Standards for optimizing corrugated board packaging for exporting industry

- A feasibility study

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1 Summary

For the globally active brand owner companies there are many problems and shortcomings associated with corrugated board boxes. One reason for this situation is the lack of uniform performance standards and guidelines. The feasibility study "Standards for optimizing corrugated board packaging for exporting industry" aimed at giving directions for future development of test methods and guidelines for corrugated board packaging that are based on the real needs of the exporting industry. The project consisted of mapping of demands, mapping of existing test methods, and case studies as well as analysis of gaps and needs.

Some areas found to be lacking and in need of further development were effects of vibrations and shocks on stacking strength, effects of design (e.g. perforations), and effects of creep and varying climate. Future work should aim at providing standards and especially guidelines on how to use standards and specifications. Different guidelines for generalists and specialists should be considered. The generalist would need checklists and instructions on what a minimum specification should include. The specialist would need more technical guidelines on effects of e.g. water, humidity and creep, and on how properties of papers, board and boxes could be translated to package performance.

2 Introduction

The packaging industry and their customers seek to reduce costs and environmental impact of packaging. A general trend for packaging is that the amount of material is being reduced. The dominating material for transport packaging is corrugated board of various qualities and grammages. The average grammage of corrugated board in Europe has been reduced from 558 g/m² in 1997 to 521 g/m² in 2013 according to FEFCO Annual Statistics 2006 and 2013 (FEFCO, 2006; 2013). Today the proportion of recycled fibres is also quite high in corrugated products. Of the total consumption of raw materials in 2013, 28 % was testliner according to FEFCO (2013). This often means a lower quality of the corrugated board compared to the use of kraftliner made from virgin fibres.

While the material reduction continues, the packaging still has to fulfil its duties. The products must be protected from humidity, dirt, shocks and vibrations. The exporting industry needs packaging that withstands transport and storage conditions during varying climates. Unfortunately, the lesser amount of material increases the risk of failure. Today there is often a gap between demands and applied protection, which leads to unnecessary damaged products, less goodwill and decreased competiveness. In the global market, regional differences in materials and distribution environments contribute to the packaging performance problems. Earlier European studies have estimated very large direct and indirect damage costs already at low damage rates, e.g. Trost (1998) and Braunmiller (1999). The problems remain while the global market has become even more important today. One reason for this situation is lack of uniform performance standards and guidelines for transport packaging, which mainly consists of packages of corrugated board.

For the globally active brand owner companies there are many problems and shortcomings associated with corrugated board boxes. Each industry branch has different requirements and demands, but some common problems are:

- Corrugated board varies within the same quality, depending on where in the world it is bought. It means that the performance varies locally, despite the same nominal quality.
- There are today numerous test standards concerning different properties on paper (liner and fluting), panel or box level. Some common mechanical test methods are edge crush test (ECT), box compression test (BCT), corrugated medium test (CMT), bending stiffness test, and burst strength test (also called Mullen). There are little help or guidance on which properties are important, if they should be weighed together etc.
- The common test methods are described for laboratory standard climate which is 23 °C and 50 %RH. They do not cover what happens at other climates. Specifically, higher humidity is worse for the material but test methods are lacking. There are methods concerning water resistance such as the Cobb test, but they do not necessary cover the needs for real life distribution.
- Some attempts have been done to weigh properties together, e.g. in EUPS (End Use Performance Standard) or DIN 55468 but they only cover the needs partly. They miss the influence of humidity on the box performance. There are no

standards for some relevant properties occurring during real cargo distribution, e.g. creep at cyclic climate.

- The requirements on transport packaging are also increasing. The demands on secondary packaging, i.e. the transport packaging, become more like the demands on the primary packaging. The demands on good printing properties and high print quality have increased over time. A study concerning these properties has been carried out by Trost et al. (2013).
- The lack of a global performance standard means that many of the large packaging users, e.g. large product producing exporting companies, is at disadvantage and cannot easily specify their needs when purchasing packaging from corrugated board manufacturers.

For production and converting of corrugated there exists encyclopaedic literature of defects and remedies proposals (Tappi Press, 1999). Similar literature for the user of corrugated is missing.

The lack of relevant test methods for performance during distribution in many cases leads to the use of large safety factors, which themselves are uncertain. The safety factors are used in many different ways, which may create even more uncertainty. Examples of use of safety factors are given in Fibre Box Handbook (Fibre Box Association, 2015) where they are called environmental factors. Also quite extensive more technical handbooks exist such as Wright et al. (1992). However, there is a need for a global comprehensive performance standard or guidelines which give suitable quality of corrugated with lowest possible, but high enough, grammage.

The project “Standards for optimizing corrugated board packaging for exporting industry” is a feasibility study aiming at giving the direction of further development of test methods and guidelines for corrugated board packaging based on the real needs from industry. Figure 1 shows the project activities schematically. The work consisted of mapping of demands and mapping of existing standard test methods followed by analysis and proposal for future work. Mapping of demands seen by the industry and mapping of existing standards will be described below, followed by an analysis with results presented. It is a complex reality that meets users of transport packaging with many different factors and circumstances to react on. This is illustrated with two typical but also totally different industrial case studies. Parts of the project results have been presented at international conferences by Trost and Alfthan (2015a; 2015b; 2015c).

2.1 Literature review

There are published results preceding the present study. The stresses encountered during transport are well known to be varying and often especially tough during loading and unloading, e.g. Bernad et al. (2010). There are also many studies of stacked cargo on pallet, including modelling approaches, e.g. Rouillard et al. (2004). Reimers (2011) demonstrates the problems related to the existing BCT quality definition of heavy duty corrugated board and the practical performance of packaging made from such boards. Improved determination of the performance of heavy duty corrugated board packaging will make it possible for users and manufacturers to select corrugated board grades for optimum costs and benefits considering differences in transport, handling and storage stresses. Extension of the standard for worldwide shipment will have to be achieved by making a supplementary assessment of creep strength.

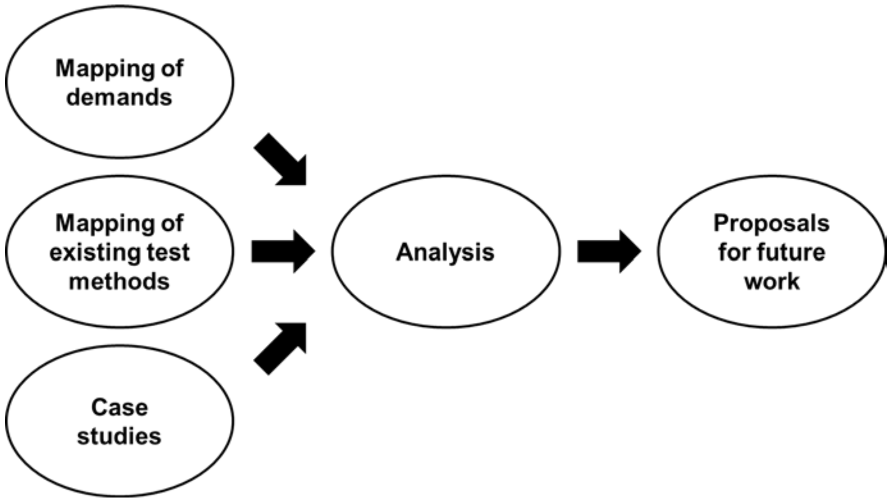


Figure 1. Schematic overview of activities in the project towards more useful test methods for corrugated board and boxes.

