INTERNATIONAL STANDARD

ISO 11556

Second edition
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Paper and board — Determination of curl using a single vertically suspended test piece

Papier et carton — Détermination du tuilage au moyen d'une éprouvette unique suspendue verticalement

Reference number
ISO 11556:2005(E)

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 11556 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*, Subcommittee SC 2, *Test methods and quality specifications for paper and board*.

This second edition cancels and replaces the first edition (ISO 11556:1998), of which it constitutes a minor revision, and Technical Corrigendum 1, published 2003-04-01, which has been incorporated into this edition.

Introduction

The presence of curl in paper and board may be detrimental to its processing, and therefore there is a need for its measurement. Curl can be inherent in the paper when manufactured, or can be developed in the sheet during its use. This International Standard describes the procedure to be used for determination of curl in a pack of sheets.

Paper and board — Determination of curl using a single vertically suspended test piece

1 Scope

This International Standard gives a procedure for determining the curl of paper and board using a vertically suspended test piece, and defines the terms used in curl measurement.

This International Standard may be used to measure any curl when

— the curl formed approximates the arc of a circle;

— the curl is stable enough to remain constant during the time required to cut the test pieces and make the measurement. This primarily includes curl in paper or board as received or after exposure to a constant climatic condition, such as a test room or print shop.

NOTE 1 The choice of conditioning climate and conditioning time depends on the purpose of the testing.

NOTE 2 For papers coated on one side or gummed-label papers, a period of at least 24 h, after production, should be allowed to permit the paper to stabilize before any curl tests are done.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
curl
deviation from a flat surface

NOTE Its measurement has three major components:

— its magnitude;

— the angle of the curl axis in relation to the paper or board's machine direction;

— the side towards which the sheet curls.

3.1.1
magnitude
measured deviation of a test piece from a flat surface

NOTE 1 Magnitude is expressed as the reciprocal of the curvature of the curled test piece with units of m^{-1}.

NOTE 2 The radius of curvature for the curled test piece is the distance from the arc to the centre of the circle of which the arc is a part. The reciprocal radius ($1/R$) has a value of zero for a flat sheet.

NOTE 3 Curl characteristics of paper and board are time dependent and the magnitude of any curl displayed may be transient.

3.1.2
angle of curl axis
ϕ (see Annex A)
angle between the axis of the curl and the machine direction of the paper or board, viewed from the concave side

NOTE 1 For a curl that has its axis perpendicular to the machine direction, $\phi = 90°$; for a curl that has its axis parallel to the machine direction, $\phi = 0°$. When the axis of the curl is neither perpendicular nor parallel to the machine direction, it is sometimes referred to as “diagonal curl” (occasionally as “asymmetric curl”, “twist curl” or “wrap curl”). For diagonal curl, if the machine direction is positioned in a clockwise direction from the axis of the curl, this is deemed as a positive (+) rotation, but if it is in a counter-clockwise direction, then this is deemed as a negative (–) rotation. The angle of curl axis can be positive or negative between 0° and 90°.

NOTE 2 Note that the rotational direction in a diagonal curl is reported as being clockwise (+) or counter-clockwise (–) from the axis of the curl to the machine direction, and not from the machine direction to the axis of the curl.

3.1.3
concave side
side towards which the paper or board curls

NOTE See Annex A.

3.2
induced curl
change in **curl** (3.1), caused by some treatment to one or both sides of the paper or board

NOTE A curl is often 'induced' in a test piece to indicate the processability of a paper or board in an end-use situation.

3.3
double curl
flipper curl
a form of curl which tends to alternate between the two sides with light manipulation of the sheet

NOTE This tendency is a phenomenon which may be described as two curl patterns that are finely balanced within the same sheet of paper or board.

4 Principle

Test pieces of paper or board are exposed to the desired test environment. The curl is measured with the test pieces suspended such that the axis of the curl is vertical.

5 Apparatus

5.1 A device to cleanly cut out test pieces to a set diameter or size. For circles, the preferred diameter is 112,8 mm ± 0,1 mm (100 cm^2). For square test pieces, the preferred size is (100 mm × 100 mm) ± 0,1 mm.

NOTE Circular and square laboratory cutters to produce 100 cm^2 test pieces are commercially available for sheet grammage determinations.

