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Fine ceramics (advanced ceramics, advanced technical ceramics) — Reinforcement of ceramic composites — Determination of distribution of tensile strength and tensile strain to failure of filaments within a multifilament tow at ambient temperature

Céramiques techniques — Renfort de céramiques composites — Détermination de la distribution de la résistance en traction et de la déformation à la rupture en traction de filaments dans un fil multifilamentaire à température ambiante

Reference number
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Foreword

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This document was prepared by Technical Committee ISO/TC 206, *Fine ceramics*.

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Fine ceramics (advanced ceramics, advanced technical ceramics) — Reinforcement of ceramic composites — Determination of distribution of tensile strength and tensile strain to failure of filaments within a multifilament tow at ambient temperature

1 Scope

This document specifies the conditions for the determination of the distribution of strength and rupture strain of ceramic filaments within a multifilament tow at room temperature by performing a tensile test on a multifilament tow.

This document applies to dry tows of continuous ceramic filaments that are assumed to act freely and independently under loading and exhibit linear elastic behaviour up to failure. The outputs of this method are not to be mixed up with the strengths of embedded tows determined by using ISO 24046[1)].

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 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

ISO 10119, *Carbon fibre — Determination of density*

EN 1007-2, *Advanced technical ceramics — Ceramic composites — Methods of test for reinforcements — Part 2: Determination of linear density*

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
gauge length
L_0
initial distance between two reference points on the tow

Note 1 to entry: Usually the gauge length is taken as the distance between the gripped ends of the tow.

3.2
initial cross-section area
S_0
cross-section area of the tow

1) Under preparation.

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3.3
tow elongation
A
increase of the gauge length during the tensile test

3.4.1
total compliance
C_t
ratio of the measured displacement to the corresponding force during the tensile test

3.4.2
load train compliance
C_l
ratio of the load train elongation, excluding the specimen contribution, to the corresponding force during the tensile test

3.5
strain
ε
ratio of the tow elongation A to the gauge length L_0

3.6
filament rupture strain
$\varepsilon_{r,j}$
strain at step j in the non-linear parts of the force-displacement curve

3.7
filament strength
$\sigma_{r,j}$
ratio of the tensile force to the cross-section area of all unbroken filaments at step j in the non-linear parts of the force-displacement curve

3.8
average filament strength
$\bar{\sigma}_r$
statistical average strength of the filaments in the tow for each test determined from the Weibull strength distribution parameters of the filaments

3.9
mean filament strength
$\bar{\bar{\sigma}}_r$
arithmetic mean of the average strengths

4 Principle

A multifilament tow is loaded in tension at a constant displacement rate up to rupture of all the filaments in the tow. The force and displacement are measured and recorded. From the force-displacement curve the two-parameter Weibull distribution of the rupture strain and of the strength of the filaments is obtained by sampling the nonlinear parts of the curve at discrete intervals, j, which correspond to an increasing number of failed filaments in the tow.

5 Significance and use

Because measurement of the displacement directly on the tow is difficult, it is usually obtained indirectly via a compliance measurement which includes contributions of the loading train, the grips and the tabbing materials. These contributions have to be corrected for in the analysis. When it is possible to measure the tow elongation directly (by using a suitable extensometer system) this

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correction is not needed. The calculation of the results in Clause 10 also applies in this case by setting the load train compliance equal to zero.

The evaluation method is based on an analysis of the nonlinear domain of the force-displacement curve, which is caused by progressive filament failure during the test. The size of this domain is promoted by higher stiffness of the loading and gripping system. When the force-displacement curve does not show this nonlinear domain, the evaluation method of this document cannot be applied.

The distribution of filament rupture strains does not depend on the initial number of filaments for those tows that contain a large number of filaments; hence, it is not affected by the number of filaments which are broken before the test, provided this number remains limited. The determination of the filament strength distribution requires knowledge of the initial cross-sectional area of the tow. The variation in filament diameters, which affects the strength values, is not accounted for.

The Weibull parameters determined by this test method and extrapolated to the respective gauge length cannot be compared directly with those obtained from tensile tests on monofilaments according to ISO 19630 because of variability in test conditions[1].

6 Apparatus

6.1 Tensile testing equipment

The test machine shall be equipped with a system for measuring the force applied to the specimen and the displacement, or directly the tow elongation. The machine shall conform to grade 1 or better in ISO 7500-1. The grips shall align the specimen with the direction of the force. Slipping of the specimen in the grips shall be prevented.

NOTE The use of a displacement transducer placed at the ends of the grips[5][6] (see Figure 1) or on the tow itself[4][5][6] will probably limit the contribution of different parts of the load train to the measured displacement, and hence increase the accuracy.

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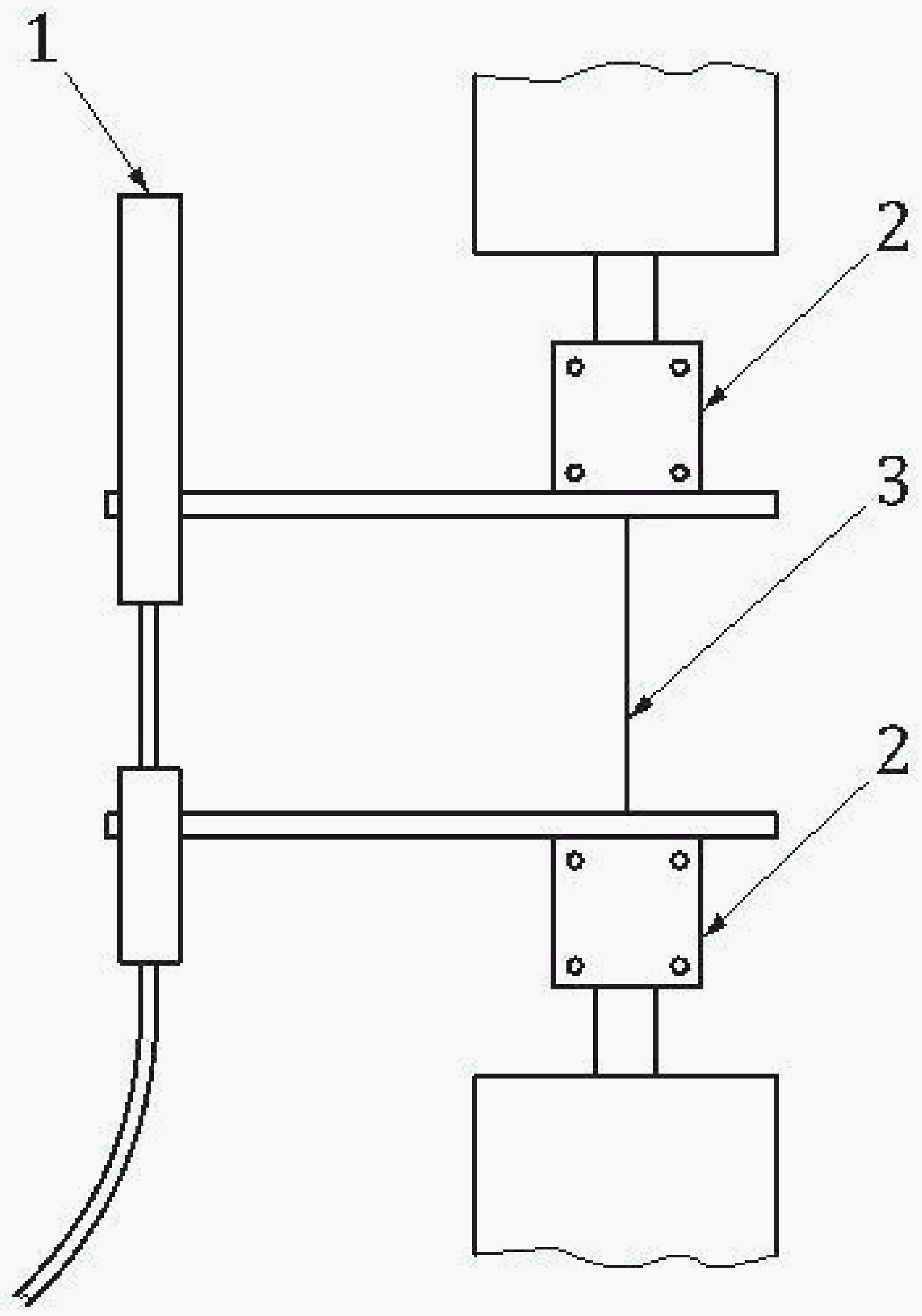