Daum (2009) describes the challenges encountered by Hewlett-Packard when using corrugated board from Asian sources for a global market. Changes of the supply chain caused a dramatic increase of damaged corrugated board for one printer product. In a large investigation on perforated boxes, effects of factors such as headspace between the flaps and placements of manufacturers joint are studied. One finding is that boxes of recycled fibre withstood cyclic humidity climate poorly.

Parrott (2011) describes a project in which Intel Corporation wanted to standardize corrugated material parameters worldwide. The original parameters used by the company were burst strength, ECT and BCT. Correlations between these parameters are investigated. Since there is a strong correlation between ECT and BCT, the company decided that their primary material parameter should be ECT, sometimes complemented by BCT when engineering assessments are needed. Burst strength was omitted in newer specifications. The author notes that “In gathering this material we were able to continuously improve quality and ensure that all material is meeting Intel Corporation’s specifications”, which illustrates that some problems can be solved by just starting to address them and make adjustments and corrections where needed.

Pathare et al. (2014) review the research on different areas for evaluating strength of corrugated boxes for horticultural products. They also discuss requirements necessary for corrugated boxes used for transporting and storing fresh produce in the horticultural industry. Although it is a review on the state of the art, different test standards available or how to use different test specifications are not mentioned.

Molina-Besch and Pålsson (2014) study how companies in practice work during packaging development to reduce negative environmental impacts along supply chains. The structure of the analytical framework is based on the division of environmental impacts caused by packaging into (1) impacts related to product waste, (2) impacts related to logistics, and (3) impacts related to packaging material.

Nine companies developing packaging are investigated. Problems reported regarding the development of protective packaging are:

- Lack of information about product damages from shops and distribution centres because the administrative burden of reporting damages is high
- Varying transport conditions in different markets
- Rough handling of single product orders by transport providers
- Unreliable and shifting demand
- Difficulties to find a good balance between product protection, marketing, logistics, and environmental requirements

Dominic et al. (2015) develop a conceptual sustainable packaging model that integrates the variables of technical design, supply chain systems and environmental demand factors and then used the model to identify improvements on corrugated container design. Integration of the design criterion for a unit load in the supply chain creates opportunity to observe the packaging system holistically.

There are several software programs that are used to support package design, e.g. CAD software aimed at packaging, visualisation tools, and software for predicting mechanical performance. Some studies have been performed on their capabilities.

Sohrabpour and Hellström (2011) investigate eighteen models and four softwares for predicting corrugated board and box properties to identify the ones that best accounts for observations in the supply chain. Eight of the investigated models use paper properties to predict board properties while ten models predict corrugated box properties. Box properties may be short time strength like BCT, or long time stacking strength. In contrast to the BCT which is conducted in ideal conditions in the laboratory, stacking strength considers environmental factors, e.g. stacking time and humidity. This makes stacking strength one of the most useful box parameters. Stacking strength estimations can be based on BCT. In order to decrease the gap between theory and practice, suggestions are made to improve the use and development of models and software for corrugated box design. A holistic perspective for modelling corrugated board and box is proposed. That could eventually enable practitioners and researchers to identify causes to variation in predictions by considering control and noise factors.

Ge et al. (2012) demonstrate the possibility of integrating several market standalone design and modelling software programs into an optimized and sustainable packaging solution. A case study to apply SolidWorks, ArtiosCAD, Illustrator, CAPE and Walmart score card modelling into a combined design process is presented. The study deals with the graphics and structure interface between the modules and the software. The synthesized process and the file format exchange between these software programs are discussed. As a result of the integration, the designer is able to place a completed virtual prototype package onto a shelf and transport packaging, allowing designers to visualize packages in realistic shelf context and space utilization in a distribution environment. This kind of design work does not provide information on mechanical performance.

The literature thus suggests strategies for systematic improvements and design of corrugated board packaging but also point out lacking areas related to performance in real logistic chains compared to laboratory experiments. Variations in loading and climate are currently difficult to take into account in other ways than through the use of safety factors.

2.2 Corrugated terminology

The most often used material in transport packaging is corrugated board. The basic single wall design of the corrugated board consisting of liner and fluting layers is shown in Figure 2. Further liner and fluting layers can be added to form double and triple wall corrugated board.

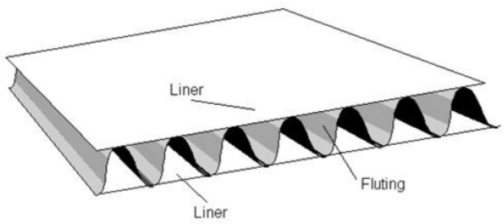


Figure 2. Basic design of corrugated board, single wall corrugated board.

A kraftliner is a paper predominantly made from primary kraft pulp, while a testliner is predominantly based of recycled fibres. The fluting or the medium could be either semi chemical fluting, which is predominantly made from semi chemical primary fibres pulp or it could be recycled fluting mainly made on recycled fibres.

In Table 1 different flute profiles are given. The flute types E, F, G and N is also called mini-flute grades. It should be pointed out that there is no global consensus around the flute grades and Table 1 gives a typical classification of today. Quality G and N are similar and used differently by different producers. There are also less common grades available e.g. D flute, which is called R flute by some producers. Also some manufacturers include the liner thickness in the description of flute type.

The design of boxes is often following FEFCO (European Federation of Corrugated Board Manufacturers) codes, consisting of four digits (FEFCO 2007). The two first digits in the code describe type of design according to Table 2. The last two digits are serial numbers. One of the most common designs is the regular slotted container (RSC) with FEFCO code 0201.

Table 1. Flute grades of corrugated board according to Svenska Wellpappföreningen (2015) and for quality N according to Steadman (2002).

Flute type	*Flutes per meter, approx.*	*Flute height (mm), approx.*
A	110	4.8
B	150	2.4
C	130	3.6
E	290	1.2
F	350	0.7
G	560	0.5
N	555	0.4

Table 2. Description to basic type groups according to FEFCO (2007).

