PD CEN/TS 16010:2013

BSI Standards Publication

Plastics — Recycled plastics — Sampling procedures for testing plastics waste and recyclates

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee PRI/89, Plastics recycling.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2013

ISBN 978 0 580 75314 5

ICS 13.030.50; 83.080.01

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 28 February 2013.

Amendments issued since publication

Amd. No.	Date	Text affected

TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

TECHNISCHE SPEZIFIKATION

CEN/TS 16010

January 2013

ICS 13.030.50; 83.080.01

English Version

Plastics - Recycled plastics - Sampling procedures for testing plastics waste and recyclates

Plastiques - Plastiques recyclés - Procédures d'échantillonnage pour l'essai des déchets de plastiques et des recyclats

Kunststoffe - Kunststoff-Rezyklate - Probenahmeverfahren zur Prüfung von Kunststoffabfall und Rezyklaten

This Technical Specification (CEN/TS) was approved by CEN on 22 October 2012 for provisional application.

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Ref. No. CEN/TS 16010:2013: E

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Foreword

This document (CEN/TS 16010:2013) has been prepared by Technical Committee CEN/TC 249 “Plastics”, the secretariat of which is held by NBN.

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

This Technical Specification is one part of a series of CEN publications on Plastics Recycling that is structured as follows:

— EN 15342, *Plastics — Recycled Plastics — Characterization of polystyrene (PS) recyclates*

— EN 15343, *Plastics — Recycled Plastics — Plastics recycling traceability and assessment of conformity and recycled content*

— EN 15344, *Plastics — Recycled Plastics — Characterisation of Polyethylene (PE) recyclates*

— EN 15345, *Plastics — Recycled Plastics — Characterisation of Polypropylene (PP) recyclates*

— EN 15346, *Plastics — Recycled plastics — Characterisation of poly(vinyl chloride) (PVC) recyclates*

— EN 15347, *Plastics — Recycled Plastics — Characterisation of plastics wastes*

— EN 15348, *Plastic — Recycled plastics — Characterization of poly(ethylene terephthalate) (PET) recyclates*

— CEN/TR 15353, *Plastics — Recycled plastics — Guidelines for the development of standards for recycled plastics*

— CEN/TS 16011, *Plastics — Recycled plastics — Sample preparation*

According to the CEN/CENELEC Internal Regulations, the national standards organisations of the following countries are bound to announce this Technical Specification: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

Recycling of plastics waste is one type of material recovery process intended to save resources (virgin raw materials, water, energy), while minimising harmful emissions into air, water and soil as well as their impacts on human health. The environmental impact of recycling should be assessed over the whole life cycle of the recycling system (from the waste generation point to the disposal of final residues). To ensure that recycling constitutes the best environmental option for treating the available waste, some prerequisites should preferably be met:

— the recycling scheme being contemplated should generate lower environmental impacts than alternative recovery options;

— existing or potential market outlets should be identified that will secure a sustainable industrial recycling operation;

— the collection and sorting schemes should be properly designed to deliver recyclable plastics waste fractions fitting reasonably well with the available recycling technologies and with the (changing) needs of the identified market outlets, preferably at minimum costs for society.

This Technical Specification has been produced in accordance with the guidance produced by CEN on Environmental Aspects and in accordance with CEN/TR 15353, *Plastics — Recycled plastics — Guidelines for the development of standards for recycled plastics*.

NOTE CEN/TR 15353 considers the general environmental aspects which are specific to the recycling process.

This Technical Specification is intended to serve two purposes.

1. To provide a guide to plastic recyclers and others that enables a calculation to be made of the risk of inaccuracy presented by a chosen sampling regime. This will help to inform decisions about sampling that can also be influenced by factors such as the supply record of a supplier or the reliability of a process. This is covered in Clause 5.

2. To define the sampling procedures to be followed to characterise the material being sampled. These procedures may be followed where a particular level of accuracy is required, or where the sampling is in support of the resolution of a dispute. This is covered in Clause 7 and Annex A.

It is not the intention of this Technical Specification to develop new sampling methods.

1 Scope

This Technical Specification specifies a system for sampling procedures for testing plastics waste and recyclates which take into account the specifics of the plastics waste and recyclates. It is intended to cover all stages of the plastic recycling process.

The sampling procedures include the statistical specifics of the plastic waste and the behaviour of recyclates.