Key
1 displacement transducer
2 grip
3 test specimen

Figure 1 — Test setup (principle sketch)

6.2 Data recording

A calibrated recorder shall be used to record force-displacement curves. The use of a digital data recording system is recommended.

7 Test specimen

7.1 General

Specimens with a gauge length of 200 mm shall be used to establish the filament strength and filament rupture strain distributions. Specimens with gauge lengths of 100 mm and 300 mm shall be used to determine the load train compliance. Examples of two types of test specimen are given below.

7.2 Window type specimen

A window type specimen is shown in Figure 2. A stretched tow is fixed between two identical plates of material, each containing a central window. When the displacement is not measured directly on the tow, the height of the window defines the gauge length.

NOTE This type of specimen has the advantage of easy handling.

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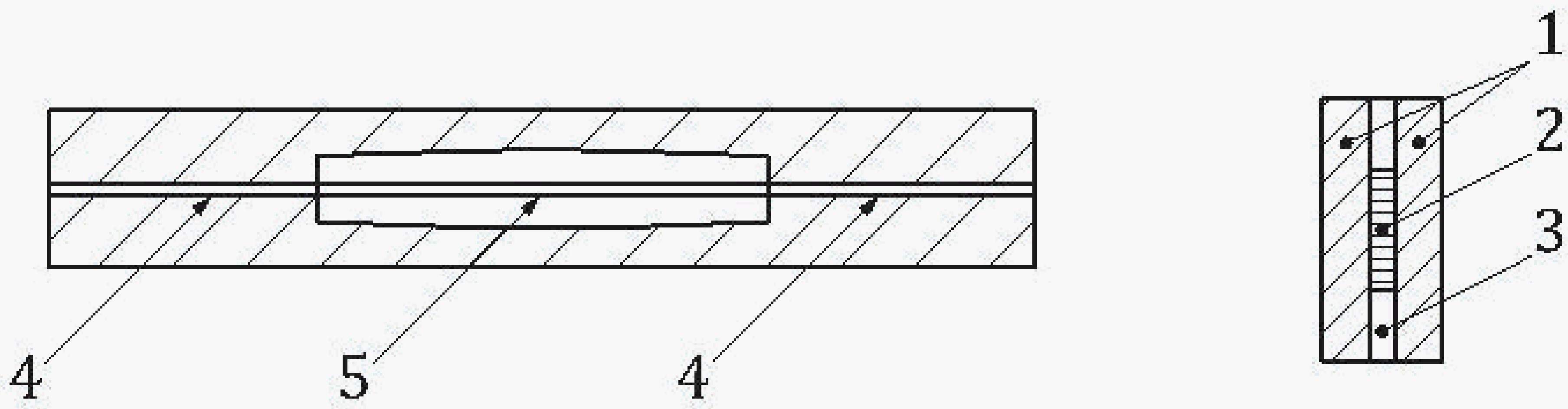

Key

1 plates

2 tow

3 glue

4 gripped end

5 gauge length

Figure 2 — Window type specimen (principle sketch, side view)

7.3 Cylindrical end type specimen

A cylindrical end type specimen is shown in Figure 3. Both ends of a stretched tow are fixed in small diameter cylindrical tubes generally made of metal. When the displacement is not measured directly on the tow, the distance between the inner ends of the tubes with the tow in a stretched condition defines the gauge length. Tube length shall be such that adhesion of tow specimen to tube is optimized. Length larger than 30 mm is recommended.

Key

1 tube

2 gauge length

Figure 3 — Cylindrical end type specimen (principle sketch)

8 Test specimen preparation

8.1 General

Extreme care shall be taken during specimen preparation to ensure that the procedure is repeatable from specimen to specimen. When glue is used, the same type and the same bonding length shall be used for the preparation of all test specimens of a given series. Specimens shall be handled with care to avoid breaking filaments.

High repeatability in specimen preparation is required in order to allow a correct determination of the load train compliance.

A sizing agent is present on certain fibres. It protects the filaments against damage during handling or prevents inter-filament friction during the tests. It should not be removed. Owing to its low Young's modulus, it does not contribute to load sharing. Care should be taken that the glue will not run into the tow outside the frame. Epoxy or resin that exhibit excellent wetting properties with SiC and Alumina-based ceramics are appropriate.