Two first digits in the code	*Description*
01	Commercial rolls and sheets
02	Slotted-type boxes
03	Telescope-type boxes
04	Folder-type boxes and trays
05	Slide-type boxes
06	Rigid-type boxes
07	Ready-glued cases
09	Interior fitments

3 Methods

The aim of the feasibility study was to make an inventory of problems concerning transport packaging for the goods producing companies, i.e. the brand owners, and existing test or verification methods. To know the problem means that you can find ways to develop the area. Therefore the work consisted of mapping of demands and shortcomings at the exporting goods producing industry and mapping and analysis of existing test methods and standards. Illustrative case studies were also performed.

3.1 Mapping of demands

In order to map the demands from the goods producing industry a quite comprehensive questionnaire was developed, partly based on earlier work on systems for distribution quality by Trost (1992), and work on goods classification by Björkman and Trost (1994). A number of interviews were made with packaging responsible persons at some large brand owners from different industry sectors. The represented companies were Duni, Ericsson, ESAB, Gambro Lundia, McNeil, SKF Mekan and Xylem Water Solutions.

The following topics were among those covered by the questionnaire:

- Types of damages, where they occur in the distribution chain, and how they are followed up
- Damage frequency and statistics, and the influence on packaging development
- Test methods used on boxes and pallets
- Organization of packaging development, e.g. if development is performed in-house or by packaging supplier or consulting firms, and if the responsibility lies on product, division or central level in the organization
- Requirements on primary and secondary (transport) packaging and if they are evaluated together or independently of each other
- Use of packaging instructions, pallet pattern, and marking
- Important environmental factors to protect against and how these are determined
- Specification on corrugated board and boxes at purchase
- Quality control of delivered packaging material

During a workshop, problems originating with transport packaging at different companies were identified. Possible ways to solve or diminish these problems were also identified.

3.2 Mapping of existing test methods

The second activity was mapping and analysing the huge amount of European, American and global standard test methods on corrugated boxes and its constituents from organizations such as EN, ISO, ISTA, ASTM and Tappi. Identification of the most important test methods was made based on the outcome of the mapping of demands.

The mapping also covered more broad standards e.g. for the organisation of packaging, with advice for procurement or procedures for the design process.

3.3 Case studies

Since the reality looks different for different industry branches or product categories, two quite different types of problem areas were chosen for case studies. The first case was about humidity and water problems, which led to mechanical collapse of boxes. The second case was addressing the logistical and mechanical problems which were important in design of boxes and packaging systems.

The case studies were snap shots of common problems encountered in the use of corrugated board boxes and at the same time showed the vast area in which corrugated is used.

4 Results

4.1 Mapping of demands

The demands from the exporting industries were mapped through the interviews and a workshop.

4.1.1 Interview results

The mapping of demands from the packaging users resulted in conclusions about important problem areas for the goods producing companies, such as logistics and stackability or influence of humidity. One important aspect is that the packaging user wants performance of the whole box, but quite often the supplier provides properties of the components making up the box, i.e. liner and fluting for corrugated board.

During the interviews, several problems with corrugated packaging today were identified. Poor pallet patterns and overhang on pallets cause many damages. Examples of this are shown in Figure 3. Stackability during transport and collapse cannot easily be predicted. Therefore many companies use very large safety factors. The problems have increased with the number of sub-suppliers of packaging as well as products in non-European markets such as China and India. One example of the problems with uncertainties when dimensioning box strength is shown in Figure 3(d).

Today there is a lack of specifications that works worldwide. There is a need for clear and reasonable requirements, which also could be checked in a straightforward way by the purchasers. A common problem is that it is very hard today to compare corrugated board boxes performance from different suppliers, since data sheets are often given on paper or panel level. Different producers focus on different properties, where they have their advantages. The interpretation of some specifications is sometimes unclear, e.g. the meaning of a specific Cobb value in practice. Many of the large retailers demand shelf ready packaging for fast moving consumer goods in order to save costs for unpacking and expose the products better. The perforation on these boxes makes it more difficult to meet the transportation demands and the boxes may open before arrival to the retailer. A common problem is straps that deform the package, and may damage the product inside.

Among the users it was found that on box level, BCT is regarded as the most valuable method. On the other hand there are not so many other box level methods to choose. Practically all companies use it. For panel and paper properties, the following were regarded important by the users:

- ECT (Edge Crush Test)
- FCT (Flat Crush Test)
- Bending stiffness
- Friction
- Printability

(a)

(b)

(c)

(d)

Figure 3. Examples of poor pallet patterns and overhang causing damages: (a) Poorly secured cargo on pallet and poorly secured pallets in the vehicle causes tilting and collapsed boxes; (b) Overhang on pallet and poor pallet pattern increases the risk for damage, and even collapsed load, during handling; (c) Poor pallet pattern and no securing will probably cause tilting and falling during transport; (d) A too weak box causes tilting and collapse in warehouse.

4.1.2 Workshop results

At the workshop several problem areas as well as possible solutions were identified. The problem areas “Logistics”, “Stackability and side impact” and “Climate” were identified as especially important due to the complexity and lack of standardised testing. The workshop outcomes on these areas are summarised in Figures 4-6. There is obviously an overlap with the results from the interviews.

The areas “Logistics” and “Stackability and side impact”, Figures 4-5, illustrate the complexity of the real world’s demands. In addition there are extreme cases occurring in the distribution chain, like the penetration of the box by goods from the inside or a forklift from the outside. Standards today give little support to a user trying to make adequate specifications.

Figure 6 on the area “Climate” illustrates the climatic influence on the boxes. Creep is the gradual deformation due to long term loading. It becomes especially important at high or varying humidity. The possible solutions with modification of material properties obviously have to be made by the material producers. Of course the problems presented in Figures 4-6 do not occur independently of each other. There is obviously always a climate also during logistics and stacking

Logistics

Problems:

- Varying transport distances; local, European, global
- Mixed cargo; single parcel or pallet
  - Different orientation of cargo, symbols not followed
  - Shocks and vibrations during transport and handling
- Pallet
  - Overhang of incoming packaging sheet material
  - Bad pallet optimization, e.g. overhang and cavities in the middle of the pallet
  - Insufficient friction gives dislocations
  - Dislocated cargo gives problem in automatic storage houses
  - Poor cargo securing (stretch film/banding); against pallet and floor in vehicle; too hard or to loose

Possible solutions:

- BCT measured in different directions
- Drop tests for single parcels
- Transport tests (e.g. ASTM D 4169)
- Collection of damage track record
- Friction measurements (e.g. TAPPI 815)
- Friction lacquers, interlayers

Figure 4. Examples of identified problems and possible solutions for “Logistics”.

