Flatness and stability

Flatness and good dimensional stability are critical paperboard properties. The proper flatness or “shape” of the paperboard sheet, as well as of the die-cut carton blank, is of major importance for good runnability in all processing of paperboard, including packing line efficiency.

For graphical products such as cards, book covers, folders, etc. the flatness as such is important for the presentation of the finished product.

During the converting and packaging processes the paperboard is often exposed to conditions which affect its moisture content. Depending on the type of paperboard, its raw material composition and manufacturing process, the paperboard sheet will experience changes in its shape or dimensions.

In these contexts, shape is a better descriptive term than flatness. In practice, the shape at the point of manufacture differs from absolute flatness in order to compensate for the change in shape which can occur during printing and conversion.

Key characteristics

Since many paperboard characteristics are influenced by the moisture content, it is important to manufacture to a level which corresponds to the needs of the printing, converting and packaging operations.

Moisture content is controlled during the drying process on the paperboard machine. Independent control of both the print and the reverse side of the paperboard is essential to ensure even drying and curl control. It is also possible to ensure an even moisture profile across the width of the web by on-machine measurement and control.

Cellulose fibres are hygroscopic and will react to changes in humidity by swelling during moisture uptake and shrinking when losing moisture. For the cellulose fibre itself the relative dimensional change is greater in the cross-fibre direction.

On the paperboard machine, the process always gives some preference to fibre orientation in the machine direction (MD) of the paperboard sheet. This means that there are a majority of fibres orientated with the fibre length direction parallel to the machine direction.

The relatively large potential for dimensional change across the fibre, together with the fibre orientation, makes the dimensional change and hence the shape of the sheet more pronounced in the cross direction (CD).

The fundamental principle for changes in dimensions or shape is shown by the illustration below.

If the two surfaces of the paperboard sheet are equal regarding their relative dimensional moisture change, a change in moisture will only affect the sheet’s dimensions, that is lateral expansion or shrinkage. Such paperboard grades are as close to the ideal symmetric sheet as possible, e.g. equally two-side coated or uncoated paperboard products of symmetric construction regarding composition, construction and treatment.

A paperboard sheet where the surfaces have different relative moisture expansion will bend for a given change in moisture. Examples of such paperboard products are one-side coated products or two-side coated or uncoated

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**Measurable properties**

- **Moisture content (ISO 287)**
  - Moisture content is expressed as a percentage of the total paperboard weight.
  - As paperboard is a hygroscopic material, all testing should be done in a controlled climate of 23 °C and 50 % RH.
  - It is also important that exposure during further processing is under controlled temperature and RH conditions.

- **Test method and equipment**
  - The moisture content is measured and controlled continuously on-line on the paperboard machine by scanning equipment which gives a high degree of definition in both the machine direction (MD) and cross direction (CD) of the paperboard web.
  - Laboratory testing is carried out regularly to ensure correct on-line calibration.
Flatness and stability

**SYMERICAN SHEET**
- no change in shape

**ASYMMETRIC SHEET**
- change in shape

Paperboard sheet construction and the expected shape change of an asymmetric sheet in different environments

- humid climate conditions

- dry climate conditions
Flatness and stability

paperboard with asymmetric composition, construction or treatment of the basic paperboard. In practice almost all paperboard products belong to this type.

**Dimensional changes**

As paperboard is a very hygroscopic material, many of its properties are strongly influenced by the relative humidity in the surrounding air, and hence the moisture content of the paperboard. Accordingly, a consequence of moisture change is a change in the paperboard dimensions.

**Moisture equilibrium**

Paperboard is manufactured to meet a certain shape at a predetermined moisture content. At this moisture content the paperboard will be in equilibrium with a given level of relative humidity (RH) in the surrounding air, that is it will neither gain nor lose moisture at this RH. The equilibrium moisture content will vary depending on the type of paperboard and its fibre composition.

Measurements have shown a negative correlation between the density of the paperboard and the level of equilibrium moisture. The relative humidity (RH) stated in this table applies to the surrounding air.

In printing, die-cutting and other operations it is important to maintain register control and to keep the paperboard blanks flat. Therefore it is important to keep the relative humidity of the surroundings in equilibrium with the specified moisture range of the paperboard.

**Hysteresis**

Hysteresis is a lagging effect in which a memory of the previous state is retained.

There is one range of equilibrium moisture content for increasing relative humidity and a slightly different range for decreasing relative humidity. These ranges vary for various paperboard grades.