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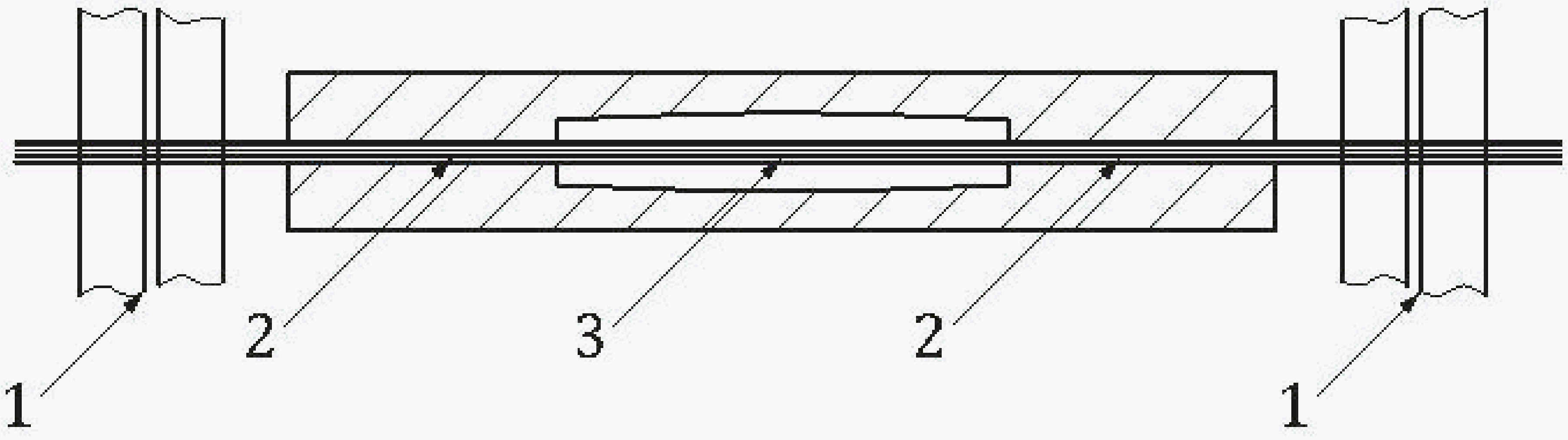
8.2 Window type specimen

An untwisted multifilament tow is glued between two identical plates made of cardboard or another suitable material. The filaments shall be stretched. To achieve this, both ends of the two plates are well soaked by the glue, then the tow is placed on the centreline of one of the plates under a small axial prestress. The ends of the tow extending beyond the plate are fixed by adhesive tapes onto a support (see Figure 4) and the parts of the tow in the gripping area are soaked with glue. The second plate is then pressed face to face with the first one.



Key

1 adhesive tapes

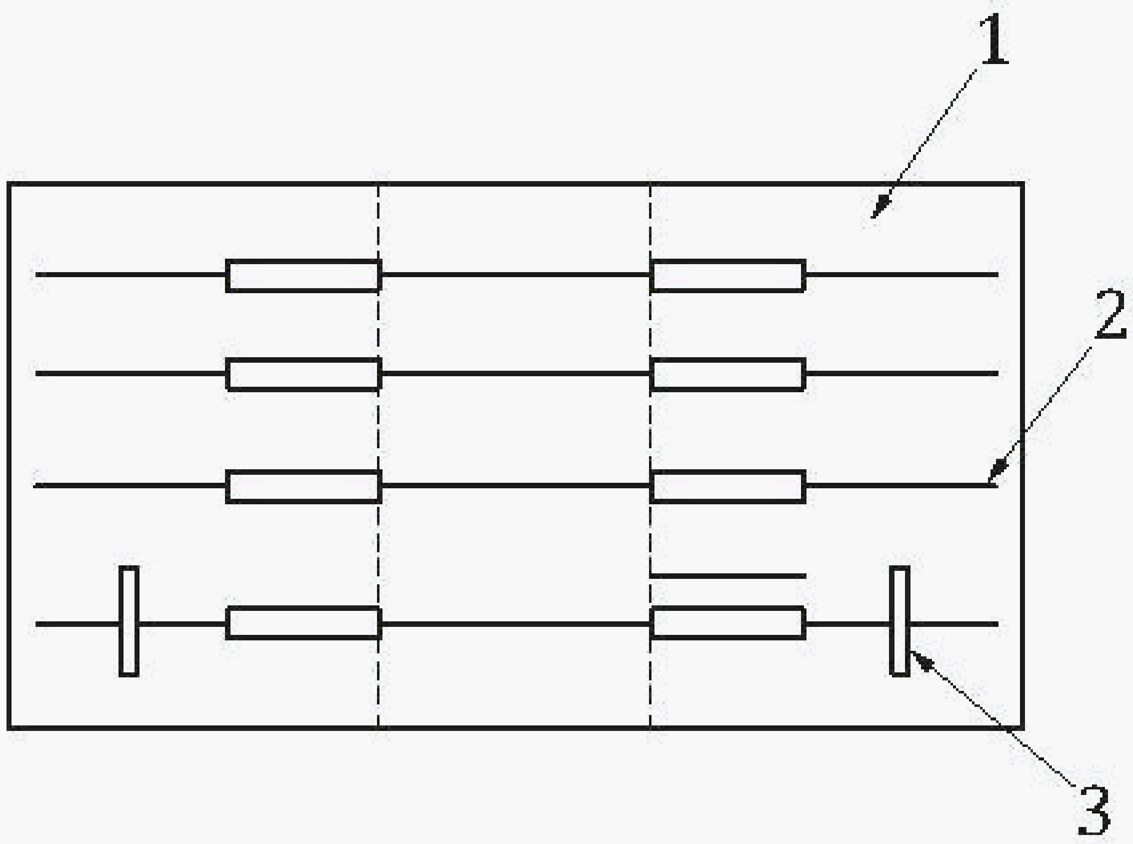
2 gripped end

3 gauge length, L_0

Figure 4 — Window type specimen, preparation (principle sketch)

8.3 Cylindrical end type specimen

The specimens are prepared on a support provided with alignment grooves in which the cylindrical tubes are placed. The untwisted multifilament tow is introduced into the tubes, stretched and glued (see Figure 5). The diameter of the cylindrical tubes shall be as small as possible, compatible with the size of the tow.



Key

1 support

2 groove for alignment

3 adhesive tapes

Figure 5 — Cylindrical end type specimen, preparation (principle sketch)

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8.4 Number of test specimens

For the establishment of the distribution of filament strength and filament rupture strain, three valid tests, as specified in 9.7, of specimens with a 200 mm gauge length are needed. When the elongation of the tow is not measured directly, an additional three valid tests at the other two gauge lengths of 100 mm and 300 mm, as specified in 9.7, are required for the establishment of the load train compliance.

