
**Paper, board and pulps — Estimation
of uncertainty for test methods by
interlaboratory comparisons**

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 6, *Paper, board and pulps*.

This first edition cancels and replaces the second edition of ISO/TR 24498:2019, which has been technically revised.

The main changes are as follows:

- ISO/TR 24498 has been changed into ISO/TS 24498 adding normative language
- Lignins and kraft liquors have been introduced in the scope of the document, and a subclause on the sampling of these materials in [5.2](#) has been added
- Subclause [7.3](#) has been updated.

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

One step in the development of any new standard test method is to estimate the uncertainty of the method. After such a procedure, a "Precision statement" is usually included in ISO test methods for pulp, paper and board and is recommended by ISO/TC 6 for all new and revised ISO/TC 6 standards. This is normally performed in a precision experiment, in which samples are sent to a number of laboratories and the results are compared. Such a precision experiment is often referred to as "interlaboratory comparative testing".

The procedures for conducting a precision statement are outlined in the ISO 5725 series^[1], which is general and does not cover the special conditions that apply in the testing of pulp, paper, board and cellulosic nanomaterials (this is the reason why some countries have published national standards or test methods dedicated to pulp, paper and board^{[2][3]}).

For example, paper and board materials as well as cellulosic nanomaterials are very sensitive to changes in relative humidity and temperature. Changes in the environmental conditions may induce significant moisture content variations in paper and board, which may induce changes in physical and mechanical properties.

Due to product heterogeneity, randomisation of the samples and /or test pieces is essential to minimize the impact of such variability. For the same reason, the variation in the properties can increase drastically when the test piece size decreases, for example when measuring grammage or Cobb water absorptiveness.

These reasons make it necessary to have special instructions for precision experiments for pulp, paper, board and cellulosic nanomaterials.

One effect of the heterogeneity of the product is that a large number of measurements is required in order to achieve sufficient precision. Most standardized test methods are therefore based on 10 or more measurements. The result is generally the average of these measurements.

Uncertainty has multiple components including a random component and a systematic component. This document focuses on the random component, defined by a repeatability and reproducibility of the measurements.

There are four main purposes for testing:

- Research, where the main question is whether there is an expected maximum difference between two samples, for instance, papers produced using different pulp mixtures.
- Verification of conformance with a specification. This can be at the production central testing laboratory site or in an independent laboratory.
- Evaluation of a new test method, where the aim is to verify that the precision of the test method is acceptable.
- Determination of a precision statement for an existing test method either where one does not exist or where it requires revision.

When the uncertainty of a test method is to be expressed, the following aspects should be considered.

- The conditions for the tests. Are the conditions as similar as possible, or as different as possible?
- The uncertainty can be expressed in different statistical measures, as a standard deviation or as a confidence interval.
- The uncertainty can be expressed either as a variation in the test results themselves, or as the difference between two test results.

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Paper, board and pulps — Estimation of uncertainty for test methods by interlaboratory comparisons

1 Scope

This document presents guidelines for a methodology for the estimation of the uncertainty of methods for testing lignins and kraft liquors, pulps, paper, board, cellulosic nanomaterials, as well as products thereof containing any portion of recycled material or material intended for recycling.

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 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.

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 <https://www.electropedia.org/>

3.1

interlaboratory comparison

organization, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories in accordance with predetermined conditions

[SOURCE: ISO 13528:2015, 3.1]

3.2

interlaboratory test

series of measurements of one or more quantities performed independently by a number of laboratories on samples of a given material

[SOURCE: ISO 11459:1997, 3.16]

3.3

repeatability condition of measurement

repeatability condition

condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time

Note 1 to entry: A condition of measurement is a repeatability condition only with respect to a specified set of repeatability conditions.

Note 2 to entry: In chemistry, the term “intra-serial precision condition of measurement” is sometimes used to designate this concept.

[SOURCE: JCGM 200:2012, 2.20]

**3.4
repeatability limit**

r

value less than or equal to which the absolute difference between two test results obtained under repeatability conditions is expected to be with a probability of 95 %

[SOURCE: ISO 3534-2:2006]

**3.5
repeatability standard deviation**

standard deviation of test results obtained under repeatability test conditions

[SOURCE: ISO 3534-2:2006]

**3.6
reproducibility condition of measurement**

reproducibility condition

condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects

Note 1 to entry: The different measuring systems may use different measurement procedures.

