Creasability and foldability

The purpose of creasing is to make well-defined folding lines, which facilitate the folding operation and provide the conditions for the paperboard product to obtain its intended shape and function. The ideal crease should perform like a perfect hinge when folded. This cannot be fully achieved, but the challenge is to come as close to such a hinge function as possible.

Creasability and foldability are two closely related and very important properties:

- for obtaining the intended carton shape and function
- when designing creative shapes, in both graphical and packaging applications
- for packaging line efficiency and runnability
- for achieving box compression strength and stacking performance.

The application determines the creasability and foldability demands. These demands can arise from production, carton shape, size or function.

The paperboard choice

Paperboard catalogues and brochures often contain the manufacturer's subjective opinion about the paperboard creasability and foldability, for example "good" or "very good". Structure, construction, type of pulp, and basic measurable properties provide the paperboard with its creasability and foldability. The judgement "good" or "very good" must be based on facts about these properties.

The paperboard choice is important but the construction of the creasing tool and its performance are equally important for achieving a satisfactory result.

The paperboard's stiffness and strength properties contribute to the folding result. Folding Box Board is generally stiffer than Solid Bleached Board, for a given grammage, which instead has better strength properties. Foldability is a question of stiffness and strength, related to the application demands.

The following text deals only with the aspects to be considered when creasing and folding basic grades of paperboard. The additional considerations for plastic- or metal-laminated paperboard are not discussed.

In most cases the paperboard consists of a number of fibre plies and layers of coating. The individual characteristics of the different plies and the paperboard construction as a whole have a great influence on the creasability and foldability. The multi-ply construction makes an important contribution to creasability and foldability.

The demands on creasability and foldability vary with the application. Folding Box Board (mechanical pulp with chemical pulp in the surface plies) and Solid Bleached Board (pure chemical pulp) can together satisfy a wide range of different demands.

Solid Bleached Board has advantages when the requirements for precision and machine speed are high and when the carton shape demands deep and narrow creases. This is especially so if the creases are located very close to each other in small areas, when creasing with narrow radii, and if the crease angles are small. Since the creasing operation causes a mechanical deformation, the measurable strength properties such as tensile strength, compression strength, elongation, and elasticity are vital.
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Creasability characteristics

Creasability is explained as:
• The paperboard’s ability to permit deep and narrow creases. Folding such a paperboard is easy and the result will be well-defined edges and corners.
• The paperboard’s ability to adapt to the crease rule shape and retain the desired geometry of the crease. Accuracy and precision in the crease shape and location are important. The folding operation is difficult to perform if the crease is too shallow or wide.
• The paperboard’s ability to be folded is measured by the folding factor. The higher the folding factor attained without the surfaces cracking, the better the creasability and runnability in converting and packaging machines.
• The paperboard’s ability to “forgive”. A forgiving paperboard is less sensitive to variations in the creasing conditions (width, depth, and thickness), for example, due to the tools becoming blunt. The paperboard will be more reliable in the converting machines. The compression strength of paperboard in general is 2–3 times less than the tensile strength. The material will collapse where the compression forces start to appear, but the surface plies are unaffected and retain their tensile strength. This course of events is desirable. The areas with compression are initially delaminated into several thin layers within the paperboard and the plies separate. During the subsequent folding operation the delamination will fully develop and the surface plies where the tensile strength is unaffected create the hinge.

It is obvious that creasing is a severe treatment. The surface plies of the paperboard, including the pigment coating, must be strong enough to withstand the required forces and elongations. Deep and narrow creases are difficult to perform. The surface plies may crack either when the crease depth limit of the material is exceeded, or during folding.

The criteria for good creasability become more obvious if the folding factor as a function of the creasing depth or width is shown in an illustration. The end points of each graph represent either a badly defined crease or cracking of surfaces (deep creases).

