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Textiles — Determination of fabric deformability by forced mechanical distension

Textiles — Détermination de la déformabilité des étoffes par distension forcée mécaniquement

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 38, *Textiles*, Subcommittee SC 24, *Conditioning atmospheres and physical tests for textile fabrics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 248, *Textiles and textile products,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The determination of the deformation characteristics is relevant for all production processes in which flat textile fabrics (including reinforcement textiles) are formed into a three-dimensional shape. This example is the case for upholstery applications or the majority of current liquid composite molding (LCM) processes. Knowledge about the development of deformation effects such as changes in fibre orientation, undulation, and gaps in the textile is crucial for the safe design of processes and components.

Textiles — Determination of fabric deformability by forced mechanical distension

1 Scope

This document specifies a method for the automatic determination of the deformability of textile fabrics, including continuous-fibre reinforcement textiles. This method is not applicable to resin impregnated fabrics.

The method is suitable for use with fabrics such as woven or knitted fabrics, nonwovens, non-crimp fabrics, fabrics made of glass rovings or untwisted carbon filament yarns intended for reinforced composite materials. When applying the method to multi-axial non-crimp fabrics, the evaluation of the fibre orientation and gaps only incorporates the uppermost layer.

The method can be used for fabrics treated with powder binder.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 139, *Textiles — Standard atmospheres for conditioning and testing*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
reinforcement textile
fabric whose fibres are used to absorb and transfer the mechanical loads within a fibre-reinforced composite material

3.2
deformability
conformability for forced three-dimensional deformation

3.3
specimen plane
plane which is defined by the inserted undeformed test specimen

3.4
specimen holder
device consisting of a retaining ring and a ring-shaped fitting body that retains the test specimen during deformation with a settable, evenly distributed pressure

3.5
deformation body
rotationally symmetrical body that deforms the test specimen centrally out of the *specimen plane* (3.3) in a vertical upward direction

3.6
deformation level
level with specified height to which the *deformation body* (3.5) elevates out of the *specimen plane* (3.3)

3.7
deformation force
resulting force acting vertically on the *deformation body* (3.5) that arises during deformation

3.8
fibre orientation
orientation of the fibres or filaments of the test specimen, determined in the textile plane using image processing

3.8.1
fibre-angle change
change of the global *fibre orientation* (3.8), determined using image processing

3.8.2
undulation
local change of the *fibre orientation* (3.8), determined using image processing

3.9
gap
open area between adjacent yarns, determined using image processing

EXAMPLE Non-crimp fabric gap, woven/knitted fabric gap.

3.10
waviness
continuous deformation over a certain region (>2 cm^2) diverging from the textile plane, determined using laser triangulation

3.11
loop formation
deformation of individual yarns out of the textile plane, determined using laser triangulation

3.12
out-of-roundness
deviation of the contour of the test specimen from a circular shape of equal area, determined using image processing

3.13
overall image
image recorded with the overall image camera for determining the contour of the test specimen

3.14
detail image
image recorded by the detail camera with a minimum size of 1 000 mm^2 and a minimum resolution of 64 pixels per millimetre

3.15
non-crimp fabric
fabric made of several unidirectional layers of straight multifilament yarns which are bonded using an auxiliary stitching thread or chemical means

Note 1 to entry: The expression “non-crimp fabric” is commonly used in the composite sector.

3.16
residual deformation
continuous deformation of the sample diverging from the support surface, determined using laser triangulation, measured after completion of the deformation and return of the *deformation body* (3.5) below the support surface

3.17
anisotropy
measure for the orientation of fibres in a nonwoven

Note 1 to entry: Values are between 1 (all fibres parallel to reference direction) and -1 (all fibres perpendicular to reference direction), where 0 means complete isotropic (random) orientation

3.18
thinning-out
tendency of a nonwoven fabric to build local thin places due to mechanical stress

4 Principle

This document specifies a method by which the textile fabric (including reinforcement textiles) to be examined is forced to be deformed in a defined manner by a rotationally symmetrical deformation body. Key figures and characteristic values that describe the textile to be examined regarding its deformability are determined. For this, the mechanical resistance to a defined three-dimensional deformation is measured and the resulting structural faults in the mesostructure and macrostructure are examined using a digital image analysis system and laser triangulation.