5.2 A device for supporting the test piece during measurement, see Annex B.

5.3 A device for measuring the chord and chord-to-arc distance to within 0,5 mm (for example, a modified engineer's vernier calliper, see Annex C).

5.4 A device for measuring the angle of curl accurately to within 1°.

NOTE Automated methods of determining the curl magnitude and the angle of the curl axis may be used provided they are at least as accurate as the method described in this International Standard.

6 Sampling

If a consignment of paper or board is being evaluated for curl, select the sample in accordance with ISO 186. Protect the sample from moisture change if the curl is to be measured as received.

If the test is being made on another type of sample, report the source of the sample and, if possible, the sampling procedure used. Make sure that the test pieces are representative of the paper or board sample.

After sampling, care should be taken to ensure that all samples are kept in the same relative orientation.

7 Preparation of test pieces

Select undamaged specimens free from folds or wrinkles, and preferably free from watermarks. In the areas from which the test pieces will be cut, lightly mark the machine direction, if possible on the same side of each test piece. When marking the test piece, take care not to make indentations which may affect the curl. This side of the test piece will then be referred to as the “marked side”. Cut ten test pieces, one at a time, with the machine direction marks lying along the centre-line of the test piece.

Circular test pieces are preferred. However, square test pieces conforming to the dimensions given in 5.1 are also acceptable.

It is very important that one side is marked.

If possible, the marked side should be identified by a distinguishing feature, such as wire marking, coating, watermark, glazing, etc. If the side cannot be identified, then the side facing the wrapper of a sealed ream, or the upper face of the top sheet on an open skid of paper, should be the marked side.

8 Procedure

8.1 General information

The procedure specified in 8.2 assumes that an instrument such as a modified engineer's vernier calliper (see Annex C) is employed. This instrument can be used to measure the chord length and chord-to-arc distance, from which parameters the curl magnitude (as reciprocal radius of curvature) is calculated. In principle the instrument can be used, with the formula in 9.1, to determine the curl of any sample. There will, however, be practical limitations imposed by the geometry of the measuring apparatus. Examples of curl shapes which may be obtained are shown in Annex A, which also shows the chord length (C) and chord-to-arc distance (h).

NOTE The chord-to-arc distance is the maximum distance from the chord to the arc, measured upon a line perpendicular to the chord.

8.2 Method

8.2.1 Exposing the test pieces to the test environment

Suspend the test piece in the test environment by means of a small hook or clip placed near the edge of the test piece along the line marking the machine direction. Within the required time limits, observe the approximate curl axis and concave side. Keeping the test piece in the same environment, carefully remove the test piece and, using a small-headed pin, fix it at its centre against the vertical support (see 5.2) so that the concave side is facing the operator. Rotate the test piece so that the axis of curl is vertical. At the top of the test piece, mark the centre-line of the curl axis and then, at this point, fix the top of the test piece to the support by another pin.

If determining the curl of paper or board without conditioning (i.e. as received), the exposure and measurement procedure should be carried out as rapidly as possible to minimize any significant change in curl.

NOTE 1 Care is needed when attaching the test piece to any suspending or supporting devices so as not to bend the test piece in such a way that the curl would be affected.

NOTE 2 Test pieces may be exposed and measured horizontally by placing the test pieces on a flat surface with the concave side up, if it can be shown within experimental error that gravity does not have a significant influence on the test result. (Board test pieces are generally too stiff to be significantly influenced by gravity.)

In cases where square test pieces exhibit a significant diagonal curl, difficulties in measurement are such that the results should be treated with caution.

8.2.2 Measurement of chord length and chord-to-arc distance

Use circular or square test pieces. Protect test pieces from drafts during the measurements. Using the modified vernier calliper, measure the length of the chord (C) across the centre of the test piece to the nearest 0,5 mm and measure the chord-to-arc distance (h) to the nearest 0,5 mm.

Repeat the procedure with the remaining nine test pieces.

NOTE 1 In order to obtain accurate measurements when using the modified vernier calliper, it is recommended that the vernier calliper be supported by means of a laboratory jack.

NOTE 2 Results obtained from test pieces of different shapes should not be compared with one another.

8.2.3 Identification of the side towards which the paper or board curls

If a side can be positively identified, record the side towards which each test piece is curling. If the side cannot be identified, record whether it curls towards or away from the marked side.