Assessment of creasability

An objective evaluation of the creasability of various paperboards is performed by calculating the folding factor after creasing. The bending moment \( M \) is measured before and after creasing. The folding factor \( F \), also called moment reduction, is calculated using the following formula:

\[
F = \frac{M_{\text{uncreased}} - M_{\text{creased}}}{M_{\text{uncreased}}} \times 100 \%
\]

- Folding factor = 0 \( \Rightarrow \) uncreased paperboard
- Folding factor = 100 % \( \Rightarrow \) perfect hinge

The following conclusions can be made:
Good creasability is characterised by:
• A high folding factor attained at low creasing depths.
• A further increase in creasing depth will result in only a small change in the folding factor (as horizontal a curve as possible).
• The material should not be too sensitive to surface cracking during creasing or folding and bending, i.e. it should allow a wide range of depths/widths.

A straight and horizontal line in the illustration is optimum. In practice, the creasing tools become blunt, and variations occur in the settings of the creasing depth and the machinery. Thus, a paperboard that gives small changes in folding factor due to alterations in depth is forgiving as its creasability is only marginally affected by changes in
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the machinery and make-ready. Cracking in either of the two surface plies usually occurs when the creasing depth is increased. Therefore, a paperboard that can take as deep creasing as possible is desirable.

In paperboard with poor creasability, the folding factor is very dependent on the creasing depth, and cracking occurs as soon as the depth is exceeded.

A 3D illustration can be used to show the relation between folding resistance, crease width, and crease depth.

The exact shape, symmetry and position of the creases have become more important as packaging applications increasingly require greater reliability and efficiency.

The final shape of the crease, i.e., its width and depth, is not only defined by the creasing tool geometry but also by the type of paperboard and its ability to adapt to the geometry of the tool. Another important observation is that the dynamic character of the creasing operation means that different board grades require different dwell times or impression times to ensure satisfactory creases are developed, i.e., some boards can be run faster than others.

Symmetry is important, especially for smaller sized cartons and cartons with very high demands on accurate shape and dimensions. If the creases are asymmetrical, the folded corner will not look as intended, and it can, depending on the degree of asymmetry, give incorrect alignment. These cartons might have a negatively affected appearance or even cause stoppages in the packaging line.

The geometric positions of edges and creases are also important for similar reasons. In this case the tolerances of the tools and the consistency of the paperboard’s dimensional movements also play a key role.

**Different paperboard ply constructions**

Pulp quality and composition as well as the paperboard construction have a great influence on the creasability of the paperboard.

The use of multi-ply paperboard is one important criterion for good creasability. Complete delamination of the inner plies is desirable to achieve the hinge when folding.

The following illustration shows an example of the creasability of three different multi-ply sheets. A sheet made of mechanical pulp with a surface ply of bleached chemical pulp (A), an I-beam construction with mechanical pulp in the middle plies and bleached chemical pulp in the top and bottom plies (B), and finally a multi-ply and homogeneous sheet made of bleached chemical pulp (C).

The differences in creasability are significant. A radical improvement in the creasability is gained when mechanical pulp is used together with two plies of bleached chemical pulp in an I-beam construction of the paperboard (B) instead of the paperboard with only a top surface ply (A). By redistributing the surface ply to both sides of the sheet, a wider creasing range and better folding factor are acquired. This proves the importance of strong surface plies. The best creasability performance is achieved with a multi-ply paperboard made of dense and strong chemical pulp (C).

To summarise, the use of chemical pulp alone or in combination with mechanical pulp gives advantages in creasability as shown in the illustration above. It is also important to note that paperboard is a visco-elastic material, which means that all the properties mentioned are time-dependent.

As stated previously, the dwell time during creasing and the type of paperboard both significantly affect the fold quality. Chemical pulp has advantages over time as its properties are more stable and it preserves the shape of the creases from gradually deteriorating. Chemical pulp also more accurately conforms to the tool geometry. This contributes to consistent performance in conversion and packaging.
Key properties
For the creasing operation the following paperboard properties are crucial:
• elasticity and elongation
• tensile strength
• compression strength
• bending moment/resistance
• delamination strength
• flatness and dimensional stability.