Stackability and side impact

Problems:

- Unknown security factors, hard to specify
- Collapse due to shocks and vibrations
- Creep, see Climate
- Perforations opening during transport

Possible solutions:

- BCT tests on box level
- BCT tests for stacked pallets
- Transport tests, see Logistics
- Construction of box, e.g. increased bending stiffness

Figure 5. Examples of identified problems and possible solutions for “Stackability and side impact”.

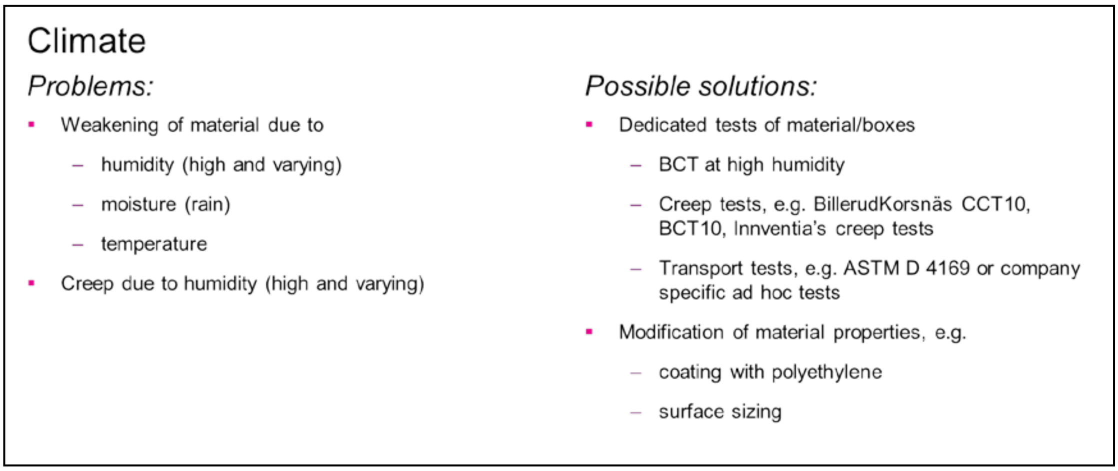


Figure 6. Examples of identified problems and possible solutions for "Climate".

4.1.3 Analysis

During the interviews, BCT was identified as the most valuable measure for the companies using corrugated packaging. The standard method is only for laboratory climate of 23 °C and 50% RH. A comprehensive literature survey about this method was recently presented by Frank (2014). Testing of BCT is usually performed on single boxes. This does however not take into account the dramatic reduced stacking strength caused by even small stacking misalignment, which is common during distribution, see e.g. Maltenfort (1980), Meng (2007) and Meng et al. (2007). Another question is how to relate the BCT value to real transportation conditions or vibration tests on a vibration table, and collapse due to creep.

The connection between paper and corrugated board properties and box performance is lacking. There are some methods to relate paper and corrugated board properties to BCT. The most well-known is the formula for strength for corrugated boxes developed by McKee et al. (1963). Frank (2014) gives additional examples of algorithms and equations for going from paper and board to boxes. A complicating factor is that test methods on paper or panels show the properties before converting. It is well known that the converting process reduces the strength properties of the board to some extent by crushing the board (Batelka, 1994). It has also been found that properties are lost in converting to different extent at different corrugating plants (Edholm, 1998). Chalmers (2007) introduced a new test method for corrugated based on torsional stiffness to address this issue. MD torsional stiffness is according to Chalmers a more sensitive predictor of corrugated board performance in the corrugator and quantifier of the amount of damage incurred during the box conversion process than conventional measurements such as thickness, FCT, ECT, or BCT.

Creep of corrugated boxes have been studied for a long time, but is yet not fully understood. Kellicutt and Landt (1951) investigate the relation between applied load and time until collapse. They find that the time to failure of boxes under static loading decrease logarithmically as the load approached the box compression strength. The study is performed at constant laboratory climate of 23 °C and 50% RH. Koning and

Stern (1977) study the secondary creep rate and life time. They find that the life time is almost proportional to the inverse of the secondary creep rate.

One factor that is very important and demanding is varying air humidity, or even sometimes liquid water as rain as noted in the area “Climate” in Figure 5. There is a general lack of methods for varying climate. The common test methods for paper, corrugated board and boxes are prescribed for laboratory standard climate of 23 °C and 50% RH. In some countries, products intended for installation are however standing outdoors in their packaging for months making both climate and creep important. When the humidity varies the creep situation is dramatically different as shown by e.g. Bronkhorst (1997). Bronkhorst does however find a relation between the average secondary creep rate and life time similar to the one found by Koning and Stern (1977). Leake (1988) and Leake and Wojcik (1989) study corrugated boxes stored for long time in warehouses with daily climatic variations. They find that a high-amylose starch based adhesive in the corrugated box gave an improved performance in comparison to a standard corn starch adhesive. These changes of performance are not detected by standard BCT. Eschke and Reimers (2003) studies heavy duty corrugated, made by wet strength liners and with wet strength gluing during long time loading in varying humidity conditions. One important finding is that the material needs to have a resistance against changing humidity in order to withstand long time loads. The resistance is evaluated from wet burst strength together with measurement of water resistance of the gluing. Henning (2015) studies corrugated boxes with identical ECT and/or BCT and find that the long term compression performance could vary widely. According to Henning this is not well addressed by typical end user specification practices. An examination of critical properties of corrugated board and its component papers provides insights for increasing useful box life.

When summarizing the demands it is important to note that each branch has different problems to solve. However there are also common problems and demands, such as long border crossing distances, also meaning purchase of corrugated boxes from different sources. The main demands are on mechanical and climatic behaviour of the boxes. The most commonly used measurement of performance is BCT, but it does not take the real situation into account. Loads during distribution are much more complicated. Stacking is seldom optimal. Effects of shocks and vibrations during transport are hard to predict accurately. Varying humidity is difficult to account for and accelerates failure due to creep.

4.2 Mapping of existing test methods

The standard test methods for corrugated board and boxes from EN, ISO, ISTA, ASTM and Tappi were mapped and analysed. These standards cover different aspects of the corrugated box and its constituents, such as test methods on the paper, board and box level but also so called rough handling performance protocols. The commonly used ASTM D4169 is an example of the last category. In Figure 7, a schematic overview of some measured parameters on different levels is shown. Some of these, e.g. friction measurements, could be used both on paper level (liner or fluting for corrugated) and on panel level.

Following are some of the most important test methods which have been identified. Standards intended for use with corrugated board, liner and fluting are listed in Appendix 1.