The sampling method should produce a representative testing sample. Differences can arise due to:

- the mixture of plastics;
- the origin (e.g. green dot in Germany, or electronic/automotive industry);
- the previous use of the plastic material;
- the residual contents (e.g. of containers);
- inert, residual or moisture content on or in the material.

This Technical Specification is without prejudice to any existing legislation.

2 Normative references

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

CEN/TR 15353:2007, *Plastics — Recycled plastics — Guidelines for the development of standards for recycled plastics*

CEN/TS 16011, *Plastics — Recycled plastics — Sample preparation*

EN ISO 472:2001, *Plastics — Vocabulary (ISO 472:1999)*

ISO 11648-1:2003, *Statistical aspects of sampling from bulk materials — Part 1: General principles*

ISO 11648-2:2001, *Statistical aspects of sampling from bulk materials — Part 2: Sampling of particulate materials*

3 Terms and definitions

For the purposes of this document, the terms, definitions and abbreviated terms given in EN ISO 472:2001, in CEN/TR 15353:2007 and the following apply.

NOTE The terms used are confined to the field of bulk sampling.

3.1
bulk material
amount of material within which component parts are not initially distinguishable on the macroscopic level

[SOURCE: ISO 11648-1:2003]

3.2
sample
combination of a set of increments of material taken from a lot, intended to supply information, and possibly serve as a basis for a decision concerning the lot or the process by which it has been produced

[SOURCE: ISO 8656-1:1988]

3.3
increment
quantity of bulk material taken in one action by a sampling device

[SOURCE: ISO 11648-1:2003]

3.4
laboratory sample
sample intended to be used for an inspection or for laboratory tests

[SOURCE: ISO 8656-1:1988]

3.5
test sample
sample taken from the laboratory sample and prepared in a suitable manner for subjection to particular tests

Note 1 to entry: Test samples might be prepared, for example, for the determination of particle size distribution, moisture content, chemical composition, physical or other properties. See also CEN/TS 16011.

[SOURCE: ISO 8656-1:1988]

3.6
central limit theorem
fundamental theorem of probability and statistics, stating that the distribution of the mean of a random sample from a population with finite variance is approximately normally distributed when the sample size is large, regardless of the shape of the population's distribution

Note 1 to entry: If x_1, x_2, …., x_n are independent measurements (i.e. a random sample of size n), from a population where the mean of x is μ, and the standard deviation of x is σ, then:

The distribution of $\bar{x} = \dfrac{x_1 + x_2 + \ldots + x_n}{n}$ has mean and standard deviation given by:

$$\mu_{\bar{x}} = \mu \text{ and } \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

When n is sufficiently large, then the distribution of $\bar{x}$ is approximately normal.

3.7
Student's *t*-distribution
t-distribution
probability distribution that is effective in the problem for estimating the mean of a normally distributed population when the sample size is small

3.8
duration
length of sample time when sampling from a continuous stream

3.9
plastics waste
plastics fraction of waste

3.10
waste
material or object which the holder discards, or intends to discard, or is required to discard

[SOURCE: ISO 15270:2008]

4 Symbols and abbreviations

n number of single samples, number of measurements

x_n independent single measured value

$\bar{x}$ arithmetic mean (average value, average)

s standard deviation of samples

σ standard deviation of population

μ is the real value of the true mean of the known distribution

t the value of the Student deviation for different levels of confidence

5 Calculating the probability that a given set of samples is representative

5.1 General

In everyday circumstances plastics recyclers require sampling for two basic purposes: to provide input quality control and to verify the quality of the output recycled plastic. Although the physical properties of input and output materials might be very different, the underlying statistical principles are the same. The samples taken shall be sufficiently representative of the batch to satisfy the user of the sample information that it is relevant for his purpose. The sampling regime will be based on a number of factors including:

— the physical form and homogeneity of the material being sampled;

— the level of confidence in the consistency and reliability of the material being sampled;

— the consequences of the sample not being representative.

The purpose of this section is to provide a tool for the plastic recycler to use to calculate the effectiveness of his chosen sampling routine or, conversely, to calculate the risk associated with a particular sampling regime.

Sample sizes are often small, and the population standard deviation (σ) is usually unknown. The population standard deviation (σ) can be replaced with the sample standard deviation (s). To be more conservative in the analysis, the *t*-distribution may be used rather than the normal distribution. When sample sizes are large the results are the same (Central Limit Theorem).