The test is carried out on a circular test specimen, which the testing instrument - by means of a pneumatic specimen holder - holds in position with a defined force, which is equal around the circumference of the retaining ring. During the test, the test specimen is incrementally deformed by a deformation body acting from below and measured after each deformation level.

The force acting vertically on the deformation body caused by the deformation is measured.

Several images of the original undeformed test specimen and later of the deformed test specimen are recorded with a detail camera on a central circular path and evaluated. For non-crimp fabrics, the fibre orientation as well as the occurrence of gaps between the yarns of the non-crimp fabric are determined. For woven fabrics, the angle between the warp threads and weft threads as well as the area and proportion of the woven fabric gaps are determined. For knitted fabrics, the area and proportion of the gaps is determined. For nonwovens, the anisotropy and thinning-out are determined. The out-of-roundness of the test specimen is additionally determined with an overall image camera.

Additionally, deformations out of the textile plane may be recorded on the rotating test specimen using a laser triangulation sensor and output as numerical values for the waviness and the loop formation.

5 Apparatus

5.1 Mechanical cutting equipment, to produce the circular test specimen from the laboratory sample.

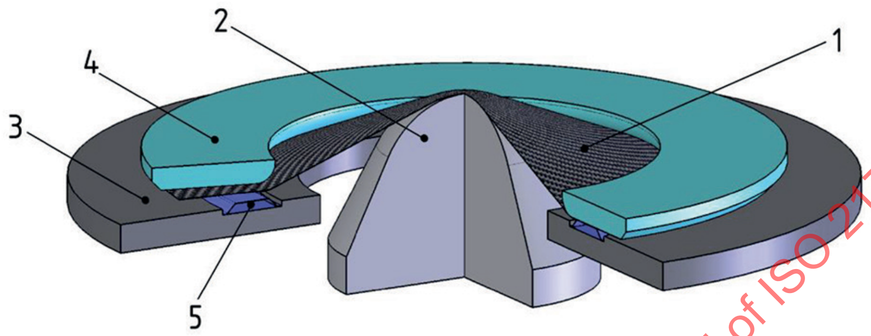
NOTE Examples of suitable mechanical cutting equipment include punches and ultrasound cutters.

5.2 Deformability test apparatus

Test device in which the test specimen is inserted and uniformly retained over the entire circumference using a specimen holder, whereby the retaining pressure can be specified in the range of 0 MPa to 0,1 MPa (i.e. 1 bar). The test device has a rotation device for motor-driven rotation of the test specimen at variable speed [maximum speed (10,0 ± 0,1) min^{-1}], a motor-driven vertically moving deformation body [elevation 0,00 – (100,00 ± 0,01) mm], a force sensor (0 N to 500 N with an accuracy of ±0,5 %) to record the vertical force acting on the deformation body, an overall image camera to record the top view of the entire test specimen, a detail camera to record detail images of the test specimen to detect fine structural faults, as well as a laser triangulation sensor (sampling time shorter than 20 ms from data acquisition to data storage) to record the deformations varying from the textile plane.

The deformation body features a spherical contact surface with a diameter of (100,0 ± 0,1) mm. This deformation body can be black or white. The black deformation body is used to test light-coloured materials and the white deformation body to test dark materials. The white deformation body can be backlit.