Note 2 to entry: A specification should give the conditions changed and unchanged, to the extent practical.

[SOURCE: JCGM 200:2012, 2.24]

**3.7
reproducibility limit**

R

value less than or equal to which the absolute difference between two test results obtained under reproducibility conditions is expected to be with a probability of 95 %

[SOURCE: ISO 3534-2:2006]

**3.8
reproducibility standard deviation**
standard deviation of test results obtained under reproducibility test conditions

[SOURCE: ISO 3534-2:2006]

**3.9
uncertainty**

<measurement> non-negative parameter which characterizes the variability in the values obtained from measurements

4 Procedure

The preferred procedure is for an expert from the working group responsible for developing an ISO Standard to organize the interlaboratory testing while the standard is being developed.

In these conditions, tests are performed with commercially available materials, as uniform and stable as possible, utilizing test instruments which are also available on the market and in the participating laboratories. A call for participation of laboratories outside of the working group may be permitted.

In the case where an interlaboratory test cannot be implemented by the working group, the use of comparative testing services data (for example from pulp and paper, collaborative testing services round robins, or CEPI Comparative Testing Service) are recommended. In this case, the most recent data should be provided and recalculated in the format used in the ISO/TC 6 standards.

If neither of the two first options are possible, bibliographic data should be reported.

5 Preparation of an interlaboratory study

5.1 Laboratories

5.1.1 Qualification of laboratories

Any laboratory that would be considered qualified to run the test is permitted and encouraged to participate in the interlaboratory study.

Laboratories shall be properly equipped to follow all details of the procedure, including climate conditions when specified, and be willing to assign the work to a skilled operator on a timely basis with competent personnel having knowledge of the materials and of the property to be tested.

In many situations it is preferable that participating laboratories meet the requirements of ISO/IEC 17025^[4] or equivalent, or that at least they participate in a comparative testing service and have been shown to be competent in the test for which the precision data is being obtained.

The decision on permitting a laboratory to participate should be based on information provided to the working group, including information as to the required time for calibrating the apparatus and for testing all of the materials.

5.1.2 Number of participating laboratories

It is recommended to include at least eight laboratories to obtain a valid estimate of the uncertainty associated with the test method.

No interlaboratory round robin test should be performed with less than five laboratories.

5.2 Sample preparation and distribution

5.2.1 Number and type of material

The number and types of materials to be included in the interlaboratory study should cover the range of the values of the property being measured and be representative of the number of types or classes of materials to which the test method is to be applied. It also should cover each scale of the instrument (e.g. Scott Bond) if applicable.

If the interlaboratory study is restricted in any of these areas, the omitted information should be reported in the precision statement.

5.2.2 Selection of the material

5.2.2.1 General

The sampling procedure shall be appropriate to the property to be assessed and the type of material (pulp, paper, board or cellulosic nanomaterial).

It is up to the person responsible for the interlaboratory study to check if the material selected is suitable or not. If not, the material shall be changed.

It is also up to the person responsible for the interlaboratory study to check if the property is normally distributed. When normality of distribution cannot be proven, it is advised to group the data. One can also use comparability techniques, i.e. to compare the average mean differences between laboratories, once the consistency of data coming from these laboratories is also proven graphically.

Each selected product shall be sampled so that the variability among the specimens of that material will be minimized. In this way, several basic considerations shall be kept in mind. There are always cross-machine variations in properties, and the rate of change on the edges of the web may be significantly greater than in the middle. The changes in the machine direction are usually less severe. Since paper is anisotropic and two-sided, care shall be taken when the reel is split into sheets to ensure that the machine direction is differentiated from the cross direction and that the two sides of the paper are identified if relevant.

This can be achieved for example by cutting the sheets with different dimensions in the machine and cross directions and drawing a line on the edge of each sheet, on the same side.

Sampling for chemical analysis and for some physical tests such as burst does not require distinguishing between machine and cross direction or sheet sidedness.