8.2.4 Measurement of the angle of axis of curl

Using the device described in 5.4, for each test piece, record to the nearest degree the angle from the axis of curl to the machine direction and whether this angle is clockwise (+) or counter-clockwise (–) as defined in 3.1.2.

9 Calculations

9.1 Magnitude of curl

The magnitude of the curl (K) for each test piece, expressed as the reciprocal radius of curvature, is calculated from:

$$K = \frac{1}{R} = \frac{8h}{C^2 + 4h^2} \times 1\,000 \qquad (1)$$

where

$\frac{1}{R}$ is the reciprocal radius of curvature, in m^{-1};

C is the chord length, in mm;

h is the chord-to-arc distance, in mm.

Where possible, determine the mean and standard deviation of the curl magnitude.

9.2 Angle of curl axis

9.2.1 All test pieces curl towards the same side.

9.2.1.1 If all angles have the same sign, calculate the mean angle and the standard deviation and record the mean angles as either positive or negative.

9.2.1.2 If some of the measured angles are positive and some are negative, but all the values are less than 20°, determine the algebraic mean and the standard deviation and report the algebraic mean as positive or negative.

9.2.1.3 If some of the measured angles are positive and some are negative, and all angles exceed 70°, subtract each negative angle from 180°, to give positive values greater than 90°. Combine these calculated positive values with the measured positive values and calculate the mean angle and the standard deviation. If this mean angle is less than 90°, subtract it from 180° and report the resultant angle as a negative angle.

9.2.1.4 If some of the angles are positive and some are negative, and some are between 20° and 70°, record the curl components of each test piece separately.

9.3 Variation in side towards which paper or board curls

If some test pieces curl one way and some the other way, record the curl components of each test piece separately.

NOTE An alternative method of reporting the data for curl components is given in informative Annex D.

10 Repeatability and reproducibility

Based on data from four laboratories testing four different papers and ten determinations per paper, the following precision data were found for curl magnitude.

10.1 Repeatability

The 95 % probability limit for the difference between two test results within a single laboratory was 2,2 m^{-1}, for different paper samples, using either round or square test pieces.

10.2 Reproducibility

The 95 % probability limit for the difference between two test results from different laboratories was 2,6 m^{-1}, for different paper samples, using either round or square test pieces.

11 Test report

The report shall include the following information:

a) a reference to this International Standard;

b) the date and place of testing;

c) all the information for complete identification of the sample;

d) all the information for complete identification of the test environment;

e) if the paper or board were tested as received or after conditioning the test pieces;

f) if conditioned, the conditioning time and atmosphere;

g) the shape of the test pieces;

h) if the test pieces were tested in a vertical or horizontal plane;

i) the number of test pieces tested;

j) where possible, the mean and standard deviation of the curl magnitude, in m^{-1};

k) where possible, the mean and standard deviation of the angle of the curl axis and whether it is positive or negative (see 3.1.2 and 9.2.1);

l) if the mean and standard deviation of the curl angle cannot be calculated (see 9.2.1 and 9.3), the results for curl components for each test piece;

m) whether the test pieces curl towards the same side, or if they differ, in the direction towards which they curl;

n) if possible, the identification of the marked side (see last paragraph of Clause 7);

o) if the test pieces show any double-curl tendency (see 3.3);

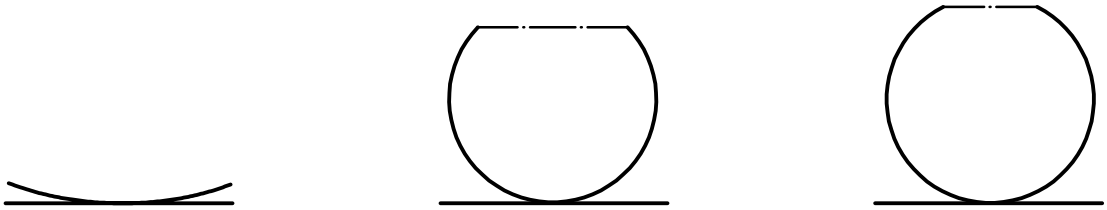
p) any deviation from the procedure specified.