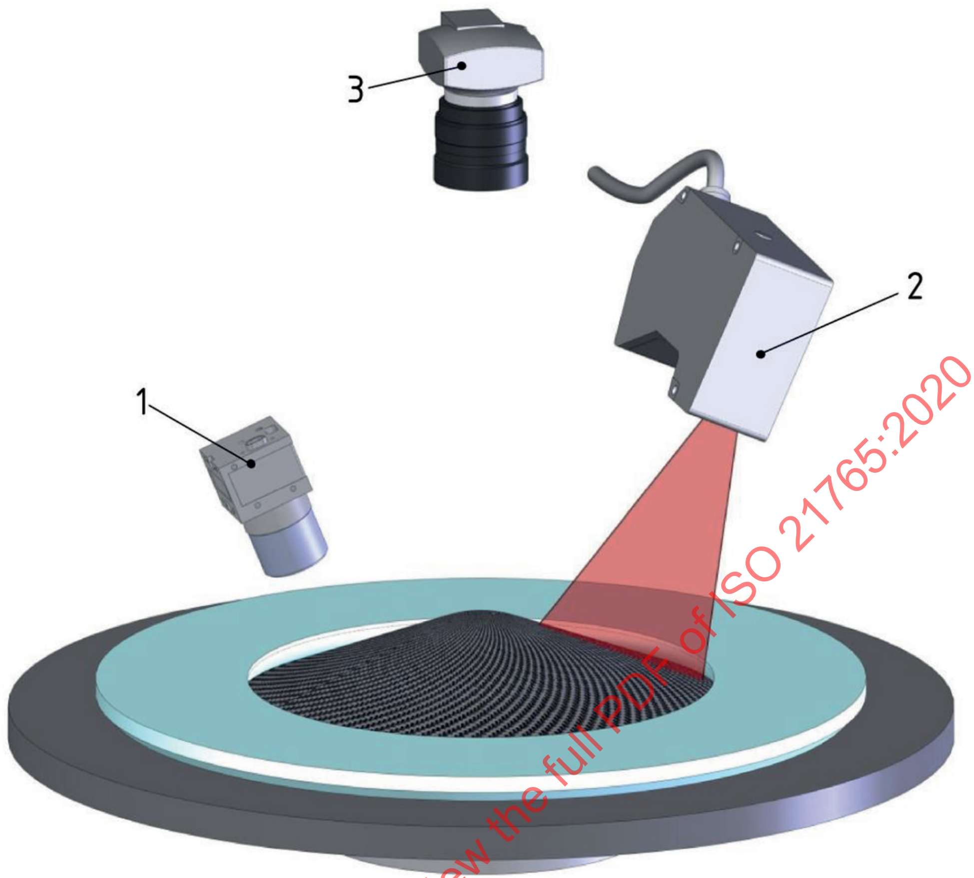
The equipment for retaining the test specimen and for defined deformation is shown in Figure 1.



Key

1 test specimen
2 deformation body
3 support surface
4 retaining ring
5 fitting body

Figure 1 — Specimen holder and deformation body



Key

1 detail camera

2 laser triangulation sensor

3 overall image camera

Figure 2 — Schematic diagram of the optical sensors

Figure 2 illustrates the arrangement of the optical sensors. It shows a detail camera with lighting, an overall image camera for recording the complete test specimen, as well a laser triangulation sensor to record the test specimen topography[1]).

Annex A shows an example of images of laser triangulation measurements.

6 Test specimen

A circular test specimen with a diameter of (327 ± 3) mm shall be used which is mechanically cut out of a laboratory sample. It shall especially be noted here that no test specimens are taken from the selvedge region or damaged areas of the laboratory sample. No thermal cutting procedure shall be applied to prevent adhesions and influences at the edges of the test specimen.

When producing the test specimen, it shall especially be ensured that all yarns are completely cut through and that the structure of the test specimen is not displaced.

1) An applicable tester is the "DRAPETEST" supplied by Textechno Herbert Stein GmbH & Co.. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

The direction of production and top/bottom side of the test specimen shall be recognizable or shall be marked accordingly.

7 Procedure

7.1 Inserting the test specimen

The test specimen is placed on the support surface of the specimen holder and aligned so that the direction of production runs parallel to the side panels of the tester and the test specimen lies centrally on the round display area. It shall be ensured that all test specimens within a test series are inserted with the desired side (top/bottom) pointing upwards. The overall image camera then records an image of the undeformed test specimen and determines the out-of-roundness from it. The retaining ring is applied and fixed using the holding devices without additionally compressing the test specimen. To make this possible, the retaining ring is equipped with several fixing positions for different test specimen thicknesses. The first position shall be selected, where the holding devices can still be closed without additionally compressing the test specimen. A pneumatic retaining pressure is then applied uniformly on all sides. A check is then made to ensure that all holding devices of the retaining ring are pressed against the holder.

7.2 Specifications of the test

7.2.1 Test parameters

a) Retaining pressure with which the test specimen is retained during the test. The standard value is 0,1 MPa (i.e. 1 bar).

b) Deformation levels at which the textile surface is measured. The standard value is 10 mm between the levels beginning at 0 mm. The standard value for the highest deformation level is 80 mm.

c) Number of recordings of the detail camera per revolution. The number of recordings per revolution depends on the textile architecture. Images at each fibre direction and at the intermediate directions should be selected. The minimum value of the directions to be considered is 4. The angular distance between the images is the same and should not be smaller than 30°. The number of recordings is twice the number of directions.