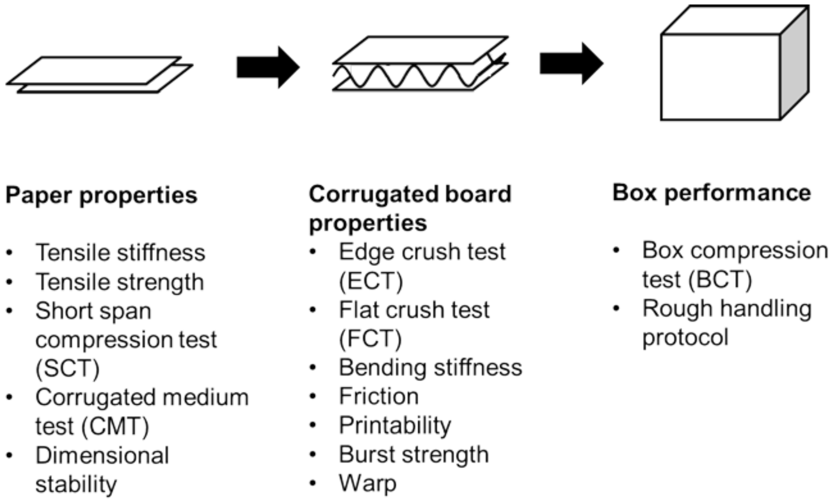


Figure 7. Some test methods on paper level, board level or box level.

4.2.1 General guidelines

Several standards proved general guidelines on packaging. These provide a framework that can help reducing variations in packaging design and help users to specify their packaging. ASTM D6198-07, “Standard guide for transport packaging design”, focuses on the design process, and concerning test methods refers to other ASTM methods. The following procedure is recommended:

1. Identify physical characteristics of the package contents
2. Determine marketing and distribution requirements
3. Identify environmental hazards the packages may encounter
4. Consider all available alternatives (materials, benchmark with competitors etc.)
5. Design the transport package
6. Select the proper type of closure for the package
7. Determine adequacy of protection by performance tests
8. Redesign the package or product if required
9. Develop the methods of packing
10. Document all work

ASTM D3951-10, “Standard practice for commercial packaging”, is mainly applicable to continental USA, excluding Hawaii and Alaska. It establishes minimum requirements for packaging of supplies and equipment as covered in Title 49 of the Code of Federal Regulations. Concerning performance testing the use of ASTM D4169 shall be “required when determining the performance level of a shipping unit. The supplier shall be responsible for requirements specified herein and in the contract or purchase order. The purchaser reserves the right to perform any or all of the tests”.

ASTM D5639/D5639M-11, "Standard practice for selection of corrugated fiberboard materials and box construction based on performance requirements", provides information on corrugated board for the user who wants guidance in selecting attributes of materials and box construction based on performance requirements. The attributes should according to the standard be part of specifications which set levels that the boxes shall reach in order to be acceptable, and they should be measurable by using standard methods. The standard aims at assisting users developing specifications for corrugated containers through an analysis of performance requirements and relationships of materials and box construction attributes. Rail and motor freight classifications applicable for common transportation have established minimum requirements for certain attributes of corrugated packaging valid in USA. There are two distinctly different methods commonly used for specifying boxes. The most common approach is to specify materials, such as defining flute, board weights and thicknesses as well as ECT, burst strength, and FCT minimums. An alternative approach is to define some measure of performance.

ASTM D1974/D1974M-10, "Standard practice for methods of closing, sealing, and reinforcing fiberboard boxes", describes several methods for closing, sealing, and reinforcing solid and corrugated board (excluding triple wall corrugated board) boxes used for shipment. It is said that "performance-based methods are encouraged because they allow for considerable flexibility in the choice of packaging materials and methods yet provide assurance of a given level of performance". Performance levels are not given in the standard. Testing according to ASTM D4169 and field experience are recommended to rate alternative methods. ASTM D1974 also contains a lot of common sense knowledge about glues, tapes etc.

ASTM D4727/D4727M-07, "Standard specification for corrugated and solid fiberboard sheet stock (container grade) and cut shapes", describes the paper components of corrugated box, i.e. liner and fluting. The aim is to provide guidelines for production (and purchase) of liner and fluting. The specification covers board primarily used for the production of boxes and interior details such as pads, sleeves, liners, partitions, die-cut sheets, etc. A variety of grades reflecting varied performance levels are specified.

4.2.2 Standards on specific methods

Raw material properties obviously contribute to the properties of a product. In Figure 7, this is illustrated for paper, corrugated board and boxes. Starting at the box level, there is e.g. the commonly used BCT. BCT mostly depend on the corrugated board stiffness and the compressive strength along the flutes measured as ECT, which makes it possible to predict BCT if the corrugated board properties are known, using e.g. the formula by McKee et al. (1963), or one of the methods presented by Frank (2014). There will be uncertainties since simplifications are needed to derive the relation, and the manufacturing process (including e.g. creasing, folding and gluing) is not taken into account. Similarly, bending stiffness can be calculated from tensile stiffness of the constituent liners and fluting, and ECT can be calculated from compressive strength measured as SCT. In this way it is possible to approximately predict at least some of the properties of the product, if the properties of the constituents are known. Measurements on papers or corrugated board can hence provide good indications of box performance, and provide valuable information when designing or purchasing packaging solutions.

On the paper level, tensile properties are obtained from tensile testing according to ISO 1924-2. Compressive strength is obtained from the short span compression test, ISO 9895. There are alternative strength measurements often also containing a structural contribution to strength, e.g. the corrugated crush test according to ISO 16945 and the ring crush test according to ISO 12192.

On the corrugated board level, several methods has been developed and standardised. Some are also applicable to paper and paperboards. To some extent corrugated board properties can be predicted from paper properties. The reliability of the predictions is limited by simplifications, e.g. neglecting effects of the manufacturing process and gluing. In other cases the paper properties are not known. Measurements on corrugated board thus have an important role when choosing materials.

ISO 5628, “Paper and board - Determination of bending stiffness by static methods - General principles”, describes how to measure bending stiffness, where 4-point bending is the preferred method especially for corrugated board.

ISO 3037, “Corrugated fibreboard - Determination of edgewise crush resistance”, is a widely used ECT standard. Other standards are Tappi 811, Tappi 838, and Tappi 839. ECT is considered to be one of the most important test methods on board level. USA based Fibre Box Association has published an application guide concerning this method (Fibre Box Association 2005). However it should be noted that in USA, the test pieces are often waxed according to Tappi 811 or using neckdown according to Tappi 838. Tappi 839 corresponds closer to the ISO standard.

ASTM D5264-98 (Reapproved 2011), “Standard practice for abrasion resistance of printed materials by the Sutherland Rub Tester”, covers a procedure for determining the abrasion resistance of printed materials using the Sutherland Rub Tester, or its equivalent. The test method is applicable to labels, folding boards, corrugated boxes, inserts, circulars, and other packaging materials having applied graphics on a flat substrate. It is also a well-known method to use when evaluating readability.