9 Test procedure

9.1 Determination of the initial cross-section area

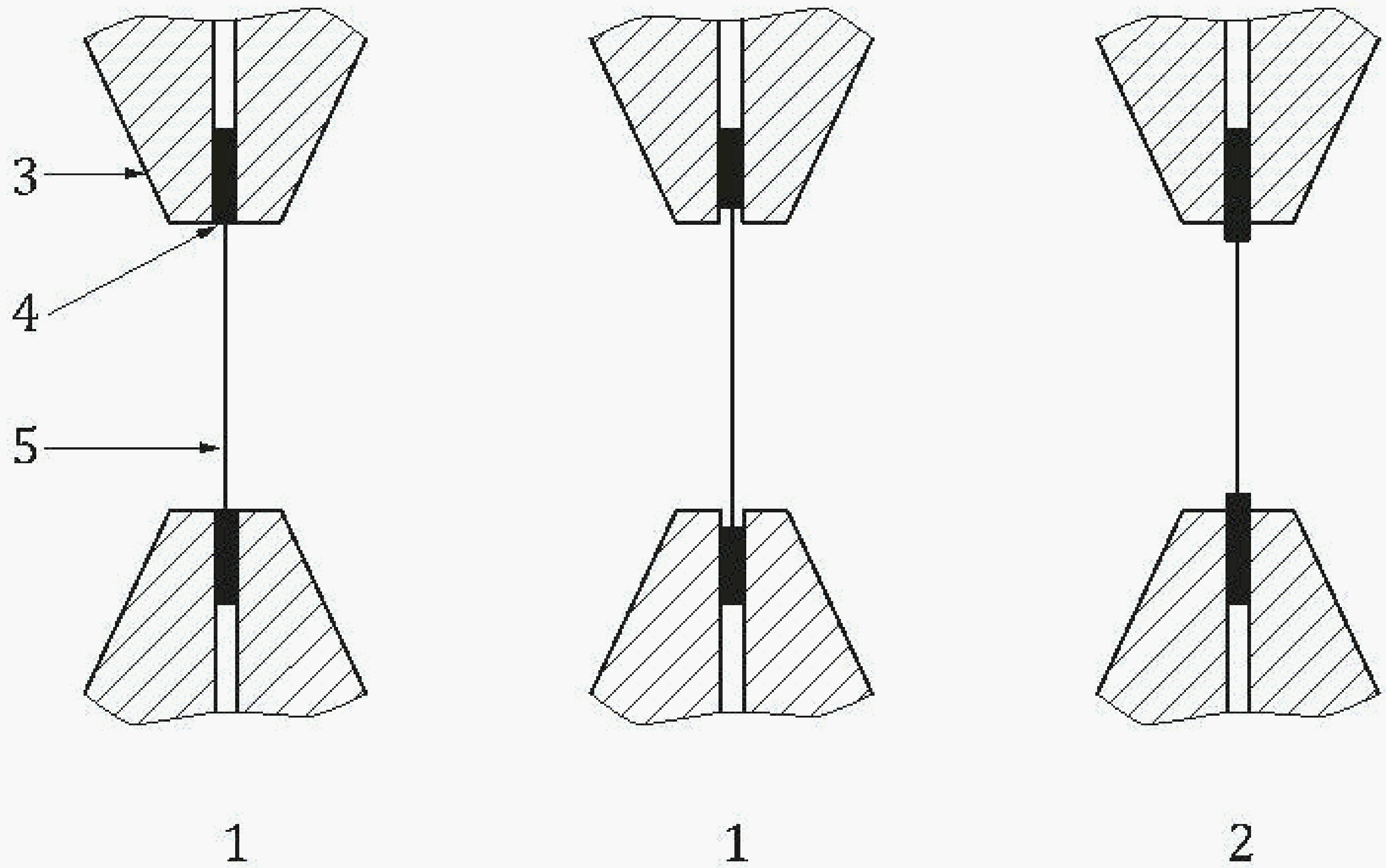
For the purpose of determining the filament strength distribution, as well as the elastic modulus on the specimens with a 200 mm gauge length, the initial cross-section area of the multifilament tow shall be calculated from the linear density determined according to EN 1007-2, and from the density determined in ISO 10119. Alternatively, the initial cross-section area can be determined by measuring the number and the average diameter of the filaments in the tow, for instance through image analysis.

9.2 Determination of the gauge length

The gauge length shall be measured with an accuracy of ± 0,5 mm.

9.3 Gripping

The specimen shall be placed in the test equipment in such a way that axial alignment is as accurate as possible. During gripping, care shall be taken not to load the specimen in tension. When the displacement is not measured directly on the tow, the specimen shall be inserted in the grips in such a way that the distance between the grips is equal to or less than the gauge length (see Figure 6).



Key

1 acceptable

2 not acceptable

3 grip

4 tube

5 tow

Figure 6 — Test specimen mounting (principle sketch)

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9.4 Selection of strain rate

A strain rate around $10^{-4}s^{-1}$ shall be used for all the tests. The corresponding crosshead displacement rate shall be determined from a test on a specimen with the largest gauge length of 300 mm performed according to 9.5. The force-displacement curve obtained from this test shall have the appearance shown in Figure 7. In particular, the curve shall have a linear followed by a nonlinear rising part, as well as a nonlinear decreasing part. It shall furthermore meet the validity requirements of 9.7. When the force-displacement curve does not meet these criteria, tests at lower crosshead displacement rates shall be performed until this is the case. Calculate the strain rate from the displacement rate and check whether it falls in the required range. If not, decrease the crosshead displacement rate until this is the case. Use this crosshead rate in all subsequent tests, irrespective of the gauge length of the specimen.

9.5 Test procedure

Mount the specimen in the load train. Set the displacement rate on the machine. When a window type specimen is used, carefully cut both sides of the supporting plates. Start the load versus displacement recording. Load the specimen up to failure under constant displacement rate. Remove the failed specimen from the grips. Check the validity requirements of 9.7.

It is recommended that a lubricant is introduced in the tow in order to reduce inter-filament friction. Lubricant oil and petrol have been used on SiC fibres.

9.6 Determination of load train compliance

Repeat steps 9.2, 9.3 and 9.5 three times for each of the gauge lengths of 100 mm, 200 mm and 300 mm.

9.7 Test validity

The test is invalid in the following circumstances:

— failure to specify and record test conditions;

— the linear region in the rising part of the force-displacement curve is lacking;

— one or more load drops with an amplitude larger than 5 % of the maximum force occur in the rising part of the force-displacement curve;

— filament rupture occurs preferentially in the grips or near the gripped ends (the test is valid when both parts of the test specimen after failure have a significant number of filaments, but not all, extending beyond half of the gauge length);

— one or more load drops at constant strain with an amplitude larger than 5 % of the maximum force occur beyond the point of maximum force of the force-displacement curve (this restriction does not apply for the determination of the load train compliance);

— the nonlinear domain at the origin of the curve exceeds 10 % of the displacement corresponding to the maximum force.