   1) For 0°/90° architectures, 45° angle steps are to be provided (0°, 45°, 90°, 135°): 4 directions / 8 images

   2) For 0°/+60°/-60° architectures, 30° angle steps are to be provided: 6 directions / 12 images

   3) For 0°/90°/+45°/-45° architectures, 45° angle steps are sufficient 4 directions / 8 images

d) Range, resolution and rotation speed of the triangulation. Standard values are 360°, 10 measurements for each angular degree and 1 min^{-1}.

7.2.2 Evaluation parameters

a) Image edge width to be ignored. The standard value is 0 pixels.

b) Maximum distance for fusing gaps along the fibre orientation. The value depends on the application. Standard value is 0 mm.

c) Filter criteria for gaps, specified as minimum length in mm, minimum width in mm, and minimum area in mm^2. The minimum values are selected depending on the application.

d) Classification limits for gaps and fibre orientation can be specified depending on the application.

e) Detection threshold for regions with loop formation. Standard value is 4,5 mm.

f) Parameterization of the laser triangulation. Maximum number of measurement dropouts of the laser triangulation between two valid values to be interpolated. Standard value is 0 measurement points, i.e. no interpolation.

7.3 Test procedure

The tests should take place in a suitable standard atmosphere according to ISO 139. The test specimens should be adjusted to the standard atmosphere before the test. The testing atmosphere shall be stated in the test report.

NOTE The standard atmosphere described in ISO 291 (temperature of 23 °C, relative humidity of 50 %) is included in the ISO 139.

At each individual level, the force measurement and the image recording of the surface of the test specimen along a central circular path take place, whereby the detail camera automatically follows the surface of the test specimen at the same distance. Subsequently, the recording of the surface structure using the laser triangulation sensor takes place.

After all measurements at the last deformation level, the deformation body returns below the support surface level.

To measure the residual deformation and roundness, the following steps shall be carried out without touching or moving the test specimen. First, the retaining ring shall be removed and kept removed for a relaxation period of (30 ± 3) s, after which an image of the test specimen is recorded with the overall image camera to determine its out-of-roundness. Subsequently, the ring shall be applied again within 3 s. Next, the residual deformation is measured by means of laser triangulation.

All images are saved to be able to achieve traceability and calculate changes to the characteristic values due to changed evaluation parameters.

8 Calculation and specification of the results

8.1 Non-crimp fabric

8.1.1 General

Table 1 gives characteristic value names, symbols and units used to calculate specifications of non-crimp fabrics.

Annex A shows examples of images of a non-crimp fabric made of carbon at the deformation levels 80 mm and 40 mm.

Table 1 — Non-crimp fabric application case

Characteristic value name	Symbol	Unit
Deformation force	F	N
Maximum gap width	$G_{\mathrm{w,\,max}}$	mm
Average gap width weighted by the length	$\overline{G}_{\mathrm{w}}$	mm
Gap portion	G_{p}	%
Gap shape	G_{s}	-
Fibre-angle change	Δ_{α}	°
Undulation	Δ_{loc}	°
Loop formation	Ω	mm^2
Waviness	Λ	mm

Table 1 *(continued)*

Characteristic value name	Symbol	Unit
Out-of-roundness	Θ	%

8.1.2 Deformation force

The deformation force, F, is measured for all selected deformation levels. The force measured at the first angle position is evaluated. The deformation force is determined depending on the deformation level.

8.1.3 Gap width

From each detail image, the maximum gap width, $G_{\mathrm{w,\,max}}$, and the average gap width weighted by the length $\bar{G}_{\mathrm{w}}$ of all valid gaps are determined. The gap widths, $G_{\mathrm{w,\,max}}$ and $\bar{G}_{\mathrm{w}}$, are determined depending on the deformation level and the angle position.

8.1.4 Gap portion

From each detail image, the area of all valid gaps is determined and set in relation to the total area of the image. The gap portion, G_{p}, is determined depending on the deformation level and the angle position.

8.1.5 Gap shape

The gap shape, G_s, is a dimensionless aspect ratio of the valid gaps. It is formed from the ratio between the gap length and width. The value is 0 for a circle and approaches 1 for thin gaps. It is averaged over each detail image. The gap shape is determined depending on the deformation level and the angle position. It is calculated for an approximation of the gap by an ellipse according to the following Formula (1):

$$G_s = \frac{\sqrt{\left(a^2 - b^2\right)}}{a} \quad (1)$$

where

a is the semi-major axis of a gap;

b is the semi-minor axis of a gap.