This illustration shows a typical moisture hysteresis of a paperboard where the climatic conditions have been run through in a sequence from 1 to 4. This implies that the moisture content of paperboard also depends on earlier climatic conditions. A different moisture content will be reached even in a standardised climate of e.g. 50 % RH depending on whether the paperboard has come to this climate from a dry or humid climate. To avoid this problem all testing must be done in a standardised climate at 50 % RH and +23 °C and the sample must first be pre-conditioned in a climate of about 35 % RH and +23 °C. In this way, the test material will, from a moisture content viewpoint, always be tested under the same moisture conditions. The displayed curve is valid for paperboard manufactured from a specific raw material. Other paperboards of different fibre composition follow different curves.

![](image)

Moisture hysteresis of a paperboard

<table>
<thead>
<tr>
<th>Moisture content</th>
<th>Paperboard type</th>
<th>Moisture content in paperboard at 15 % RH</th>
<th>Moisture content in paperboard at 50 % RH</th>
<th>Moisture content in paperboard at 90 % RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>High density (SBB) %</td>
<td>High density (SBB) %</td>
<td>~3.2</td>
<td>~6.0</td>
<td>~11.5</td>
</tr>
<tr>
<td>Medium density (WLC) %</td>
<td>Medium density (WLC) %</td>
<td>~3.6</td>
<td>~6.7</td>
<td>~12.0</td>
</tr>
<tr>
<td>Low density (FBB) %</td>
<td>Low density (FBB) %</td>
<td>~3.9</td>
<td>~7.2</td>
<td>~13.5</td>
</tr>
</tbody>
</table>
Moisture expansion coefficient

The moisture expansion coefficient ($\beta$) is defined as the relative dimensional change in percent divided by the corresponding change of moisture content in the paperboard.

$$\beta_{MC} = \frac{\Delta L}{L \Delta MC} \times 100 \%$$

$\Delta L$ = Change of length due to moisture expansion
$\Delta MC$ = Moisture content change in paperboard sample

$\beta$ is specific for a given type of paperboard and practically constant.

$\Delta RH$ = Relative humidity change

The moisture expansion coefficient for a typical paperboard is three times as large in the cross direction (CD) as in the machine direction (MD) of the sheet. In the thickness direction it is ten times as large as in the cross direction.

Here once again the hysteresis effect comes into play as the moisture content in the paperboard also depends on whether the paperboard has come to the climate equilibrium from a dry or humid environment.

In a relative humidity of 50 % the equilibrium moisture in the paperboard can be anywhere between the upper and lower part of the hysteresis curve as shown to the right.

The paperboard is manufactured to match a relative humidity during printing and conversion of 50 % RH at +20 °C. It is therefore manufactured to a slightly higher moisture content to allow some drying, which is normal. The paperboard is prevented from drying out too much by a moisture-proof wrapping.

It is very important that the paperboard is handled and stored correctly all the way from printing and converting, through packing and use (see recommendation under General technical information in the Product Catalogue).

### Parameters

<table>
<thead>
<tr>
<th>Change in moisture content from 7% to 6.5%</th>
<th>$\Delta MC = 7 - 6.5 = 0.5 %$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expansion coefficient (CD)</td>
<td>$\beta_{MC} = 25 \cdot 10^{-2} % / %$</td>
</tr>
<tr>
<td>Dimensional change (%)</td>
<td>$\beta_{MC} \times \Delta MC = 25 \cdot 10^{-2} \times 0.5 = 0.125%$</td>
</tr>
<tr>
<td>Sheet size (CD)</td>
<td>500 mm</td>
</tr>
<tr>
<td>Dimensional change (mm)</td>
<td>$500 \times 0.125 % = 0.6 \text{ mm}$</td>
</tr>
</tbody>
</table>

### Typical $\beta$ values (SBB)

<table>
<thead>
<tr>
<th>Machine Direction</th>
<th>Cross Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5 $\times 10^{-2}$</td>
<td>25 $\times 10^{-2}$</td>
</tr>
</tbody>
</table>
The paperboard will in practice follow the upper part of the curve during printing and conversion. This implies that from the moisture and moisture expansion (shape) point of view the result is limited to the change from points 1 and 2.

If the paperboard is allowed to dry out to a moisture content below the equilibrium of 50%, the equilibrium moisture and shape will be unpredictable. This will result in moisture and hence a moisture expansion (shape), depending on where the equilibrium moisture is established on the vertical line between points 2 and 3.

The situation described above is valid for the paperboard during its lifetime in storage and processing throughout packing and use.