10 Calculation of results

10.1 Calculation of the load train compliance C_l

Calculate the initial total compliance $C_{t,0}$ (mm/N) for the tests at each of the gauge lengths from the slope $1/C_{t,0}$ of the linear rising part of the force (N)-displacement (mm) curve (see Figure 7). Calculate the average value $\overline{C}_{t,0}$ at each of the three gauge lengths.

Plot $\overline{C}_{t,0}$ against L_0 (see Figure 8).

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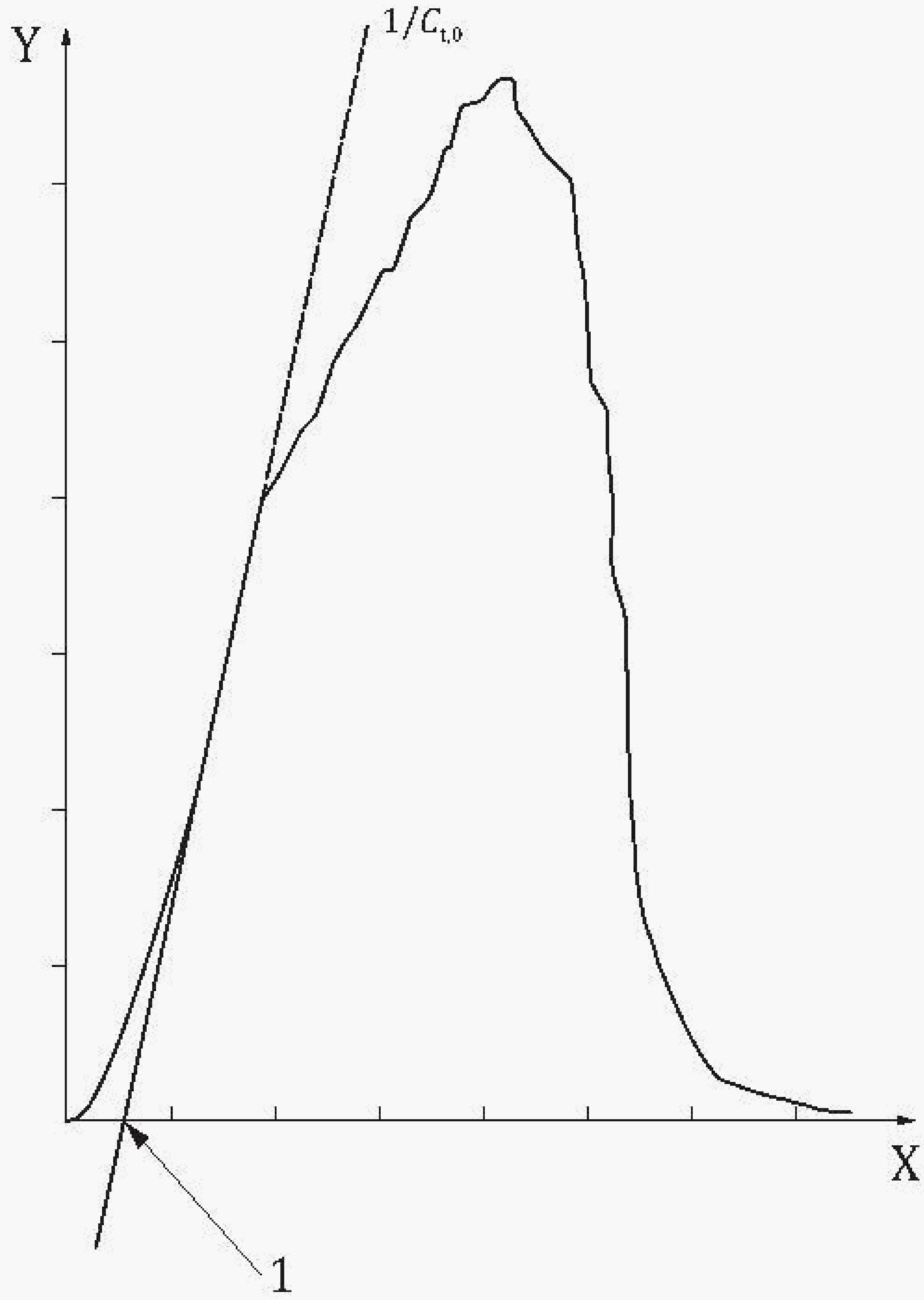
Perform a linear regression analysis of $\overline{C}_{t,0}$ versus L_0 and determine the load train compliance C_l from the intercept at $L_0 = 0$.