8.1.6 Fibre-angle change

The fibre-angle change Δ_{α} describes the change of the average orientation of all fibres of the uppermost layer within a detail image compared with the undeformed state. The fibre-angle change is determined depending on the deformation level and the angle position.

8.1.7 Undulation

To determine the undulation Δ_{loc}, the detail image is divided into at least 25 partial images with a size of at least 40 mm^2 and an aspect ratio of approximately 4:3, and the fibre orientation in the respective partial image is compared with the global fibre orientation of the complete detail image. The absolute deviations of the local fibre orientation in each partial image from the global fibre orientation are averaged over all partial images and result in the undulation value. The undulation is determined depending on the deformation level and the angle position.

8.1.8 Loop formation

The regions with loop formation Ω are extracted from the height data of the laser triangulation. The area of these regions is the value for the loop formation. The loop formation can be determined globally for the entire test specimen or in sectors. It is then determined either depending only on the deformation level or on the deformation level and angle position.

8.1.9 Waviness

The waviness, Λ, is determined from the height data of the laser triangulation. The deviation of the measured surface from an ideally deformed surface is measured and the absolute values are averaged over the entire circumference of the test specimen. The waviness is determined depending on the deformation level.

8.1.10 Out-of-roundness

The out-of-roundness, Θ, of the test specimen is calculated before and after the deformation. For this purpose, the perimeter of the test specimen is determined by means of image processing from an image recorded by the overall image camera arranged centrally above the test specimen. The out-of-roundness is determined as the average value of all absolute deviations of the individual points of the perimeter to an associated circle of the same area, divided by the radius of the circle, in %.

8.2 Woven fabrics

8.2.1 Characteristic value names, symbols and units

Table 2 gives characteristic value names, symbols and units used to calculate specifications of woven fabrics.

Annex A shows an example of images of a woven fabric made of carbon at the deformation level 40 mm.

Annex B shows statistical data obtained on glass woven fabric.

Table 2 — Woven fabric application case

Characteristic value name	Symbol	Unit
Deformation force	F	N
Gap portion	G_p	%
Maximum gap area	$G_{A,\,max}$	mm^2
Average gap area	$\bar{G}_A$	mm^2
Gap shape	G_s	-
Fibre-angle change	Δ_α	°
Undulation	Δ_{loc}	°
Shearing angle	B	°
Waviness	Λ	mm
Out-of-roundness	Θ	%
Residual deformation	Λ_r	mm

8.2.2 Deformation force

The deformation force, F, is measured for all selected deformation levels. The force measured at the first angle position is evaluated. The deformation force is determined depending on the deformation level.

8.2.3 Gap portion

From each detail image, the area of all valid gaps included is determined and set in relation to the total area of the image. The gap portion, G_p, is determined depending on the deformation level and the angle position.

8.2.4 Gap area

The area of each individual valid gap is recorded in each detail image. The maximum gap area, $G_{A,\,max}$, and average gap area, $\bar{G}_A$, in each image are calculated. $G_{A,\,max}$ and $\bar{G}_A$ are determined depending on the deformation level and angle position.

8.2.5 Gap shape

The gap shape, G_s, is a dimensionless aspect ratio of the valid gaps. It is formed from the ratio between the gap length and width. The value is 0 for a circle and approaches 1 for thin gaps. It is averaged over each detail image. The gap shape is determined depending on the deformation level and the angle position. It is calculated for an approximation of the gap by an ellipse according to the Formula (1).

8.2.6 Fibre-angle change

The fibre-angle change, Δ, describes the average change of the orientation of all fibres in the warp and weft direction respectively within a detail image compared with the undeformed state. The fibre-angle change is determined depending on the deformation level and angle position.

8.2.7 Undulation

To determine the undulation, Δ_{loc}, the detail image is divided into at least 25 partial images with a size of at least 40 mm^2 and an aspect ratio of approximately 4:3, and the fibre orientation in the respective partial image is compared with the global fibre orientation of the complete detail image. The absolute deviations of the local fibre orientation in each partial image from the global fibre orientation are averaged over all partial images and result in the undulation value. The undulation is determined depending on the deformation level and the angle position.