Many common statistical procedures require data to be approximately normal, but the Central Limit Theorem enables these procedures to be applied to populations that are strongly non-normal. How large the sample size shall be depends on the shape of the original distribution. If the population's distribution is symmetric, a sample size of 5 might yield a good approximation; if the population's distribution is strongly asymmetric, a larger sample size is necessary (50 or more).

Sampling error is in effect $\sqrt{\frac{1}{n}}$ and this gives a guide to the limit of detection in that it would be possible to miss a 10 % component by taking a sample of 100 pieces. It is also important to recognise that the sampling error is based on the particles as sampled. If these particles have an average mass of 10 g then a sample of 1 kg is needed to get a 10 % error and 100 kg to get a 1 % error.

5.2 Power and sample size

Power is the likelihood of identifying a significant difference (effect) when one truly exists. Errors are referred to as Type 1 and Type 2 errors. A Type 1 error results in rejecting good material and a Type 2 error results in accepting bad material. The easiest way to improve power is to increase sample size.

5.3 Calculation of the variance of sampling

To understand the effect of changing the number of samples, see Annex C. With a number of samples 'n' the factor 't' is determined with different levels of confidence. Using an estimated or calculated standard deviation 's' it is possible to calculate the influence on the sampling by variation of the number of samples with the formula in Annex A under A.5.2 (reverse calculation).

5.4 Determining the confidence in a sampling routine

In this example a load of ten tonnes of waste plastic is delivered to a plastic recycler for processing.

— The load consists of ten bags of shredded plastic, each bag weighing approximately one tonne.

— The plastic has been shredded to give pieces averaging 150 mm × 150 mm (range > 75 mm to < 200 mm) by 3 mm thick (range > 2,5 mm to < 3,5 mm).

— The average mass of each shredded piece is 0,06 kg.

— The load is known to contain a mixture of polyethylene (PE) and polypropylene (PP). The supplier claims that the PP content is less than 5 %.

— The plastic recycler hand samples each bag, taking two sample pieces from each bag; a total of 20 samples.

— Each sample is analysed to find its PP content with the results shown in Table 1.

Table 1 — Analysis results

Sample No	PP%	Sample No	PP%
1	4,25	11	6,55
2	6,15	12	6,10
3	4,90	13	6,95
4	5,30	14	4,85
5	4,95	15	6,95
6	4,15	16	7,10
7	4,95	17	6,65
8	5,75	18	4,75
9	6,80	19	4,85
10	5,15	20	4,10

The average value (mean) $\bar{x} = 5{,}56$ %.

The Standard Deviation, calculated according to A.5.1 gives s = 1,013 929.

The value for 't' to give an assumed 95 % confidence level with 20 samples can be taken from the table in Annex C giving a figure for 't' of 2,093.

The confidence interval is calculated using the formula in A.5.4 so that:

$$\bar{x} \pm t\frac{s}{\sqrt{n}} = 5{,}56 \pm 2{,}093 \times \frac{1{,}013929}{\sqrt{20}} = 5{,}56 \pm 0{,}4745$$

The end points for the confidence interval are therefore 5,085 5 % and 6,034 5 %

This means the recycler can be reasonably certain (95 %) that the PP content for the samples taken lies between 5,09 % and 6,03 %. Because the mean of the samples lies within this range it is also possible that the mean of the batch is approximately equal to 5,56 %.

Based on this result the buyer can be reasonably certain that the average PP content for the material being supplied is higher than stated by the supplier (< 5 %).

For a higher confidence level the value of '*t*' will change. For an assumed confidence level of 99 %, '*t*' will become 2,861 and the calculated end points would become 4,91 % and 6,21 % indicating the probability of a much wider spread of the value of the PP content.

Conversely, for a lower level of confidence, say 90 %, '*t*' will become 1,729 and the calculated end points would become 5,17 % and 5,95 % respectively.

Similar calculations could be made for properties such as particle size, dirt content, moisture content or other contaminants.

6 Sampling from non homogeneous material streams

It is possible that plastics recyclers might require sampling of non homogeneous material streams. This is most likely to occur with unprocessed plastic waste, where the waste is sourced from different applications. Some decisions need to be made to determine the best approach to sampling, as shown in Figure 1.

