

Tryding

Vomhoff

Korin