8.2.8 Shearing angle

The fibre orientation of the warp threads and the weft threads is measured. The deviation of the angle difference between warp threads and weft threads from the angle difference between warp threads and weft threads in the initial or undeformed state is the shearing angle β. The shearing angle is determined depending on the deformation level and angle position.

8.2.9 Waviness

The waviness, Λ, is determined from the height data of the laser triangulation. The deviation of the measured surface from an ideally deformed surface is measured and the absolute values are averaged. The waviness is determined depending on the deformation level.

8.2.10 Out-of-roundness

The out-of-roundness, Θ, of the test specimen is calculated before and after the deformation. For this purpose, the perimeter of the test specimen is determined by means of image processing from an image from the overall image camera arranged centrally above the test specimen. The out-of-roundness is determined as the average value of all absolute deviations of the individual points of the perimeter to an associated circle of the same area, divided by the radius of the circle, in %.

8.2.11 Residual deformation

The residual deformation, Λ_r, is determined from the height data of the laser triangulation. The deviation of the measured surface from the initially measured surface is determined and the absolute values are averaged.

8.3 Knitted fabrics

8.3.1 Table with characteristic value names, symbols and units

Table 3 gives characteristic value names, symbols and units used to calculate specifications of knitted fabrics.

Table 3 — Knitted fabric application case

Characteristic value name	Symbol	Unit
Deformation force	F	N
Gap portion	G_p	%
Maximum gap area	$G_{A,\,max}$	mm^2
Average gap area	$\bar{G}_A$	mm^2
Gap shape	G_s	-
Waviness	Λ	mm
Out-of-roundness	Θ	%
Residual deformation	Λ_r	mm

8.3.2 Deformation force

The deformation force, F, is measured for all selected deformation levels. The force measured at the first angle position is evaluated. The deformation force is determined depending on the deformation level.

8.3.3 Gap portion

From each detail image, the area of all valid gaps included is determined and set in relation to the total area of the image. The gap portion, G_p, is determined depending on the deformation level and the angle position.

8.3.4 Gap area

The area of each individual valid gap is recorded in each detail image. The maximum gap area $G_{A,\,max}$ and average gap area $\bar{G}_A$ in each image are calculated. $G_{A,\,max}$ and $\bar{G}_A$ are determined depending on the deformation level and angle position.

8.3.5 Gap shape

The gap shape, G_s, is a dimensionless aspect ratio of the valid gaps. It is formed from the ratio between the gap length and width. The value is 0 for a circle and approaches 1 for thin gaps. It is averaged over each detail image. The gap shape is determined depending on the deformation level and the angle position. It is calculated for an approximation of the gap by an ellipse according to the Formula (1).

8.3.6 Waviness

The waviness, Λ, is determined from the height data of the laser triangulation. The deviation of the measured surface from an ideally deformed surface is calculated and the absolute values are averaged. The waviness is determined depending on the deformation level.

8.3.7 Out-of-roundness

The out-of-roundness, Θ, of the test specimen is calculated before and after the deformation. For this purpose, the perimeter of the test specimen is determined by means of image processing from an image from the overall image camera arranged centrally above the test specimen. The out-of-roundness is determined as the average value of all absolute deviations of the individual points of the perimeter to an associated circle of the same area, divided by the radius of the circle, in %.

8.3.8 Residual deformation

The residual deformation, Λ_r, is determined from the height data of the laser triangulation. The deviation of the measured surface from the initially measured surface is determined and the absolute values are averaged.

8.4 Nonwovens

8.4.1 Table with characteristic value names, symbols and units

Table 4 gives characteristic value names, symbols and units used to calculate specifications of nonwovens.

Table 4 — Nonwoven application case

Characteristic value name	Symbol	Unit
Deformation force	F	N
Anisotropy	χ	—
Thinning-out	κ	%
Waviness	Λ	mm
Out-of-roundness	Θ	%
Residual deformation	Λ_r	mm

8.4.2 Deformation force

The deformation force, F, is measured for all selected deformation levels. The force measured at the first angle position is evaluated. The deformation force is determined depending on the deformation level.

8.4.3 Anisotropy

From each detail image, the anisotropy of all detected fibres is determined.