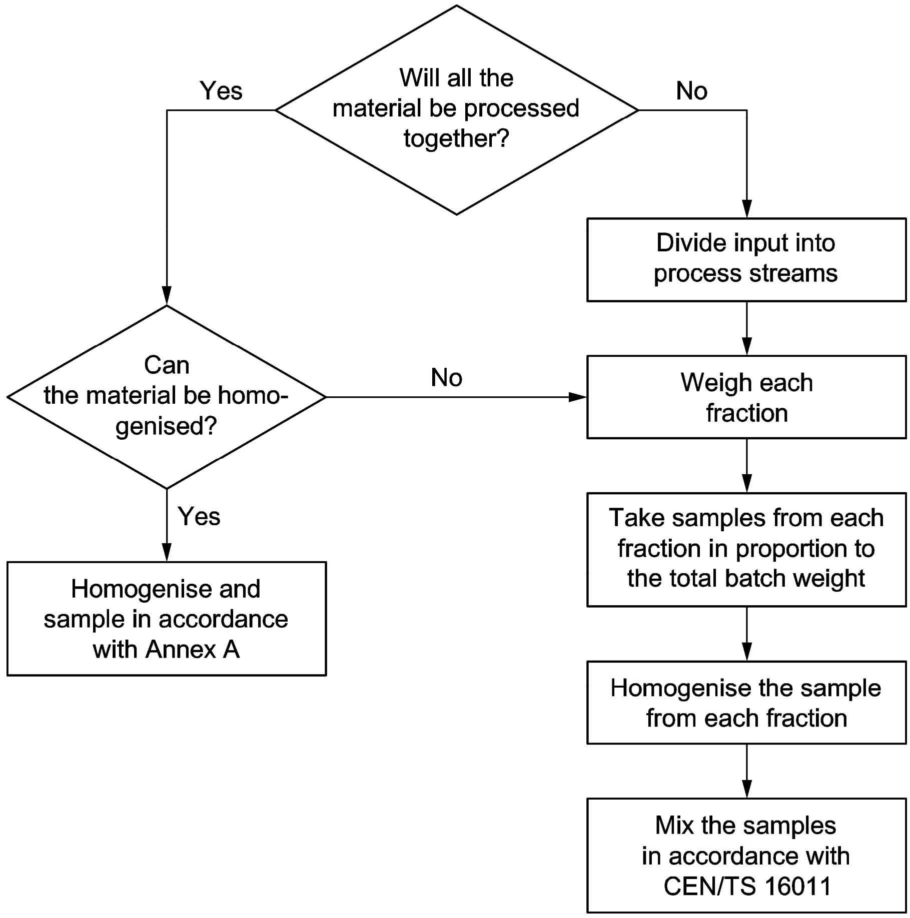

Figure 1 — Process diagram for sampling from non-homogeneous material streams

7 Procedures for the determination of material characteristics through sampling

7.1 General

The sample should always be representative of the lot or batch as a general principle. However, this is particularly important when deciding something of legal or commercial significance, such as the settlement of a dispute between buyer and seller, the calculation of a consignment value based on material content, or to provide a certificate of analysis.

The procedures set out here and in Annex A provide a simplified approach to statistical sampling and should be used where possible. Where this is inadequate for the required purpose, reference should be made to ISO 11648-1 and ISO 11648-2.

7.2 Establishing a sampling scheme

In establishing a sampling scheme for regular sampling so that a specified precision on a quality characteristic for a lot can be obtained, it is necessary to carry out the following sequence of steps. The sequence includes experimental sampling procedures, such as step g) below, which are not routine and are carried out only infrequently, as, for example, when there is a significant alteration in conditions such as a change in the source of the particulate material or in the sampling equipment.

a) Define the purpose for which the samples are to be taken. Sampling for the quality verification requirements of commercial transactions is the central purpose within the scope of this part of this sampling standard. However, the procedures described are applicable to sampling for the purpose of monitoring plant performance and for process control as well.

b) Identify the quality characteristics to be measured. Specify the total precision (combined precision of sampling, sample preparation and measurement) required for each quality characteristic. It might be found that the required precision gives impractical numbers of primary increments and sub-lots. In such cases, it might be necessary to accept poorer precision.

c) Define the lot, including its mass or duration.

d) Define the sub-lots, including their number and their masses or durations.

e) Ascertain the nominal largest particle size and density of the bulk material for use in determining the gross sample mass in step i). The nominal largest particle size also determines the minimum cutter aperture width required to avoid bias where a mechanical sampler is used, or the minimum size of the ladle required to avoid bias where manual sampling is used.