Samples shall be rendered homogeneous by appropriate randomization.

Enough test pieces or specimens from each sample shall be prepared to provide the required test material for all participating laboratories and a significant number of additional test pieces or specimens for replacement of any lost or spoiled items.

With paper and board, sampling may be performed from rolls or from reams. In each case, specified procedures should be followed. Rolls are preferred to reams because rolls are more homogeneous.

Since the sampling procedure may vary depending on the type of sample and on the particular testing method, follow the specified sampling procedures and test methods.

5.2.2.2 Sampling from rolls

If sampling is performed on rolls, all specimens should be taken from a small area of a single roll, avoiding the edges of the roll. Usually, specimens taken adjacent to each other in the machine direction are more similar than those adjacent in the cross direction.

5.2.2.3 Sampling from reams

Reams are usually constituted from sheets issued from four to six mother rolls. If sampling is performed on reams of papers or boards, measurements should be performed on at least 25 consecutive top sheets from each ream in order to eliminate from the sample sheets showing deviation.

If one pack does not contain enough material, additional reams shall be sampled. In this case, it shall be verified that all the reams are from the same production, and that their characteristics are close enough to ensure a uniform statistical population.

Randomization shall be performed after the selection of all the necessary reams, and not ream by ream.

5.2.2.4 Sampling of cellulosic nanomaterials

Rolls or reams, pulp-like samples, sheets or other samples resembling pulp, paper or board shall be sampled using the appropriate sampling technique described herein or in the corresponding ISO standard.

Powders, granules, flakes or other dry forms shall be rendered homogeneous by appropriate randomization and representative samples taken using the appropriate sampling technique.

Slurries or suspensions of cellulosic nanomaterials shall be rendered homogeneous by stirring or other appropriate methods and representative samples taken from the homogeneous mixture.

5.2.2.5 Sampling of lignins and kraft liquors

Lignins shall be rendered homogeneous by stirring or other appropriate methods and representative samples taken from the homogeneous mixture.

5.2.3 Identification and packaging

Samples should be identified by codes by the person responsible for the round-robin in order to be tested anonymously by the participants.

The side to be tested and/or machine or cross direction shall be clearly identified if relevant.

Where relevant (depending on the test) samples shall be pre-conditioned and conditioned according to ISO 187 before being packed.

Samples should be packaged in moisture barrier, light-proof packages to ensure that no changes in physical, optical or chemical properties occur.

5.2.4 Additional and specific care

Specific care shall be taken when sampling and handling microbiological samples.

Whenever possible, submit samples to the testing laboratories in the original unopened containers. Otherwise transfer the representative sample to a sterile plastic bag or pack it in household aluminium foil, under aseptic conditions. Identify each packed sample with a properly marked strip of masking tape, excluding any solvent markers and adhesives.

5.3 Documentation for the interlaboratory study

Adequate documentation for the participants in the study shall be prepared by the person responsible for the study, and shall include at least the following information:

- a description of the samples to be tested;
- the procedure to be implemented to perform the measurement. In principle, the draft or existing ISO standard is the procedure to be used;
- when important, a required day or week for the analysis (for microbiological tests for example, analysis should be ideally performed by the different laboratories within two months because the microbe number could change);
- conditioning or ageing of the samples;
- a request for additional information such as relative humidity, temperature, type of instrument, date of analysis (important parameters for microbiological tests for example);
- a request for comments on the measurements;
- a deadline for returning the results.

A template shall be distributed for recording:

- all the replicate measurements (an electronic spreadsheet is in most cases suitable), including the number of decimal places to be used, and calculations for the average, standard deviation, coefficient of variation or other parameters depending on the specifications of the draft standard;
- additional information such as relative humidity, temperature, type of instrument;
- comments on the measurements.

One file per laboratory shall be used, containing one sheet per sample assessed. One example of a template is given in [Annex B](#).

6 Testing

On receipt of the samples, when climate conditions are specified in the procedure, the unopened packages should be stored for a few hours at a standardized temperature in order to reach temperature equilibrium. Then, packages should be unpacked, and samples conditioned at standardized temperature and humidity for 12 h, or longer if necessary, to ensure that the equilibrium moisture content is reached.