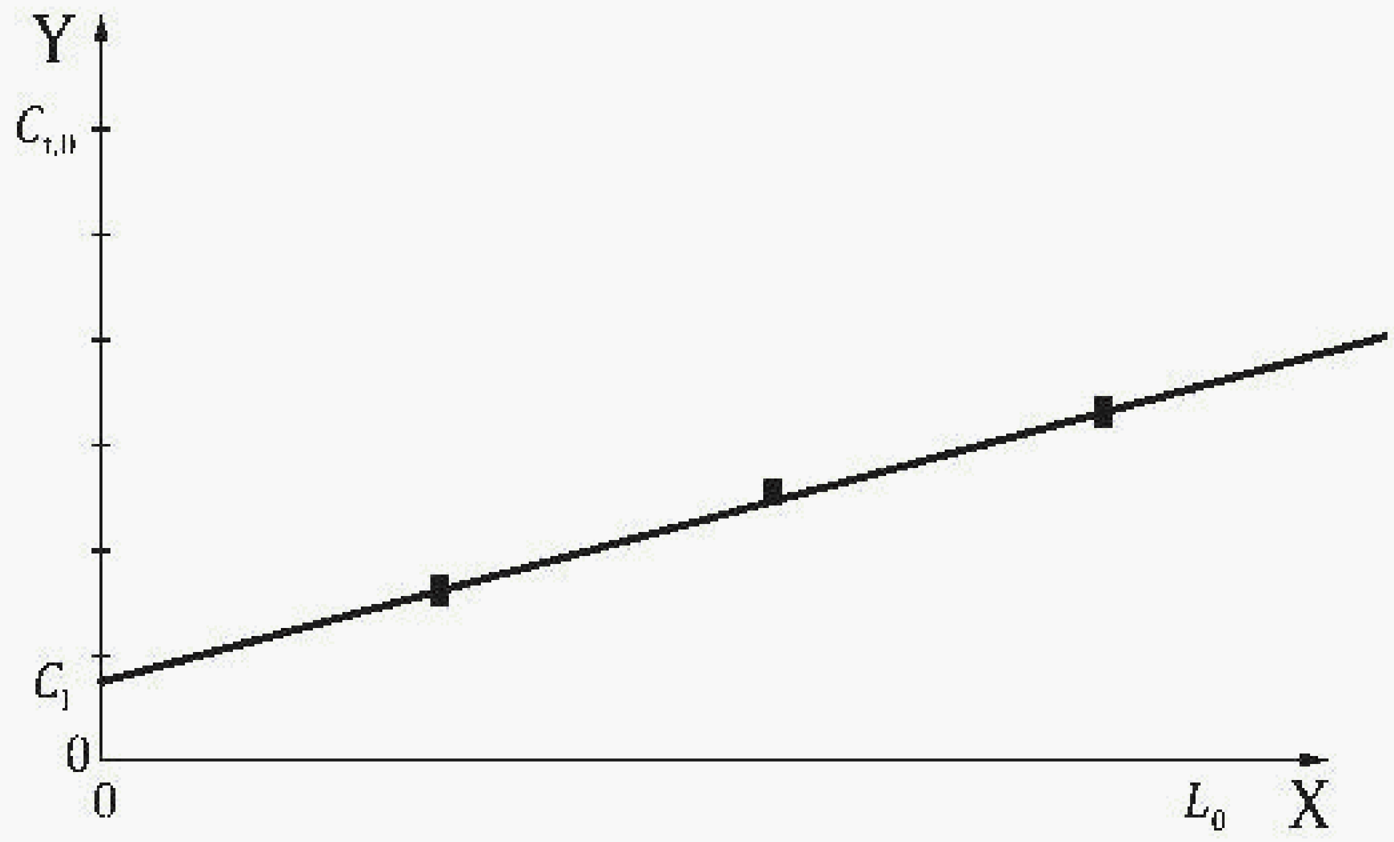
Key

X force F (N)

Y displacement (mm)

1 true origin

Figure 7 — Force displacement curve and determination of true origin



Key

X gauge length L_0 (mm)

Y $\overline{C}_{t,0}$

Figure 8 — Determination of load train compliance

When the displacement is measured directly on the tow, $C_l = 0$.

10.2 Calculation of probability of filament rupture P_j from the tests on specimens with a gauge length of 200 mm

10.2.1 Determination of the true origin

The true origin of the force-displacement curve is defined by the intersection of the linear rising part of the curve with the abscissa (see Figure 7).

10.2.2 Construction of envelope curve and determination of instantaneous compliance $C_{t,j}$

For each test draw the envelope to the nonlinear part of the force-displacement curve containing all the local maxima. Select at least 30 points on the envelope curve uniformly distributed along the abscissa, excluding the linear part (see Figure 9). For each point calculate $C_{t,j}$ from the slope $1/C_{t,j}$ of the line through the point j and the true origin of the force-displacement curve.

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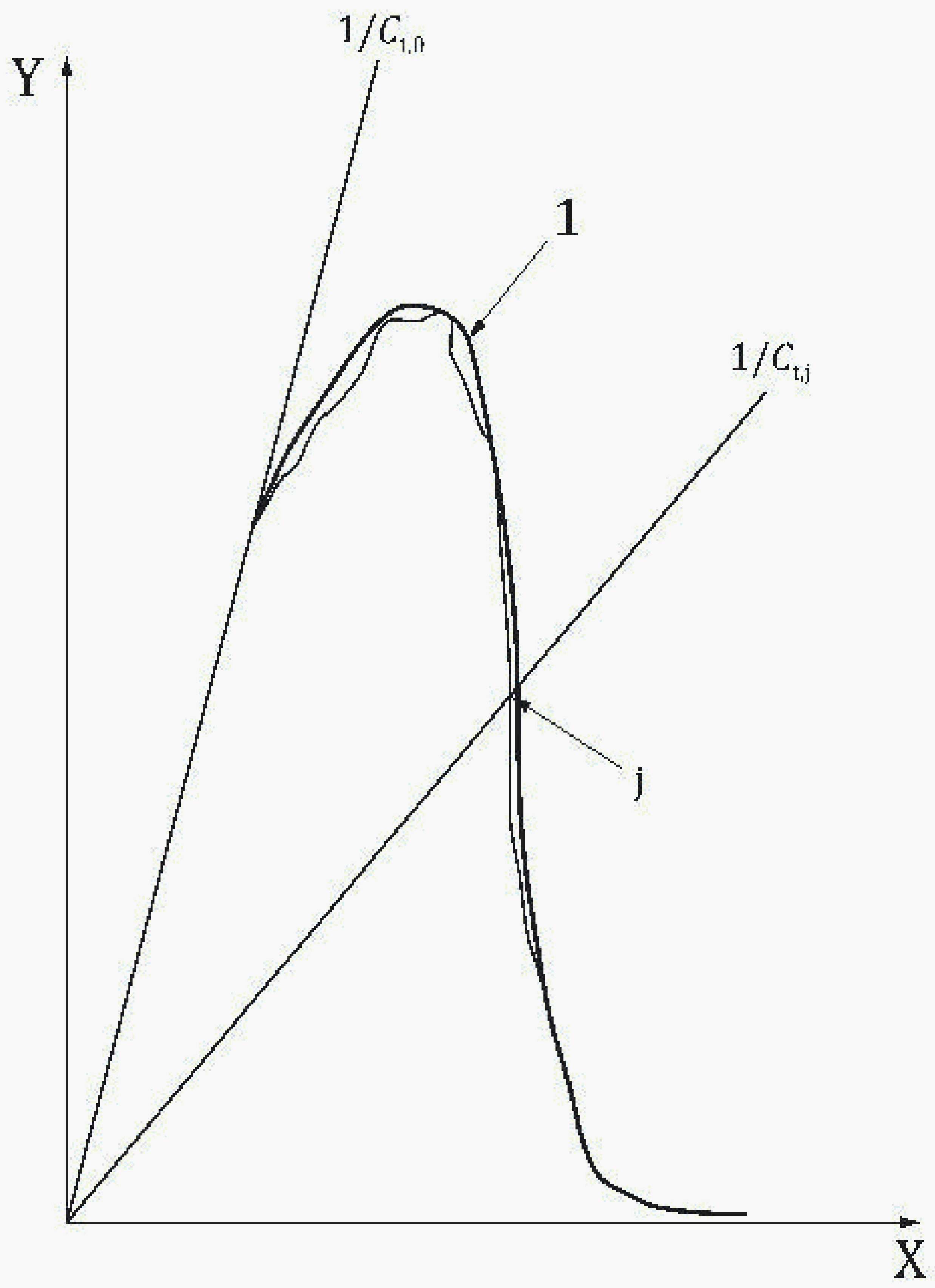

Key

X force F (N)

Y displacement (mm)

1 envelope

Figure 9 — Construction of the envelope curve and instantaneous compliance

10.2.3 Probability of filament rupture

Calculate the probability of filament rupture P_j using Formula (1).

$$P_j = \frac{C_{t,j} - C_{t,0}}{C_{t,j} - C_l} \quad (1)$$

where

P_j is the probability of filament rupture at step j;

$C_{t,j}$ is the total compliance at step j, in millimetres per newton (mm/N);

$C_{t,0}$ is the initial total compliance determined from 10.1, in millimetres per newton (mm/N);

C_l is the load train compliance calculated from 10.1, in millimetres per newton (mm/N).