f) Check that the procedures and equipment for taking increments avoid significant bias (see 7.3).

g) Determine the variability of the quality characteristics under consideration.

h) Determine the number of primary increments to be taken from the lot or the sub-lots to be tested (see A.4).

i) Determine the minimum gross sample mass (see A.4.1 and A.7).

j) Determine the sampling intervals, in tonnes for mass-basis systematic sampling and stratified random sampling within fixed mass intervals, or in minutes for time-basis systematic sampling and stratified random sampling within fixed time intervals. (Detailed descriptions can be found in Clauses 10, 11 and 12 of ISO 11648-2:2001.)

k) Take primary increments at the intervals determined in step j) during the whole period of handling the lot.

In experimental sampling, each increment may be analysed separately to assess the variability of the quality characteristic in the lot by monitoring the variogram. Alternatively, the primary increments may be taken from a sub-lot to constitute a sub-lot sample which may also be analysed to assess lot variability. These are only two of a variety of other experimental sampling schemes possible (see, for example, the fully-nested and staggered-nested experiments described in ISO 11648-1).

In regular sampling, a typical sampling scheme is to combine sub-lot samples so as to constitute a gross sample for analysis. Periodically, checks should be made on the precision achieved by the sampling scheme by means of replicate sampling, i.e. by replication of the gross sample. For example, if duplicate sampling is used, each alternate primary increment is diverted so that gross samples A and B are formed from which two test samples are prepared and tested.

Sub-lot samples are usually prepared and analysed separately to improve the overall precision. Other reasons for separate preparation and analysis of sub-lot samples are:

— for convenience of materials handling;

— to provide progressive information on the quality of the lot;

— to provide, after division, reference or reserve samples; or

— to reduce, in the moisture test result of a large lot, any bias caused by moisture loss (or gain) due to climatic conditions.

Large primary increments may be divided at step i) before constituting a lot sample or sub-lot sample. However, this will introduce an additional source of sampling error, which can be determined. If all of the primary increment or divided primary increment is size reduced to enable further division, it is necessary to recalculate the minimum sample mass for the lot, using the nominal largest particle size of the size reduced bulk material in the formula (see A.4.3).

The initial design of a sampling scheme for a new plant or a bulk material with unfamiliar characteristics (e.g. a new material type) should, wherever possible, be based on experience with similar handling plants and material type. Alternatively, an arbitrary number of increments, for example 100, may be taken and used to determine the variability of the bulk material, but the precision of sampling cannot be determined beforehand.

Establishing a satisfactory scheme for sampling from stationary situations such as from stockpiles, stopped conveyor belts, bulk vehicles, presents particular difficulties if bias is to be avoided. Sampling in these situations should be carried out by systematic stratified sampling, but only when it can be shown that no systematic error can be introduced due to any periodic variation in quality or quantity which might coincide with, or approximate to, any multiple of the proposed sampling intervals. In the event that it is possible that systematic errors can be introduced due to periodic variations in quality or quantity, stratified random sampling should be used.

7.3 Minimisation of bias

Minimisation of bias in sampling and sample preparation is vitally important. Unlike precision, which can be improved by collecting more primary increments, by preparing more test samples, or by assaying more test portions, a bias cannot be reduced by replication. Consequently, sources of bias should be minimised or eliminated at the outset by correct design of the sampling and sample preparation system. The minimisation or elimination of possible bias should be regarded as more important than the improvement of precision.

Sources of bias that can be eliminated include sample spillage, sample contamination, and incorrect extraction of increments, while sources that can be minimised but not eliminated are, for example, net moisture flows between the sample and the outside air as well as loss of dust and particle degradation in sample preparation prior to size distribution determination.

The guiding principle to be followed is that it is essential that increments be extracted from the lot in such a manner that all parts of the bulk material have an equal opportunity of being selected and becoming part of the test sample which is used for chemical or physical testing, irrespective of the size, mass or density of individual particles. In practice, this means that a complete cross-section of the bulk material is to be taken when sampling from a moving stream, and a complete column of bulk material is to be extracted when sampling from a stationary lot.

Annex A
(normative)

Procedures for the determination of material characteristics through sampling

A.1 General

Materials and samples are assumed to follow the normal distribution.

NOTE The processes of sampling, sample preparation and measurement are experimental procedures. This Technical Specification is intended to be of practical use for all stages of the recycling process.

A.2 Independence of samples

Each increment shall be independent from another.