A check that the testing instrument is calibrated according to the instructions given in the ISO standard or draft standard method shall be performed or, if such instructions are not given, according to the instructions given by the instrument manufacturer.

Tests shall be performed according to the procedure received, and all the individual values recorded in the supplied template, as well as all the other data requested.

Finally, the completed form shall be sent back to the coordinating laboratory before the stated deadline.

7 Analysis of the results

7.1 Calculations

Standard deviation is the most fundamental expression of dispersion. The confidence interval, which is derived from the standard deviation (provided that the variable has a normal distribution), is the fundamental expression of uncertainty. The confidence interval is incomplete unless it is accompanied by an estimate of the probability. This probability is often selected to be 95 %, as, for instance, in the definition of repeatability and reproducibility limits. 19 values out of 20 are expected to be inside a 95 % confidence interval. The 95 % confidence interval is $\pm 1,96 \times s$, where s is the estimated standard deviation. The assumptions are that the variable has a normal distribution and that the standard deviation is known, or that it is estimated on the basis of a sufficient number of values that the uncertainty in the standard deviation can be neglected.

The uncertainty of a test method can either be expressed as the variation in the test results themselves, or as the absolute value of the expected maximum difference between test results.

When the test results have a normal distribution, the difference between two test results will also have a normal distribution, with zero as the expected mean, and the standard deviation is increased by a factor of 1,41, compared to the standard deviation of the original test results.

The repeatability and reproducibility limits can thus be calculated as $\pm 1,96 \times 1,41 \times s = \pm 2,77 \times s$, for test results that have a normal distribution and when the standard deviation s is based on a large number of tests or t distribution tables.

It is up to the organiser of the interlaboratory study to check that the variables have a normal distribution.

The three common procedures in assessing whether a random sample of independent observations of size n come from a population with a normal distribution are: graphical procedures (such as histograms or side-by-side box plots), numerical methods (skewness and kurtosis indices) and formal normality tests (such as Shapiro-Wilk test, Kolmogorov-Smirnov test, Lilliefors test and Anderson-Darling test)^[5] ^[6] ^[7] ^[8]. Professional statistical support should be sought in evaluating the data distribution.

An assumption that data are normally distributed is required in order to use the procedures described in this document. If the distribution is not normal, this procedure cannot be used.

NOTE The National Institute of Standards and Technology (NIST) web page discusses checking for outliers via box plots: <https://www.itl.nist.gov/div898/handbook/prc/section1/prc16.htm>.

7.2 Case of interlaboratory study organised by the working group

7.2.1 General

The person responsible for the interlaboratory study shall take care that all participating laboratories send back complete files.

The uncertainty parameters are calculated by compiling the results on the basis that all sets of results included in the analysis contain the same number of test results.

7.2.2 Consistency evaluation

It is often helpful to study the consistency statistics when displayed grouped by laboratory and also by material. This display of consistency statistics may be done numerically or graphically (bar charts of values). The goal of displaying the data in this manner is to detect unusual features in the study data that may bias the calculated precision parameters.

Graphical consistency statistics called Mandel's h (test for outlier on the mean value) and k (test for outlier on the variance) can be used to flag laboratories that are providing data that need investigation. A single outlying laboratory average will most likely be flagged by an h test. However, if more than one laboratory average is an outlier, then the h test might no longer perform well. When multiple outliers are present, there is a tendency to mask the presence of each other in formal (non-visual) tests. If the graphical outlier checks indicate the possible presence of multiple outliers, a professional statistician should be consulted. The calculation of h and k applies only to data derived from interlaboratory studies.

Tappi T1200^[2] lists the critical values of h and k at the 0,5 % significance level. To obtain the particular critical values from this table, search down the rows to find the number of laboratories (p) and then across the columns to find the number of replicates (n) in the study. When a calculated consistency statistic exceeds this value, the laboratory data shows excessive variation. h values in excess of the critical value indicate excessive variation from the grand mean. k values in excess of the critical value indicate excessive variation from the pooled material standard deviation. Mark the values in the display of consistency statistics that exceed the critical value. Data that exceed critical values should be studied by the working group to determine if the data adversely affect the calculation of precision parameters. It is important to note that all data that exceed the critical value are not automatically "bad," because by definition 1 of every 200 results may exceed the critical value.