Elasticity (also referred to as the tensile stiffness or E-modulus), tensile strength and elongation are three important physical parameters of the surface plies. When the paperboard is creased it is stretched in four small zones. When the creased zone is folded, high tensile strength and elongation are important to avoid cracking of the surface. Equally important are the compressive forces (also in four small zones), which develop an initial compressive failure and delamination of the interior of the paperboard. The interlaminar strength (delamination strength) should be within a given range, not too high or too low, to allow delamination during creasing but to keep the paperboard intact during other operations and use. The best crease result is achieved when the paperboard is delaminated into as many thin but undamaged plies as possible.

The flatness and dimensional stability of the paperboard sheet are of vital importance to the precision of the creasing operation. Otherwise, variations in paperboard flatness and stability add to the margin of error for tools and machinery, with a resulting negative effect either on the creasing result or on the intended appearance of the carton.

Measuring equipment
Examples of laboratory systems available for measuring crease quality are: the Lorentzen & Wettre (L&W) Creasability Tester, the Marbach Crease Bend Tester and the Pira Creasability and Creasebend Tester.

The L&W Creasability Tester permits three folding angles (5°, 90°, and 160°) and has three available bending speeds (5°/s, 90°/s, and 900°/s). Bending stiffness, bending coefficient and bending moment for creased and uncreased specimens are examples of properties measured by the L&W Tester. The folding ratio is calculated as the energy required to fold creased and uncreased samples × 100%.
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The Marbach system is very similar to the L&W system but uses the following formula:

\[ F = \frac{S_B - S_F}{S_B} \]

- \( S_B \) = bending resistance on rupture of uncreased sample
- \( S_F \) = folding resistance on folding of creased sample

Crease recovery resistance (CRR)
The spring back force of a folded and creased sample can be analysed using a crease stiffness tester; this is often referred to as crease recovery resistance (CRR) and in some way characterises the paperboard’s creasability.

Crease stiffness testers are available from different manufacturers and can either provide a simple measurement of the crease stiffness (e.g. Pira style) or give a detailed analysis of force generated compared to bending angle during the folding of the crease (e.g. L&W style).

For all testers the basic principle of the method is the same. A paperboard sample is creased to a specific geometry according to thickness and prepared to a given size. The sample is then clamped in position into the tester so that the board surface, indented with the impression of the crease, touches the load cell (see previous page). The clamp is rotated through 90° and maintained at this angle for 15 seconds after which the crease stiffness measurement is taken. With Pira style testers the clamp is rotated manually by the operator and a single value is obtained for crease stiffness after 15 seconds. With L&W style testers the rotation of the clamp is performed at a constant user-defined speed by the test machine and the measurement of the force is continual. The forces can be recalculated as torques and plotted against bending angle to generate a resistance to folding plot. The resistance to folding plot can be useful to understand how different boards behave. For example, the angle at which the elastic limit is passed and subsequently the substance starts to delaminate can be identified on the curve, shown in figure 2 at position 1. The point at which the CRR is measured, i.e. after 15 seconds at 90°, is also indicated on the curve, at position 2.

Bending resistance and folding resistance

Torque vs. bending angle. At 1 delamination of the board starts and at 2 the torque will be after relaxation 15 seconds.
An understanding of CRR and board stiffness is important if cartons are to be run well on high speed packing lines. The board stiffness is important to protect the contents being packed. However, the CRR cannot be too high or the faces of the carton will bow and look unattractive or variations in spring back force will disrupt the runnability. The difference in folding speed (degrees/second) will differ greatly with the intended folding and erecting methods, ranging from a slow folding carton side-seam gluing line to an extremely rapid hot melt case erecting line with a forming cavity and plunger, typical for confectionary boxes. Analysis of CRR characteristics allows the paperboard manufacturer to design products which can be run effectively in high speed applications.

**Foldability characteristics**

Good foldability is explained as:

- the ability of a creased blank to form a carton or graphical product with the desired shape and dimensions
- minimal spring-back force.

Foldability also contributes to runnability in packaging machines and to the quality of the end product.