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10.3 Distribution of filament rupture strain

10.3.1 Calculation of filament rupture strain

Calculate the filament rupture strain $\varepsilon_{r,j}$ for each point j using Formula (2).

$$\varepsilon_{r,j} = \frac{\left(C_{t,j} - C_l\right) F_j}{L_0} \tag{2}$$

where

$\varepsilon_{r,j}$ is the filament rupture strain at step j;

$C_{t,j}$ is the total compliance at step j determined from 10.2.2, in millimetres per newton (mm/N);

F_j is the force applied on the specimen at step j, in newtons (N);

C_l is the load train compliance calculated from 10.1, in millimetres per newton (mm/N);

L_0 is the gauge length, in millimetres (mm).

10.3.2 Filament rupture strain distribution

To plot the consistent experimental distribution of filament failure strain data, the following procedure is recommended. Assign to each failure strain data obtained from laboratory testing a probability of failure P_j given by Formula (1). To create a graph representing the data P_j as a function of $\varepsilon_{r,j}$, plot P_j as the ordinate and $\varepsilon_{r,j}$ as the abscissa. The ordinate axis shall be labelled as probability of failure P_f. Similarly, the abscissa shall be labelled as failure strain.

For each test i (i = 1, 2, 3) with a gauge length of 200 mm, determine the shape parameter (modulus) and the scale parameter of the two-parameter Weibull distribution of the filament rupture strain distribution according to Formula (3):

$$P = 1 - \exp\left[-\frac{SL_0}{V_0}\left(\frac{\varepsilon}{\varepsilon_0}\right)^m\right] \tag{3}$$

where

P is the probability of filament rupture;

ε is the filament strain;

ε_0 is the scale parameter;

S is the initial cross-section area of the filament, in square millimetres (mm^2);

L_0 is the gauge length, in millimetres (mm);

V_0 is the reference volume, in cubic millimetres (mm^3).

The estimated statistical parameters are such that the values of probability of fracture calculated from theoretical Formula (3) fit the cumulative distribution of failure strains constructed using experimental strain data [Formula (2)] and associated values of probability given by Formula (1). Various fitting techniques can be used, like the method of least squares. The best fit in the least-squares sense minimizes the sum of squared residuals, a residual being the difference between an observed value and the fitted value provided by a model.

For the purposes of this document the determination of the confidence intervals on the Weibull parameters may be omitted. Instead, the average values $\overline{m}_\varepsilon$ and $\overline{\varepsilon}_0$ are determined from the three tests.

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10.4 Distribution of filament strength

10.4.1 Initial cross-section area

Calculate the initial cross-section area of the tow according to Formula (4).

$$S_0 = 10^{-3}\frac{t}{\rho} \tag{4}$$

where

S_0 is the initial cross-section area of the tow, in square millimetres (mm^2);

t is the linear density of the fibre in tex (grams per thousand metres) determined from EN 1007-2;

ρ is the density in grams per cubic centimetre (g/cm^3) according to ISO 10119.

Formula (3) does not apply when image analysis is used for the determination of S_0.

10.4.2 Calculation of filament strength

Calculate the filament strength corresponding to each point j using Formula (5).

$$\sigma_{r,j} = \frac{F_j}{S_0\left(1-P_j\right)} \tag{5}$$

where

$\sigma_{r,j}$ is the filament strength at step j, in megapascals (MPa);

F_j is the force applied to the specimen at step j, in newtons (N);

S_0 is the initial cross-section area of the tow from 10.4.1, in square millimetres (mm^2);

P_j is the probability of filament rupture at step j determined from 10.2.3.

10.4.3 Filament strength distribution

To plot the consistent experimental distribution of strength data, the following procedure is recommended. Assign to each strength data obtained from laboratory testing a probability of failure P_j given by Formula (1). To create a graph representing the data P_j as a function of $\sigma_{r,j}$, plot P_j as the ordinate and $\sigma_{r,j}$ as the abscissa. The ordinate axis shall be labelled as probability of failure P_f. Similarly, the abscissa shall be labelled as failure stress, preferably using units of MPa.

For each test i (i = 1, 2, 3) with a gauge length of 200 mm, determine the shape parameter (modulus) and the scale parameter of the two-parameter Weibull distribution of the filament strength according to Formula (6):

$$P = 1-\exp\left[-\frac{SL_0}{V_0}\left(\frac{\sigma}{\sigma_0}\right)^m\right] \tag{6}$$

where

P is the probability of filament rupture;

σ is the filament strength, in megapascals (MPa);

σ_0 is the scale parameter in megapascals (MPa);

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S is the initial cross-section area of the filament, in square millimetres (mm^2);

L_0 is the gauge length, in millimetres (mm);

V_0 is the reference volume, in cubic millimetres (mm^3).

The estimated statistical parameters are such that the values of probability of fracture calculated from theoretical Formula (1) fit the cumulative distribution of strengths constructed using experimental strength data [Formula (5)] and associated values of probability given by Formula (1). Various fitting techniques can be used, like the method of least squares. The best fit in the least-squares sense minimizes the sum of squared residuals, a residual being the difference between an observed value and the fitted value provided by a model.

For the purpose of this document the determination of the confidence intervals on the Weibull parameters may be omitted.

10.4.4 Average filament strengths

For each test (i), calculate the average filament strength $\bar{\sigma}_{r,i}$ according to Formula (7).

$$\bar{\sigma}_{r,i} = \sigma_{0,i} \Gamma\left(\frac{1}{m_{\sigma,i}} + 1\right) \quad (7)$$

for gauge length L_0 = 200 mm, where

$\bar{\sigma}_{r,i}$ is the average filament strength, in megapascals (MPa);

$m_{\sigma,i}$ is the shape parameter of the filament strength distribution according to 10.4.3;

$\sigma_{0,i}$ is the scale parameter of the filament strength distribution according to 10.4.3, in megapascals (MPa);

Γ is a mathematical function, the values of which are given in Annex A, Figure A.1.