Another common test method is the Cobb test according to ISO 535, which measures the water absorption on paper and board. It should be noted that this test only predicts the response of the material to a brief exposure to water. It gives no indication of the loss of strength to be expected following prolonged exposure to either water or high humidity (Wright et al. 1992). The method is also often used to determine printability. This is then based on company experience since the method is not in general relevant to the printing process, where the water exposure is less than a second compared to the minutes used in the test.

Standards which combines other methods to classify corrugated board by weighing together different properties to a number have been developed. One well known such standard is EUPS (End Use Performance Standard). This method is a first attempt to provide a global standard. EUPS combines the test methods of ECT, burst, FCT, and 4-point bending stiffness into 12 different quality levels of the corrugated board numbered from 10 to 120 in steps of 10. Factors that are missing in EUPS are the influence of humidity, and design of the box. Due to the mix of test methods used, EUPS favours liner properties rather than fluting properties. The classification numbers are aimed at different fluting profiles: EUPS 10-20 for E flute, EUPS 30-50 for B flute, EUPS 60-90 for C flute, and EUPS 100-120 for BC flute double wall.

DIN 55468-1 (draft Dec 2013), "Packstoffe - Wellpappe - Teil 1: Anforderungen, Prüfung" (Packaging materials - Corrugated board - Part 1: Requirements, testing), classifies single or multilayer corrugated board in different categories based on three test methods: Burst strength, puncture resistance, and ECT. It defines 26 grades of corrugated board based on measurement data from the three test methods chosen. It is not necessarily possible to directly classify these corrugated board grades in terms of performance or suitability for use of the packaging made from these boards. Since the BCT value or box performance is heavily dependent on the bending stiffness, it means that the packaging quality from two suppliers could vary a lot, even if they fall in the same category according to this DIN standard. The manufacturers' experience plays a major role in the selection of the right board for a particular load. DIN 55468-2 (Aug 2014), "Packstoffe - Wellpappe - Teil 2: Nassfest, Anforderungen, Prüfung" (Packaging materials - Corrugated board - Part 2: Wet strength, requirements, testing), classifies corrugated board based on burst strength tests after immersion in water, according to ISO 3689.

Several standards, e.g. ASTM or IEC describe tests on box levels, filled or empty boxes. Examples of such methods are ASTM D951 (water spray test) and ASTM D5276 (drop test). The most common test method is box compression test (BCT) which is covered in ASTM D642 and ISO 12048. Other examples of such methods are ASTM D951 (water spray test) and ASTM D5276 (drop test). It is possible to predict BCT from corrugated board properties with similar limitations as when predicting corrugated board properties from paper properties. It is however very difficult to predict box performance in general. Standardised measurement methods are hence necessary.

TAPPI 813, "Tensile test for the manufacturer's joint of fiberboard shipping containers", is used to determine the strength of the manufacturer's joint of commercially made corrugated and solid board transport packages. It is applicable to taped, stitched, or glued joints and may also be used to evaluate laboratory made joints similar to commercially made joints. When a transport package is dropped, compressed, or vibrated, its manufacturer's joint is subjected to stresses along with all other edges. This test gives an indication of the ability of the joint to withstand rough handling without failure, to the extent that failure is related to the tensile strength of the joint itself. In practice, if the manufacturer's joint is stronger than the tensile strength of the board, failure will occur away from the joint. However, if failure occurs within or adjacent to the adhesive area of the joint, the full potential of the box will not be reached until a stronger joint is obtained.

ASTM D4169, "Performance testing of shipping containers and systems", is the classical handling performance protocol. The method provides a uniform basis of evaluating, in a laboratory, the ability of shipping units to withstand the distribution environment. This is accomplished by subjecting them to a test plan consisting of a sequence of anticipated hazard elements encountered in various distribution cycles. The method is not intended to supplant or compensate for material specifications. Acceptance criteria must be established prior to testing and should consider the required condition of the product at receipt. It is advisable to compare the type and quantity of damage that occurred to the test specimens with the damage that occurs during actual distribution and handling, or with test results from similar containers widely used in the same situations. Methods may range from simple pass-fail judgments to highly quantitative scoring or analysis systems.

ASTM D7030, "Standard test method for short term creep performance of corrugated fiberboard containers under constant load using a compression test machine", covers creep testing of empty boxes. It also gives a simplified procedure to predict container life to failure based on average creep rate during 12 hours compression.

4.2.3 Company specifications

Some large users of corrugated and transport packaging have developed their own packaging specifications. Especially in USA also some large shippers such as FedEx have testing procedures which are made to simulate air and ground shipping environments. Since they have a quick flow and no storage, factors like stacking strength over time are not covered. FedEx package testing procedures (2011) are based on industry data, as well as international testing procedures and standards. Drop, impact, compression and vibration tests are used to evaluate the integrity and protective performance of the packaging. Package closure performance is also considered as an important acceptance criterion. Packages are opened and the contents inspected after completion of all test procedures, unless obvious damage is noted during or after an individual test. If at any point during the testing sequences damage is noted, further testing may not be completed.

Walmart (2011) have their own guidelines concerning retail ready packaging, which are designed to provide all Walmart suppliers with general information to "maximize the effectiveness of their solutions and allow them to satisfy Walmart's requirements". It should be noted that these guidelines do not cover mechanical strength of the package. They cover what happens in the retail store (assuming that everything is fine until then). They focus on sales capacity and easy handling in the shop. The five main points are thus: Easy to identify, easy to open, easy to stock, easy to shop, and easy disposal.

Another example is IKEA "Specification IOS-P-0010: Packaging - general requirements" (2013), which states that the purpose of packaging is to "protect what it sells and to sell what it protects". All tests of corrugated board shall take place after the corrugating process, but before the converting process. The requirements for corrugated board follow to a large extent EUPS, with supplement of requirements according to water absorption (Cobb 60) according to ISO 535.

4.3 Case studies

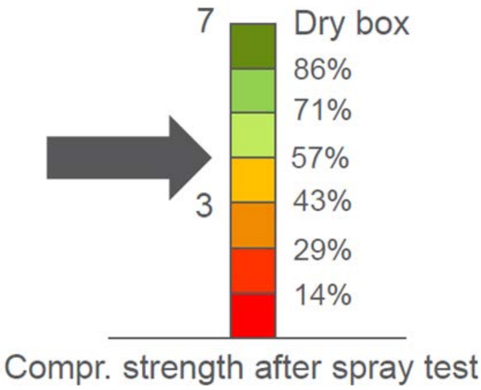
Two case studies were performed and are presented below.