By means of image analysis, the fibre the orientation of each detected fibre is determined and sorted into a histogram (range $\pm \pi$, class width 1°). The anisotropy is the number of fibres in the biggest class divided by the number of all detected fibres. The anisotropy is a number in a range between 0 and 1, which becomes 1 in case of a perfect alignment of all fibres, and 0 if all fibres are randomly distributed. The anisotropy χ is determined depending on the deformation level.

8.4.4 Thinning-out

The thinning-out, κ, is determined by means of image processing from an image from the overall image camera arranged centrally above the test specimen. The thinning-out is analysed along concentric circles, where the maximum diameter is 100 mm. It is determined as the coefficient of variation of the image brightness long a circle, in relation to the corresponding coefficient of variation of the undeformed test specimen; in %. The thinning-out, κ, is determined depending on the deformation level.

8.4.5 Waviness

The waviness, Λ, is determined from the height data of the laser triangulation. The deviation of the measured surface from an ideally deformed surface is measured and the absolute values are averaged. The waviness is determined depending on the deformation level.

8.4.6 Out-of-roundness

The out-of-roundness, Θ, of the test specimen is calculated before and after the deformation. For this purpose, the perimeter of the test specimen is determined by means of image processing from an image from the overall image camera arranged centrally above the test specimen. The out-of-roundness is determined as the average value of all absolute deviations of the individual points of the perimeter to an associated circle of the same area, divided by the radius of the circle, in %.

8.4.7 Residual deformation

The residual deformation, Λ_r, is determined from the height data of the laser triangulation. The deviation of the measured surface from the initially measured surface is determined and the absolute values are averaged.

8.5 Evaluation

The values shall be checked for plausibility. For suspicious values, the original images shall be inspected to check for damage on the test specimen, recording errors (overexposure/underexposure) or image processing errors. If necessary, the image can either be substituted by the image taken at the opposite side (180°) or it is excluded from the evaluation.

The measurement results are represented separately for each individual characteristic value.

Based on the number of test specimen for each laboratory sample, the average value, standard deviation, and maximum value are reported for each angle position and each deformation level. Here the representation can be reduced to selected important angle positions for simplification. Alternatively, all individual values can be reported.

An additional diagram can be created for each characteristic value as a function of the impacting test parameters.

NOTE Up to a deformation level of 80 mm, it is assumed that the test specimen is retained evenly on all sides. For higher deformation levels, the test specimen can slip out of the specimen holder at individual locations so that the results compared with the smaller deformation can be systematically changed. If the test specimen slips out of the specimen holder, the appropriate deformation level should be taken out of the evaluation and commented on accordingly in the test report.

9 Test report

The test report shall include the following information.

a) General:

   1) a reference to this document, i.e. ISO 21765:2020.

b) Deformability test apparatus specifications:

   1) test apparatus: manufacturer, type, serial number;

   2) overall image camera: utilized camera type and camera resolution, exposure times;

   3) lighting used for the overall image camera, number of segments;

   4) detail camera: utilized camera type and camera resolution, exposure times;

   5) utilized lighting for the detail camera;

   6) utilized laser type;

   7) utilized deformation body (geometry, colour, internal lighting);

8) software version.

c) Material:

1) complete description of the laboratory sample:

i) fibre material;

ii) textile structure (woven or knitted fabric, nonwoven, non-crimp fabric);

iii) fibre layer structure, fibre orientations;

iv) assessed fabric face (i.e. not in contact with the deformation body).

d) Test:

1) operator;

2) test date;

3) number of test specimens.

e) Test parameter:

1) standard atmosphere used and reference to the appropriate standard (ISO 139);

2) retaining pressure used;

3) measured deformation levels;

4) measured angle positions;

5) exposure times of the detail camera;

6) exposure times of the overall image camera;

7) scanned range and resolution of the triangulation sensor;

8) positioning parameter of the triangulation sensor (bottom, centre, top):

9) rotational speed of the sample during laser triangulation.

f) Evaluation parameter:

1) Image edge width to be ignored;

2) Maximum distance for fusing gaps along the fibre orientation;

3) Filter criteria for gaps:

i) Minimum gap length;

ii) Minimum gap width;

iii) Minimum gap area.

4) Classification limits for gaps and angular misalignment;

5) Maximum number of measurement dropouts to be interpolated by the laser triangulation;

6) Detection threshold for regions with loop formation

7) Number and radii of concentric circles for measurement of thinning-out on non-wovens.

g) Deviations to this document.