By multiplying the moisture expansion coefficient with the actual change in moisture content of the paperboard, the change in dimensions of the sheet is given. It is then easy to calculate the absolute change in mm as shown by the following example.

As the moisture expansion coefficient is specific to the type of paperboard, a different paperboard grade will show a different change in size.

The paperboard choice
In all applications of paperboard – graphical as well as packaging – it is important that the paperboard retains a flat shape. Changes in shape lead to poor runnability in printing, converting and packaging operations. In all graphical applications, e.g. picture postcards, book covers, etc., the shape of the finished product is also of prime importance.

Paperboard is sensitive to changes in humidity. Exposure to variations of humidity will result in a change of paperboard shape or dimensions. Paperboard is manufactured to be flat in a defined environment; exposure to another environment will create a situation where the paperboard shape is unstable. Information concerning the end use environment must be given to the boardmaker. As paperboard is made of cellulose fibres there is practically no way to prevent the paperboard adopting a moisture content which is in equilibrium with the surrounding air. Any change in moisture will affect the diameter of the cellulose fibre and hence the paperboard shape. Depending on the type of fibre and treatment the change in shape can vary from one paperboard grade to another.

Both Folding Box Board and Solid Bleached Board are manufactured from primary fibres, which means that their behaviour in different climate conditions is predictable.

Flatness and dimensional stability characteristics
Flatness and dimensional stability equate with the paperboard’s ability to withstand the effect of humidity changes in the environment.
Assessment of curl and twist

The paperboard’s shape is defined by curl and twist. Flatness should be evaluated on a single sheet and not on a pallet, since the shape of a pallet is influenced by the temperature difference between inside and outside.

A curlCD has the axis of curl in the machine direction and a curlMD has the axis in the cross direction. The curl is defined as downcurl when the printing side of the paperboard has a convex shape.

Curl is defined as the inverse of the radius of curvature, \(1/r\) (1/m = m-1). If the sheet is flat, the radius approaches \(\infty\) and accordingly the curl will approach 0.

\[ \text{Curl} = \frac{1}{r} \quad \text{(Units = m-1)} \]

Another type of curl is reel curl. This type of curl is oriented in the machine direction of the paperboard and is typically caused when the paperboard has been stored for a long period of time in reels tightly wound around a narrow diameter core. This curl can be oriented up or down relative to the printing side depending on whether the printing side has been wound in or out.

When measuring curl and twist, the chords of the nine circles are measured: see L&W curl and twist tester. Two chords C1 and C9 are shown in the illustrations. If these chords have different angles in relation to the horizontal plane the sample has twist.

The change in angle of the chords when moving in the machine direction gives a measurement of twist.

\[ \text{Twist} = 2 \times \frac{\Delta \theta}{\Delta d} \quad \text{(Units = m-1)} \]

\(\Delta \theta\) = Change of angle in radians
\(\Delta d\) = Movement in positive machine direction (m)

The twist is defined as positive when the chords are turning counter-clockwise when moving in the machine direction and negative when the chords are turning clockwise.

The twist angle is the angle in the MD where the sheet has no twist. It can take values between 0 and +/- 45°.

Key properties

The degree of dimensional, and hence curl, change is influenced mainly by:

- type of fibre and ply construction
- degree of fibre refining and internal sizing
- fibre orientation (anisotropy)
- coating type and composition
- uniformity in moisture profiles.

Radius of curvature

Curl

Twist

Positive and negative twist
Measurable properties

Curl and twist
The simplest method of measuring the curl of a paperboard is to cut a square sheet, condition it at 50 % RH and 23 °C and match the MD and CD edges to a set of curves of differing radius of curvature. Stability can be checked by measuring shape on a sample after conditioning between pre-determined relative humidities (ascending and descending). The curl and twist tester measures the curl, twist and twist angle of paperboard samples. In addition, an evaluation of how much these properties change in different climates, i.e. the dimensional stability, can also be done.

Five test pieces, taken from positions across the paperboard machine width, are mounted and conditioned to a relative humidity of 35 %, 50 % or 65 %. The curl and twist tester evaluates a cross section through the sheet in parallel with MD (see the illustration above).

At this cross section, the curvature of the sheet is assumed to follow a circle with radius r. The curvature at this cross section is expressed as the inverse of the radius r (r is expressed in metres). Each sample is assessed by nine scans, giving 81 measuring points. Sample size is 10 × 10 cm. How closely the scans correlate to a perfect circle is given by a correlation factor, where 1 means full correlation and 0 no correlation with a circle.