Foldability is vital in converting, when paperboard blanks are folded in order to create a glued side seam and when the package is erected, formed and finally sealed. Improper performance due to poor foldability can cause production stoppages and unnecessary material waste. Bulging sides and flap spring-back can be signs of poor foldability.

Foldability is achieved by ensuring good creasability – low bending resistance in the creased zone – combined with high stiffness. The low bending resistance in the crease is a guarantee of low spring-back, and together with stiffness prevents bulging of the carton side walls.

A creased blank is usually folded to 90° or 180°. Sometimes prefolding is done to reduce the bending resistance further. Side seam glued cartons have two creases folded to 180° and during erection are folded back to 90°. In this case it is also important to have a low folding resistance, i.e. carton opening force.
To achieve reliable folding it is important to maintain a high and consistent ratio between bending stiffness and folding resistance (i.e. high folding factor). If not, the result will be varying degrees of curved/distorted panels.

Paperboard is a visco-elastic material. This means that the higher the folding speed the higher the folding resistance. Measurements made on different types of paperboard show the following typical behaviour.

**Assessment of foldability**

The foldability of different paperboard types can be evaluated by knowing the ratio between the bending stiffness and the bending moment of the crease. By definition, this ratio determines the radius of curvature of the panels around the fold. The greater the radius of curvature the less the panels bulge.

\[
\text{Foldability} = \frac{\text{Bending stiffness}}{\text{Bending moment}} = \frac{S_{b,\text{creased}}}{M_{\text{creased}}}
\]

A crease with a low bending resistance has low values for the bending moment of the crease. The equation indicates that a paperboard with a high stiffness and a low bending resistance is preferable. A paperboard permitting deep creases without damage to the surface plies provides good foldability.

**Differences in CD and MD**

The orientation of the fibres in the machine direction of the paperboard sheet complicates the creasability and foldability. The creasability of a crease parallel to the cross direction (CD) is always better than the creasability of a crease parallel to the machine direction (MD).

It is more difficult to make creases parallel to the main fibre orientation. The differences in creasability in the CD and MD and the bending stiffness in these respective directions influence the total foldability of cartons or other folded paperboard products.

Sometimes the terms short grain (creases parallel to the CD) and long grain (parallel to the MD) are used.

This illustration shows a malfunction in folding. Although the sheet is creased to facilitate folding, the sheet folds beside the crease. The creases made in the MD, 1), do not have a sufficiently high ratio of:

\[
\text{Bending stiffness} \quad \text{Bending moment}_{\text{crease}}
\]

The flap therefore becomes arched. Consequently, when the next flap is folded, 2), the creases in the CD are arched as well. This increases the crease’s bending resistance to such an extent that it exceeds the bending resistance of the uncreased paperboard. The flap acts as if it is not creased at all and creates an undefined bend. This may lead to folding beside the crease. This different folding performance between the MD and CD direction must be optimised for demanding applications, i.e. deeper MD creases.

**Different paperboard ply constructions**

The requirements for foldability in this respect can be based on the same discussion as for creasability.

**Key properties**

Key paperboard properties for foldability are:

- strength and toughness in the MD and CD
- stiffness in the MD and CD
- strong elastic coating.
During the folding operation, the inner structure of the paperboard should delaminate into as many thin plies as possible without each individual ply breaking. The forces applied to the creasing zone during folding are very much like those created during creasing. The paperboard’s internal strength must be high enough for the paperboard to remain intact, except when and where creased and folded. When folded it should separate into a large number of individual layers to act as a hinge.

All the key strength characteristics for creasing are also important during the folding operation. As the above discussions indicate and the equation for foldability states, stiffness is vital in addition to the strength characteristics.

So far we have concentrated on the physical characteristics of the paperboard’s fibre material. In addition to the fibres, the coating (usually a pigment coating) must also be strong and elastic. The coating might otherwise crack and destroy the appearance of the printed package.

**Measuring equipment**
The bending apparatus used for measuring the folding factor for creasability can also be used in this context.

*Paperboard when being folded*