4.3.1 Case 1: Wetting resistance on corrugated board

The aim of the project "Wetting resistance on corrugated board" is to find a specification method of corrugated board for guaranteed compliance to wetting resistance requirement specified by the internal Ericsson requirement document. For the project Ericsson collected boxes made from a large number of corrugated board qualities from their suppliers.

The wetting resistance requirement was tested by spraying the boxes with water for 15 minutes with 6 mm/m²/min according to ASTM D951. Box compression testing (BCT) was then performed. Examples of spray tested boxes and the resulting BCT value in comparison with laboratory conditioned boxes BCT value are shown in Figure 8.

(a)



(b)

Figure 8. Wetting resistance of corrugated board: (a) Example of spray tested box; (b) Resulting BCT value after spray test in comparison with BCT value on laboratory conditioned boxes (denoted “dry” in the study).

The aim of the tests was to evaluate the corrugated board material only. Therefore, all open flutes were sealed with tape (except manufacturer’s joint). In real life situations, the important thing is the performance of the box. Some flutes will be open, dependent of which FEFCO construction is used. The tested boxes were mainly of FEFCO 0201 type, with a few FEFCO 0216 boxes. The philosophy of protection is that each package could be sent separately, using distribution companies like DHL.

The test result of BCT performance could not be correlated to measured Cobb values according to Tappi 441. It was found that a high Cobb value could result from a liner with higher grammage, since a thicker liner can absorb more water than a thinner one. The different corrugated board qualities also vary with respect to virgin and recycled fibres content, sizing, lamination etc.

Some problems as a global purchaser are:

- Solutions that are found have to be cost effective and available everywhere. For example PE-lamination is very rare in North America and Asia.
- It is not always possible to dictate the requirements, since even a large goods producer may be a small corrugated board customer, so all optimization work has anyhow to be adapted to realistic situations.

Some conclusions were drawn:

- A practical first experience based approach to specify corrugated board of good enough quality is to use the background knowledge and specify that corrugated board should have a certain minimum grammage, any type of paper with water repellent properties, coating or lamination, and a certain minimum amount of virgin fibres.
- More ideal would be to specify the performance of the box, i.e. the function during real life conditions. This means that a producer can develop better properties without being bound to a specific composition. It could also be easier for Ericsson to check the function than the composition.
- Performance based specifications need test methods that reflects the wet conditions. An idea is to spray or coat the corrugated board with water before ECT test. This has to be further developed to give a reproducible test method. Another way could be to develop a Cobb-like method to investigate the barrier properties of the outer liner by measuring the water uptake in a material, e.g. blotting paper, protected by the liner.

4.3.2 Case 2: Vibrational test to investigate possibilities of stacking two pallets high during transport

ESAB produces welding rods which are sensitive to humidity. Vacuum-packed bags made of aluminium and plastics are hence used as protective packaging. An advantage with this packaging is that a damaged bag which would risk the product quality easily can be detected. In order to achieve a quicker filling of corrugated boxes with the vacuum-packed bags, there is extra space left in the box, i.e. the welding rods do not fill 100 % of the inner volume.

The supply chain department at ESAB wanted to know if it could be allowed to stack two pallets on top of each other during transportation. To investigate this, vibrational test equivalent to a truck transport in Europe was performed with two stacked pallets at Innventia in Kista, see Figure 9. In the tests, random vibration according to SRETS schedule was used (Braunmiller, 1999). From the tests it was found that the extra air in the boxes caused the boxes to collapse and gave more instability to the pallet, see Figure 10. Due to the extra space in the individual corrugated boxes, the content did only partially carry the load above, and the pallet was collapsing making it look like an accordion. It was also clearly seen during the tests that the vibrations induced resonance causing the upper pallet to bounce on the lower one. The conclusion was not to allow stacked pallets during transport.

Figure 9. Test setup on vibration table, a stack of two pallets.

(a) (b)

Figure 10. Results of vibration table tests: (a) Typical accordion look of collapsed boxes. (b) Obvious risk for shifting of cargo.

The whole logistic problem considered by ESAB was quite complex and not limited to mechanical performance. For example, an increase in the number of layers on one pallet was considered in order to fill the pallet positions in the vehicles better. However, this would cause problems with space and logistics in the warehouse which had specific heights of the racks.

5 Discussion

In order to reach real working methods for optimizing corrugated board packaging directions for further work has to be found. A feasibility study was thus initiated. Mapping of demands and of existing standards to find the state of the art and gaps between actual needs and available methods was performed.

The challenge faced from the perspective of the user is to specify real box performance. Most methods consider material properties rather than box performance. For box performance, BCT is mostly used with safety factors to take requirements during transport and storage into account. These safety factors are based on experience and have large uncertainties. Safety factors are used in many different ways and combinations with unpredictable results. To summarize, it could be said that the uncertainty results in use of safety factors in many different ways, which creates even more uncertainty!

Some specific areas were found to be especially lacking:

- Uncertainties of loading during handling
- Effects of vibrations, shocks and creep as well as design e.g. perforation on stacking strength
- Varying climate, and especially varying humidity
- Long-time behaviour of boxes
- Algorithms to predict box level performance from corrugated board level properties, including the effect of converting

In these areas both research and development of practical tools and guidelines for the designers and users are needed. Three possible themes for future work including both development of standards and guidelines were identified:

- Effects of vibrations and shocks on stacking strength
- Effects of design, e.g. perforations
- Effects of creep and varying climate

Studies of *effects of vibrations and shocks on stacking strength* would include vibration tests on single and stacked boxes as well as drop tests. Tests on different stacking configurations and investigation of effects of stacking misalignment would be performed. The load distributions could be measured in these tests. Effects of different grammages and different proportions between liner and fluting material, and different box designs (e.g. FEFCO designs) on strength and performance values could be studied. Correlation of box, board and paper properties as well as modelling would help package designers and users to predict performance.

The *effects of design* could further be studied separately. Especially interesting is the effect of perforation which becomes more common with the raised demand on retail ready packaging. The perforations weaken the box in a way that is difficult to predict. Pure BCT testing does not capture the effect (Alfthan et al., 2013). The problem could be approached through vibration testing on pallet level, which is close to the transport situation the boxes experience during real transport. Studies at retailers and warehouses where the boxes are handled would also give valuable knowledge. Different perforations for different box designs and the effects of horizontal and vertical perforation patterns should be included.

Creep of single and stacked boxes could be studied at constant and cyclic climate in laboratories. Cyclic climate creep testing would be used to estimate the effect of varying climate conditions that are often encountered in real life during transport and storage. The study would take different materials into consideration, e.g. virgin and recycled fibres content, sizing and lamination. Tests of different grammages and different proportions between liner and fluting material are of interest, as are comparison of different designs. Correlation of box, board and paper properties as well as modelling should be used to develop methods to estimate lifetime.