10.4.5 Mean filament strength

Calculate the mean filament strength $\bar{\bar{\sigma}}_r$ according to Formula (8).

$$\bar{\bar{\sigma}}_r = \sum_{i=1}^{n} \frac{\bar{\sigma}_{r,i}}{n} \quad (8)$$

11 Test report

The test report shall contain the following information:

a) name and address of the testing establishment;

b) date of test, unique identification of report and of each page, customer's name and address and signature;

c) reference to this document, i.e. determined in accordance with ISO 22459:2020;

d) type of specimen;

e) method used for measuring the tow elongation;

f) crosshead displacement rate;

g) load train compliance;

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h) number of tests carried out and number of valid results obtained;

i) cumulative probability curves for filament rupture strain and filament strength;

j) Weibull parameters for filament rupture strain and for filament strength distribution;

k) average filament strength;

l) Young's modulus;

m) method used for the determination of the initial cross-section area;

n) linear density of fibre;

o) typical load-displacement curve.

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Annex A
(informative)

Abstract of the handbook of mathematical functions

	0,00	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09
0,0	1,000 000	0,994 326	0,988 844	0,983 550	0,978 438	0,973 504	0,968 744	0,964 152	0,959 725	0,955 459
0,1	0,951 351	0,947 396	0,943 590	0,939 931	0,936 416	0,933 041	0,929 803	0,926 700	0,923 728	0,920 885
0,2	0,918 169	0,915 576	0,913 106	0,910 755	0,908 521	0,906 402	0,904 397	0,902 503	0,900 718	0,899 042
0,3	0,897 471	0,896 004	0,894 640	0,893 378	0,892 216	0,891 151	0,890 185	0,889 314	0,888 537	0,887 854
0,4	0,887 264	0,886 765	0,886 356	0,886 036	0,885 805	0,885 661	0,885 604	0,885 633	0,885 747	0,885 945
0,5	0,886 227	0,886 592	0,887 039	0,887 568	0,888 178	0,888 868	0,889 639	0,890 490	0,891 420	0,892 428
0,6	0,893 515	0,894 681	0,895 924	0,897 244	0,898 642	0,900 117	0,901 668	0,903 296	0,905 001	0,906 782
0,7	0,908 639	0,910 572	0,912 581	0,914 665	0,916 826	0,919 063	0,921 375	0,923 763	0,926 227	0,928 767
0,8	0,931 384	0,934 076	0,936 845	0,939 690	0,942 612	0,945 611	0,948 687	0,951 840	0,955 071	0,958 379
0,9	0,961 766	0,965 231	0,968 774	0,972 397	0,976 099	0,979 881	0,983 743	0,987 685	0,991 708	0,995 813
1,0	1,000 000	1,004 269	1,008 621	1,013 056	1,017 576	1,022 179	1,026 868	1,031 643	1,036 503	1,041 451
1,1	1,046 486	1,051 609	1,056 821	1,062 123	1,067 514	1,072 997	1,078 572	1,084 239	1,089 999	1,095 853
1,2	1,101 802	1,107 848	1,113 989	1,120 228	1,126 566	1,133 003	1,139 540	1,146 179	1,152 920	1,159 764
1,3	1,166 712	1,173 765	1,180 925	1,188 193	1,195 569	1,203 054	1,210 651	1,218 360	1,226 181	1,234 117
1,4	1,242 169	1,250 338	1,258 625	1,267 032	1,275 559	1,284 209	1,292 982	1,301 881	1,310 906	1,320 058
1,5	1,329 340	1,338 753	1,348 299	1,357 978	1,367 794	1,377 746	1,387 837	1,398 069	1,408 443	1,418 961
1,6	1,429 625	1,440 436	1,451 396	1,462 508	1,473 773	1,485 193	1,496 769	1,508 505	1,520 402	1,532 461
1,7	1,544 686	1,557 078	1,569 639	1,582 371	1,595 277	1,608 359	1,621 620	1,635 061	1,648 685	1,662 494
1,8	1,676 491	1,690 678	1,705 058	1,719 633	1,734 407	1,749 381	1,764 558	1,779 941	1,795 533	1,811 337
1,9	1,827 355	1,843 591	1,860 047	1,876 726	1,893 632	1,910 767	1,928 135	1,945 739	1,963 583	1,981 668
2,0	2,000 000	2,018 581	2,037 415	2,056 505	2,075 854	2,095 468	2,115 349	2,135 500	2,155 927	2,176 632
2,1	2,197 620	2,218 895	2,240 461	2,262 321	2,284 481	2,306 944	2,329 715	2,352 798	2,376 197	2,399 918
2,2	2,423 965	2,448 343	2,473 056	2,498 109	2,523 508	2,549 257	2,575 361	2,601 826	2,628 657	2,655 859
2,3	2,683 437	2,711 398	2,739 747	2,768 489	2,797 631	2,827 178	2,857 136	2,887 512	2,918 311	2,949 541
2,4	2,981 206	3,013 315	3,045 873	3,078 887	3,112 365	3,146 312	3,180 737	3,215 645	3,251 046	3,286 945
2,5	3,323 351	3,360 271	3,397 713	3,435 686	3,474 196	3,513 252	3,552 863	3,593 037	3,633 783	3,675 109
2,6	3,717 024	3,759 537	3,802 658	3,846 396	3,890 761	3,935 761	3,981 407	4,027 709	4,074 677	4,122 321
2,7	4,170 652	4,219 680	4,269 417	4,319 873	4,371 060	4,422 988	4,475 671	4,529 118	4,583 343	4,638 358
2,8	4,694 174	4,750 805	4,808 264	4,866 563	4,925 715	4,985 735	5,046 636	5,108 431	5,171 136	5,234 764
2,9	5,299 330	5,364 849	5,431 336	5,498 807	5,567 278	5,636 763	5,707 281	5,778 846	5,851 476	5,925 188
3,0	6,000 000	6,075 929	6,152 992	6,231 209	6,310 598	6,391 177	6,472 967	6,555 986	6,640 255	6,725 794
3,1	6,812 623	6,900 763	6,990 237	7,081 065	7,173 269	7,266 873	7,361 898	7,458 369	7,556 308	7,655 740
3,2	7,756 690	7,859 181	7,963 241	8,068 894	8,176 166	8,285 085	8,395 678	8,507 971	8,621 994	8,737 775
3,3	8,855 343	8,974 728	9,095 960	9,219 069	9,344 087	9,471 046	9,599 978	9,730 916	9,863 893	9,998 943

Figure A.1 — Values of the function $\Gamma(x + 1) = x!$ for $0 < x < 3,39$[7]

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