Annex A
(informative)

Illustrations of magnitude and types of curl

Figures A.1 to A.5 are for illustration purposes only. They indicate those curl magnitudes which are probably within or outside the measurement capability of the engineer's vernier calliper, and the measurement parameters for determining the curl magnitude. They also show the types of curl which may occur.

A.1 Measurability of curl magnitude



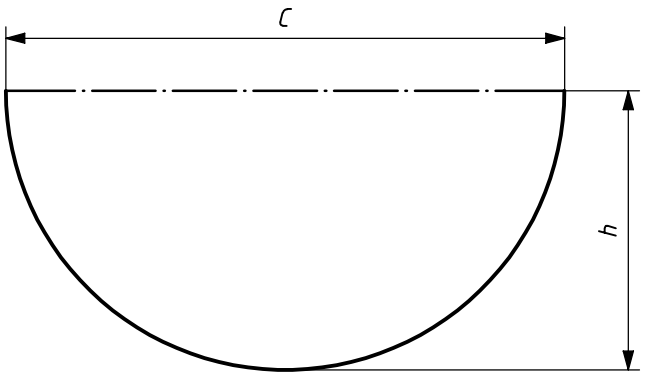
Probably within the measurement capability of the engineer's vernier calliper

Probably outside the measuring instrument's capability, because protruding part could not be positioned accurately

a) Very small curl (almost flat) **b) Large curl** **c) Extensive curl**

Figure A.1 — Measurability of curl magnitude

A.2 Measurement parameters for determining curl magnitude



Key

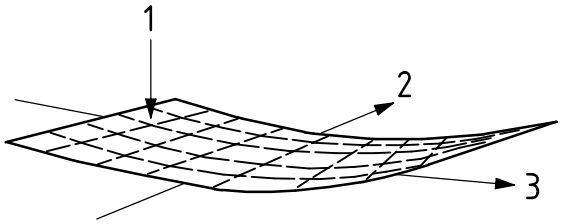
C = chord length, in mm

h = chord-to-arc distance, in mm

Figure A.2 — Parameters for determining curl magnitude

A.3 Types of curl

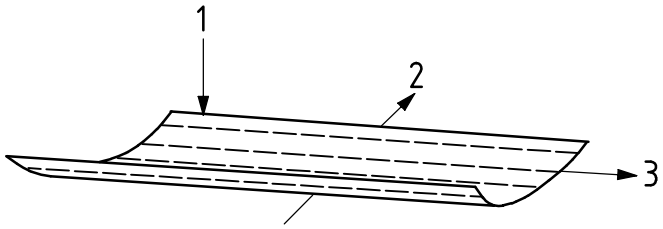
If a symmetrical curl occurs in either machine direction (MD) or cross direction (CD), then depending on the dimensions of the test piece and the test properties, the following types of curl may occur:



Key

1 top side
2 cross direction (CD)
3 machine direction (MD)

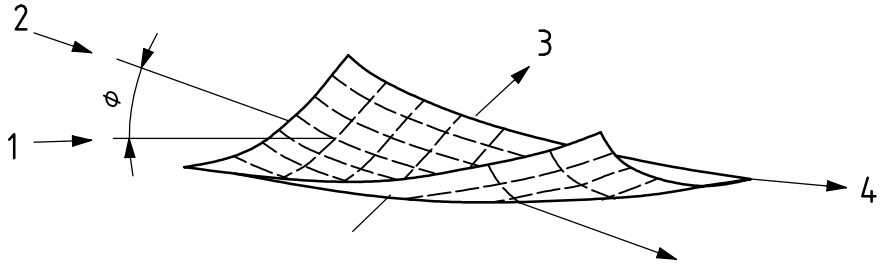
Figure A.3 — Top-side curl with axis perpendicular to machine direction (see [2] in the bibliography)



Key

1 top side
2 cross direction (CD)
3 machine direction (MD)

Figure A.4 — Top-side curl with axis parallel to machine direction (see [2] in the bibliography)



