Box compression strength

During transport and storage cartons are usually stacked and subjected to compression loading. The development towards more efficient packing means that the cartons must contribute more protection because the secondary packaging is often removed completely or partly replaced with other materials such as plastic shrink wrapping.

The box compression strength requirement (physical protection) depends on a number of factors:

- the structural design of the carton, i.e. size and dimensions, supporting elements in the carton design, flap design, and loading direction
- whether the contents support the package or not
- types of secondary (transport) packaging
- transport, storage methods and conditions (palletisation, stacking, climatic conditions)
- material properties such as stiffness and compression strength of the paperboard.

The selection of structural designs and paperboard grades is based to a large degree on experience. To prevent damage, margins of safety are often applied when selecting the paperboard. However, this often leads to over-specifying due to a lack of factual information. Today’s awareness of the importance of packaging and the need to save resources makes it even more important to develop material-efficient but functional solutions.

Key characteristics

Compression strength shows a similar relationship to density or chemical pulp content as does tensile strength. The higher the density and the amount of chemical pulp the higher the compression strength.

Structural designs and paperboard properties have to be matched to provide the required degree of performance from the packaging machine all the way through to the consumer. The carton must withstand various types of external loading and handling, protect the contents and reach the consumer without damage. The mode and duration of loading and climatic conditions are all important.

Measurable properties

Compression strength (short span compression test) Compression strength is defined as the maximum compression force per unit of width that a paperboard sample can withstand in a compression test without buckling or bending. The result is expressed in kN/m. When paperboard packages are stacked, the maximum load will of course occur in the bottom layer, and the risk of collapse there can be estimated. The important property of the material in this respect is the compression strength.

Test method and equipment

A 15 mm wide paperboard strip is fixed between two clamps. The free length between the two clamps is 0.7 mm to prevent elastic bending. The sample is compressed until the paperboard strip collapses, and the maximum force is registered.

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The paperboard choice

Box compression strength is a complex property. Since it is mainly determined by the box design, testing under realistic conditions gives the most useful data for the choice of paperboard. Stiffness and compression strength (short span) measurements can be used to estimate the box compression strength. Due to differences between the test situation and the real world, we apply a safety margin.

Box compression strength characteristics

When discussing the physical protection provided by cartons a number of terms are used, of which some but not all are defined. The following definitions are used here:

- **Box compression strength**, $F_B$: The maximum load bearing capacity of a carton (with given design and size). Units = N.
- **Compression strength** (short span), $F_C$: The paperboard’s (intrinsic) maximum load bearing capacity per unit width. Units = kN/m.
- **Stiffness**, $S$: Resistance to bending. Units = Nm.

The following equation describes the relationship:

$$F_B = K \times F_C^a \times S^b$$  \hspace{1cm} (K, a, and b are constants)

During transport and storage the box will carry dynamic loads for a specific time period. The loading conditions can be simplified into two types. Loading with a constant deformation rate (illustration A) or a constant load over a longer time period (illustration B).

By replotting loads and the corresponding times to failure, lifetime expectancy curves are obtained (illustration C). The practical box compression load is typically several times less than the values from conventional static testing (illustration A). Therefore safety margins from 2–5 are often applied by scaling up the load.

Reasonably simple, accurate and reliable methods for measuring and predicting the lifetime of boxes have not been developed. All the contributing factors such as material type, box dimensions, loading and climatic conditions are well known but not yet accurate enough to be used for predictive carton life expectancy.

Among the test methods used, the ones in the illustration on the following page are well documented and relate the compression strength of the carton to the properties of the paperboard.

During an ordinary compression test (illustration A) the box is gradually compressed between two parallel platens. Despite this, the initially uniformly distributed load is soon redistributed due to increased bulging of the panels as the compression proceeds. Shortly before failure most of the load is carried by two narrow zones in the corners where bulging is hindered due to the geometry (see the illustration below). Research has proved that simplifications whereby testing is done by using only one corner or a panel (see illustrations B and C) are sufficiently accurate, provided that the specimen is supported along its edges and that the dimensions are within certain limits.
Assessment of box compression strength

By combining test results using the above methods with theories from physics it has been shown that the compression strength of the paperboard panel is described by the following expression:

\[ F_P = c \times \sqrt{F_C \sqrt{S_{MD} \times S_{CD}}} \]

- \( F_P \) = Panel compression strength
- \( F_C \) = Compression strength (short span) in the direction of loading
- \( S_{MD} \) = Stiffness MD
- \( S_{CD} \) = Stiffness CD
- \( c \) = Constant
- \( \sqrt{S_{MD} \times S_{CD}} \) = Geometric mean stiffness

By simplifying geometrical parameters and panel size it has been found that for a range of carton panel sizes the constant \( c \) has a value of approximately \( 2\pi \) equal to 6.28. The minimum size of the panel is approximately 60 x 90 mm (width x height). If the panel is smaller, bulging is gradually diminished and the above relationship is no longer accurate.

The compression strength of a paperboard panel \( F_P \) is then:

\[ F_P \approx 2\pi \times \sqrt{F_C \sqrt{S_{MD} \times S_{CD}}} \]

\[ \approx 6.28 \times \sqrt{F_C \sqrt{S_{MD} \times S_{CD}}} \]

and consequently for a complete box consisting of four panels \( 4 \times F_P \):

\[ F_B = 4F_P \approx 8\pi \times \sqrt{F_C \sqrt{S_{MD} \times S_{CD}}} \]

The box compression strength is controlled by the paperboard stiffness and the compression strength. The illustration below gives the relationship between measured panel compression strength and the predicted value based on measurements of short span compression strength and stiffness of the paperboard, using the above equation. As can be seen, the agreement is very good.

Based on these simplifications it is possible to quantify how the measured properties of the paperboard, i.e. compression strength (short span) and stiffness, contribute to the panel and box compression strength. It is, however, important to realise that the size of the carton and the flap design have a large influence on the practical results.
The relative importance of carton size is shown in the illustration below. For very small cartons, bulging of the panels is small or non-existent, which means that only the paperboard’s compression strength is of importance (stiffness plays a minor role). In contrast, cartons with very large panels are much more dependent on stiffness than compression strength.

When comparing different materials it is also important to remember that it is not possible to find materials with maximum stiffness and compression strength at the same time.

Key properties

The box compression strength of a carton is governed by the paperboard’s compression strength (short span) and stiffness. Fundamental research and experimental data have shown that within certain limits it is possible to predict box compression performance based on the paperboard’s compression strength and stiffness. This means that for the paperboard these values can be used to compare different grades. However, it is important to point out that knowledge and facts are still lacking for a real prediction of the long term behaviour of boxes during compression loading that takes place during storage and transport.