NOTE More information on Mandel's h and k statistics and other methods dedicated to critical examination of the data is given in ISO 5725-2^[1] and ISO/TR 22971^[9].

7.2.3 Handling of outlying data

When a laboratory consistency statistic suggests that its data are not consistent with data from the other participating laboratories, but are in error, there are two possible actions: delete or retest. A retest is the preferred method if the material is unlikely to have changed since the original study. Before any retesting, the test method and testing instructions should be reviewed with the laboratory to correct any possible bias that may have caused the error.

If it is suspected that the material has changed since the conduct of the original study, or a laboratory cannot correct its procedures or instrument, the outlying data should be omitted.

7.3 Case of data provided from proficiency testing services

The two main sources of data are the CEPI-Comparative Testing Service (CEPI-CTS) and the Tappi proficiency testing service. There may be differences in how data are reported, and re-calculations may be needed (see [Annex A](#)).

For example, CEPI-CTS reports mean standard deviation within laboratories (within SD) and total standard deviation (standard deviation for proficiency assessment).

The CEPI-CTS Within SD is mainly an estimate of the material variability.

The CEPI-CTS total standard deviation includes all sources of variation such as the between-laboratory variation, and the variation between the proficiency test items. Variations due to transport instability and instability over time are considered negligible, thanks to the precautions taken in the preparation and shipment of test items

8 Re-evaluation of the uncertainty

Review of the precision statement shall be included as part of a systematic review of a standard. Development of new precision data should not be required if the existing data are determined to be acceptable.

9 Report

The following data shall be reported in an informative annex entitled "Precision of the standard":

- a) number of participating laboratories;
- b) what year the data were acquired (i.e. when the round robin was performed);
- c) atmosphere conditions during testing;
- d) repeatability standard deviation, s_r ;
- e) coefficient of variation, CV (%), for the repeatability data;
- f) repeatability limit, r ;
- g) reproducibility standard deviation, s_R ;
- h) coefficient of variation, CV (%), for the reproducibility data;
- i) reproducibility limit, R .

An example of such a statement is given in [Annex C](#).

This methodology should be used both for all new standards and for revised standards.

10 Archiving raw data

The precision raw data and final precision statement shall be saved on the ISO/TC 6 website (ISO TC server ISO/TC 6) in a specific folder along with all the other information that is saved relevant to the development or review of the standard and saved in a format that can be accessed but not changed over time (e.g., a pdf file).

Location where the data should be saved: / 04. Projects / ISO XXX / Precision

Annex A (informative)

Tappi and ISO codifications

Differences between Tappi and ISO codifications are reported in [Table A.1](#).

Table A.1 — Table of differences

Used in Tappi spreadsheet		Used in ISO/TC6	
Repeat Std Dev	S_r	Repeatability standard deviation	s_r
Repeatability	r	Repeatability limit	r
Reproduce Std Dev	S_R	Reproducibility standard deviation	s_R
Reproducibility	R	Reproducibility limit	R
Grand Mean	\bar{X}	Mean	\bar{X}
		Coefficient of variation	$CV = \frac{s_r}{\bar{X}} 100$ $CV = \frac{s_R}{\bar{X}} 100$

Annex B (informative)

Example of a recommended form to be distributed to participating laboratories for the collation of results for analysis

Laboratory
Date
Device

LAB N°:xx

Comments (if any)
Write here or send us scanned pages of the procedure with your comments

REFERENCES		GRAMMAGE FOR TISSUE PAPER							
Area in cm ²		1		2		3		4	
		g	g/m ²	g	g/m ²	g	g/m ²	g	g/m ²
Mass, g <i>fill in the white cells</i>	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								
Mean value									
standard deviation									
coefficient of variation									

REFERENCES		5		6		7		8	
Area in cm ²		g	g/m ²						
Mass, g	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								
Mean value									
standard deviation									
coefficient of variation									

Figure B.1 — Example form for collation of results on physical testing