The outcome of the type of studies outlined above should be proposals of guidelines for more efficient design and testing. Guidelines could be aimed at generalists or specialists. For the generalist, checklists of what the packaging is intended for and might be exposed to are of interest. Different industry sectors might need different checklists based on the type of goods and protection need. Practical solutions to common problems could also be included. Finally, a description of what a minimum specification should include is needed, as this would greatly help in the communication between packaging users and producers. For the specialist, more technical guidelines are needed. These should include information on effects of e.g. water, humidity, and creep, and on how properties of papers, board and boxes could be translated to package performance.

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7 Appendix 1: List of standards for use with corrugated board, liner and fluting

ASTM D642: Standard test method for determining compressive resistance of shipping containers, components, and unit loads

ASTM D951: Standard test method for water resistance of shipping containers by spray method

ASTM D996: Standard terminology of packaging and distribution environments

ASTM D1974/D1974M: Standard practice for methods of closing, sealing, and reinforcing fiberboard boxes

ASTM D3951: Standard practice for commercial packaging

ASTM D4169: Standard practice for performance testing of shipping containers and systems

ASTM D4727/D4727M: Standard specification for corrugated and solid fiberboard sheet stock (container grade) and cut shapes

ASTM D5118/D5118M: Standard practice for fabrication of fiberboard shipping boxes

ASTM D5264: Standard practice for abrasion resistance for printed materials by the Sutherland Rub Tester

ASTM D5276: Standard test method for drop test of loaded containers by free fall

ASTM D5639/D5639M: Standard practice for selection of corrugated fiberboard materials and box construction based on performance requirements

ASTM D6198: Standard guide for transport packaging design

ASTM D6804: Standard guide for hand hole design in corrugated boxes

ASTM D7030: Standard test method for short term creep performance of corrugated fiberboard containers under constant load using a compression test machine

ASTM D7386: Standard practice for performance testing of packages for single parcel delivery systems

DIN 55468-1 (draft Dec 2013) Packstoffe – Wellpappe - Teil 1: Anforderungen, Prüfung (Packaging materials - Corrugated board - Part 1: Requirements, testing).

DIN 55468-2: (Aug 2014) Packstoffe - Wellpappe - Teil 2: Nassfest, Anforderungen, Prüfung (Packaging materials - Corrugated board - Part 2: Wet strength, requirements, testing)

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ISO 186: Paper and board - Sampling to determine average quality

ISO 187: Paper, board and pulps - Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples

ISO 287: Paper and board - Determination of moisture content - Oven-drying method

ISO 535: Paper and board - Determination of water absorptiveness - Cobb method

ISO 536: Paper and board - Determination of grammage

ISO 1924-2 Paper and board - Determination of tensile properties - Part 2: Constant rate of elongation method

ISO 1974: Paper - Determination of tearing resistance (Elmendorf method)

ISO 2233: Packaging - Complete, filled transport packages and unit loads - Conditioning for testing

ISO 2470: Paper, board and pulps - Measurement of diffuse blue reflectance factor (ISO brightness)

ISO 2758: Paper - Determination of bursting strength

ISO 2759: Board - Determination of bursting strength

ISO 3034: Corrugated fibreboard - Determination of thickness

ISO 3035: Single-faced and single-wall corrugated fibreboard - Determination of flat crush resistance

ISO 3036: Board - Determination of puncture resistance.

ISO 3037: Corrugated fibreboard - Determination of edgewise crush resistance (unwaxed edge method)

ISO 3038: Corrugated fibreboard - Determination of the water resistance of the glue bond by immersion

ISO 3039: Corrugated fibreboard - Determination of the grammage of the component papers after separation

ISO 3689: Paper and board – Determination of bursting strength after immersion in water

ISO 5628: Paper and board – Determination of bending stiffness by static methods - General principles

ISO 7263: Corrugating medium - Determination of the flat crush resistance after laboratory fluting

ISO 8254-1: Paper and board - Measurement of specular gloss - Part 1: 75 degree gloss with a converging beam, TAPPI method

ISO 8791-2: Paper and board - Determination of roughness/smoothness (air leak methods) - Part 2: Bendtsen method

ISO 8791-4: Paper and board - Determination of roughness/smoothness (air leak methods) - Part 4: Print-surf method

ISO 9895: Paper and board - Compressive strength - Short span test

ISO 12048: Packaging - Complete, filled transport packages - Compression and stacking tests using a compression tester

ISO 12192: Paper and board - Compressive strength - Ring crush method

ISO 15359: Paper and board - Determination of the static and kinetic coefficients of friction - Horizontal plane method

ISO 16945: Corrugating medium - Determination of the edge crush resistance after laboratory fluting

TAPPI T 441: Water absorptiveness of sized (non-bibulous) paper, paperboard, and corrugated fiberboard (Cobb test)

TAPPI T 476: Abrasion loss of paper and paperboard (Taber-type method)

TAPPI T 811: Edgewise compressive strength of corrugated fiberboard (short column test)

TAPPI T 813: Tensile test for the manufacturer's joint of fiberboard shipping containers

TAPPI T 815: Coefficient of static friction (slide angle) of packaging and packaging materials (including shipping sack papers, corrugated and solid fiberboard) (inclined plane method).

TAPPI T 816: Coefficient of static friction of corrugated and solid fiberboard (horizontal plane method)

TAPPI T 838: Edge crush test using neckdown

TAPPI T 839: Edgewise compressive strength of corrugated fiberboard using the clamp method (short column test)

8 Innventia Database information

Title

Standards for optimizing corrugated board packaging for exporting industry - A feasibility study

Author

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Abstract

For the globally active brand owner companies there are many problems and shortcomings associated with corrugated board boxes. One reason for this situation is lack of uniform performance standards and guidelines. The feasibility study “Standards for optimizing corrugated board packaging for exporting industry” aimed at giving directions for future development of test methods and guidelines for corrugated board packaging that is based on the real needs of the exporting industry. The project consisted of mapping of demands, mapping of existing test methods, and case studies as well as analysis of gaps and needs.

Some areas found to be lacking and in need of further development were effects of vibrations and shocks on stacking strength, effects of design (e.g. perforations), and effects of creep and varying climate. Future work should aim at providing standards and especially guidelines on how to use standards and specifications. Different guidelines for generalists and specialists should be considered. The generalist would need checklists and instructions on what a minimum specification should include. The specialist would need more technical guidelines on effects of e.g. water, humidity and creep, and on how properties of papers, board and boxes could be translated to package performance.

Keywords

corrugated board, corrugated box, performance, standard, test method, transit pack

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