Key

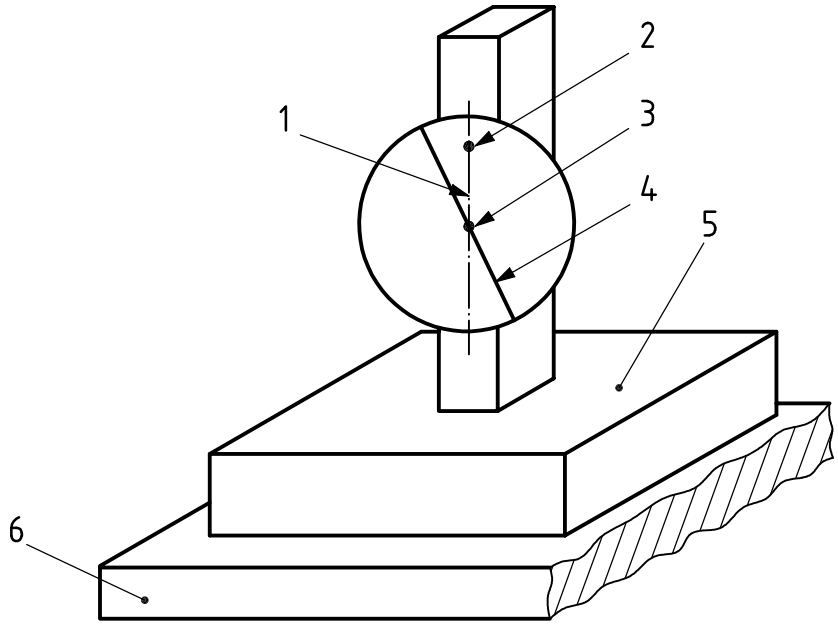
1 curl axis
2 machine direction (MD)
3 cross direction (CD)
4 curl axis

NOTE In this example, the machine direction axis is at a positive (clockwise) direction to the axis of the curl.

Figure A.5 — Top-side diagonal or twist curl (see [2] in the bibliography)

Annex B
(normative)

Method of test piece support during curl measurement (illustrated for circular test pieces)



Key

1 axis of curl, vertical
2 top pin
3 central pin
4 test piece, diameter 112,8 mm (machine direction marked)
5 wooden support
6 bench

Figure B.1 — Apparatus for test piece support during curl measurement

Annex C
(normative)

Modified engineer's vernier calliper for determining chord length (C) and chord-to-arc distance (h)

The standard gauge has been modified by fixing a rule perpendicular to the gauge.

The value of C is measured using the rule. The value of h is measured by the distance the end protrudes, using the vernier.

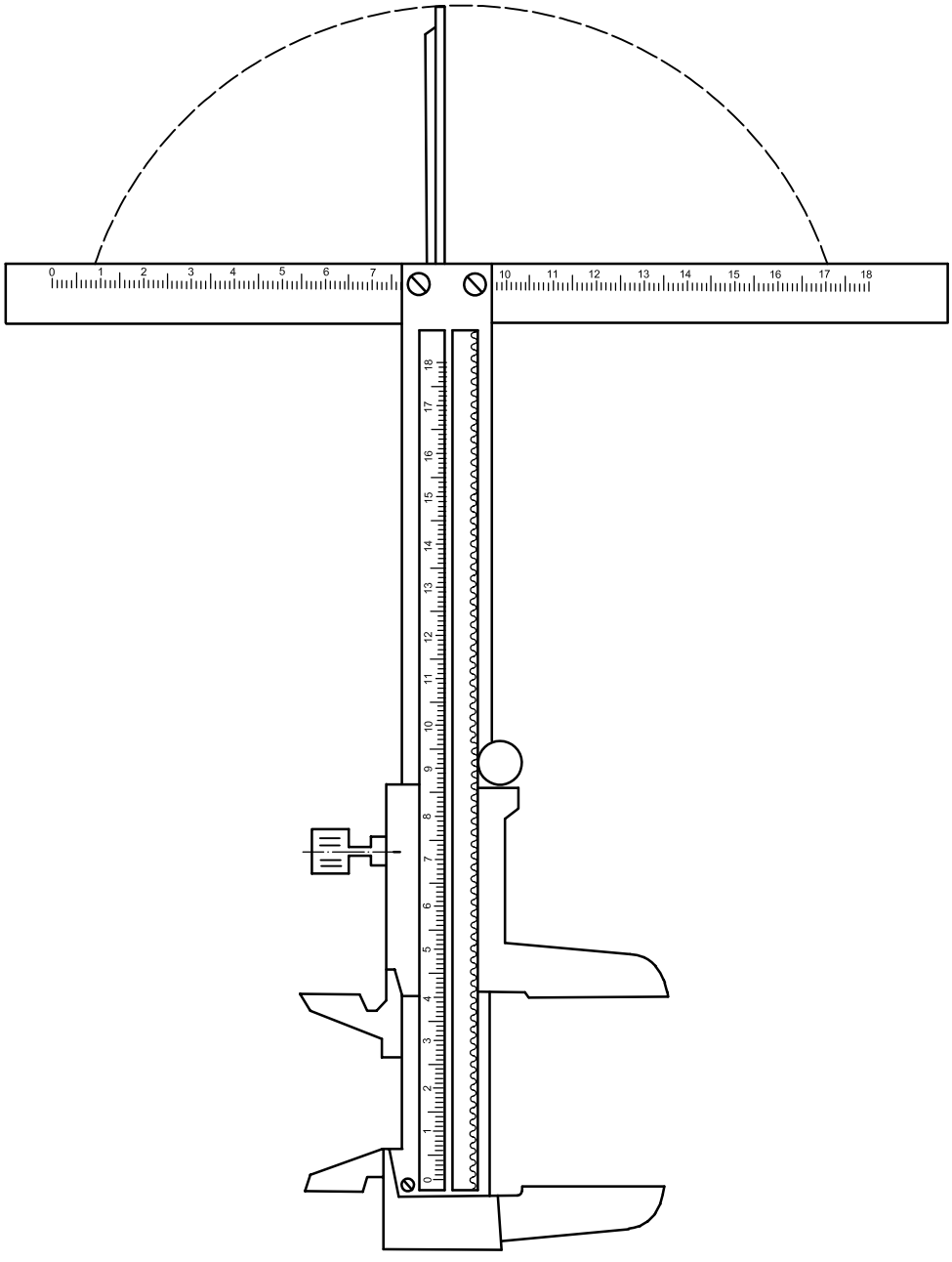


Figure C.1 — Modified engineer's vernier calliper

Annex D
(informative)

Examples of alternative curl calculations

D.1 Curl values are often quite stable and a slight machine- or cross-direction curl is sometimes specified by the customer. However, a diagonal curl (twist curl) may be very unstable, unwanted and independent of the machine or cross-directional curl values.

The procedure described in this International Standard provides a technique for calculating the curl magnitude (K) at a measured angle (ϕ). Using these values, it is possible to calculate the magnitude of the curl parallel to the machine direction, cross direction or the diagonal (45° to MD).

D.2 The curl and twist values related to the machine direction (K_x), cross direction (K_y) and diagonal direction (K_{xy}) can be calculated from:

$$K_x = K_\phi \sin^2 \phi$$

$$K_y = K_\phi \cos^2 \phi$$

$$K_{xy} = 2K_\phi \sin\phi\cos\phi$$

where

ϕ is the angle of the curl axis as defined in 3.1.2;

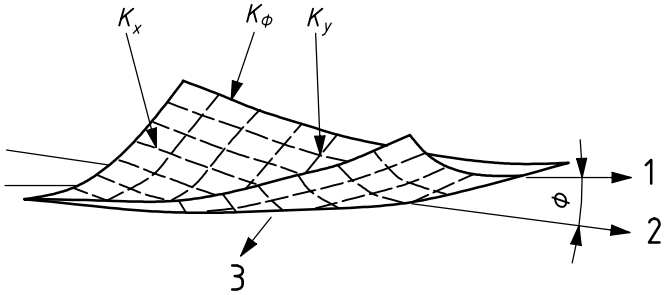
K_ϕ is the magnitude at a measured angle ϕ.

D.3 In a situation where the curl value in the machine, cross and diagonal directions is known, it is possible to determine the direction of the axis of maximum curl, by means of the following expression:

$$\phi = -0{,}5 \tan^{-1} \frac{K_{xy}}{K_x - K_y}$$

with the magnitude of the curl at this angle given by:

$$K_\phi = K_x \sin^2 \phi + K_y \cos^2 \phi + K_{xy} \sin\phi\cos\phi$$



Key
1 curl axis
2 machine direction (MD)
3 cross direction (CD)

Figure D.1 — Curled and twisted test piece

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[2] *Curl in paper; A New Approach to the Evaluation of Curl Shape* — Uesaka T. et al. — Japan Tappi 39 (10) Oct. 1985, pp. 953-959

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