Samples are independent from each other, if the second measured value is not influenced by the first one.

The samples shall be taken by a periodic systematic sampling.

A.3 Representative samples

The increment taken shall be representative.

The increments are exactly representative if every material particle/grain etc. has the same probability to get into the sample.

A.4 Increments

A.4.1 General

The minimum mass of the increment shall be determined, taking account of the maximum particle size of the material in order to avoid systematic errors during sampling.

The number of increments to be taken from a test lot shall be determined taking account of deviations in the properties of the material and the desired precision of sampling.

If no information is available the minimum increment shall be 10 times the mass of the largest single particle of the lot.

A.4.2 Minimum increment mass in pneumatic systems or from falling streams

In pneumatic systems or falling streams, a minimum increment is required for flakes, agglomerates or granules, to ensure the sample is representative. For the calculation of the different minimum increment masses see ISO 11648-2:2001, 7.2.

A.4.3 Minimum increment mass for manual sampling

If the lot is static, the minimum increment is correlated to the particle size.

$$m_1 = 27\rho \cdot d^3 \cdot 10^{-6}$$

where

m_1 is the mass, expressed in kilograms, of the increment

ρ is the bulk density of the material, expressed in tonnes per cubic metre

d is the nominal top size, expressed in millimetres, of the particles of the material

In practice if the particle size is homogeneous, the increment may be determined as a volume.

For more information on the calculation of different minimum increment masses, see ISO 11648-2:2001,7.4.

A.5 Calculation of standard deviation, arithmetic mean and variance of sampling

A.5.1 General

The results of the standard deviation and arithmetic mean can be taken for the database of the Statistical Process Control (SPC).

A.5.2 Calculation of standard deviation

The experimental standard deviation and the variance can be determined by ISO 11648 (all parts).

$$s = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

A representative number of samples is required. The principal development of standard deviation 's' is shown in Annex B.

If there is no information about the statistics of the sample, the experimental standard deviation should be calculated first with a number of samples to be determined by reference to the table in Annex B.

If 's' is unknown, use the following relation for a small number of samples and then Annex B.

$$s \approx \frac{x_{max} - x_{min}}{3}$$

where

x_{max} is the maximum measured value;

x_{min} is the minimum measured value

If x_{max} or x_{min} is unknown, use a realistic estimation.

If no information about the material is available, use the absolute maximum standard deviation of 70 % and Annex C.

A.5.3 Calculation of arithmetic mean

In the normal case of sampling, where the real mean value is not known, the range of the arithmetic average of the measured parameter is determined by:

$$\mu = \bar{x}\frac{t \cdot s}{\sqrt{n}}$$

where

't' is the probability value of the Student distribution for a certain level of confidence, for example 90 %, 95 % or 99 % (use Annex C).

A.5.4 Calculation of variance of sampling

To understand the effect of changing the number of samples, see Annex C. With a number of samples 'n' the factor 't' is determined with different levels of confidence. Using an estimated or calculated standard deviation 's' it is possible to calculate the influence on the sampling by variation of the number of samples with the formula in A.5.2 (reverse calculation).

A.5.5 Confidence interval for small sample numbers

The confidence interval is given by the formula $\bar{\chi} \pm t\frac{s}{\sqrt{n}}$

A.6 Minimum number of increments

The minimum number of increments depends on the accuracy with which the parameter has to be determined.

If the standard deviation is known, use the table in Annex C.

A.7 Minimum volume of increments

With known bulk density it is possible to calculate the minimum volume of increment.

The minimum volume depends on the volume or mass of the lot, the homogeneity and the required precision of the measurement. If no specific Information is available for the lot, the minimum volume is to be determined by table in combination with the required accuracy.

The minimum volume can be determined by the multiplication of the known bulk density and the minimum increment mass (see A.4.1).

A.8 Sample mixing

With every aggregation or division of samples it is important to avoid "de-mixing" of the material.

See CEN/TS 16011 for information on sample preparation.

Annex B
(informative)

Principal development of standard deviation '*s*' as a function of number of samples '*n*'

NOTE *n* = 1 is the value of the reverse calculation in the case of the normal distribution. A standard deviation determined by only one measurement is not possible because of the definition of '*s*'.

n	*s* = 5 % (± 2,5 %)	*s* = 10 % (± 5 %)	*s* = 15 % (± 7,5 %)	*s* = 20 % (± 10 %)
1	***5***	***10***	***15***	***20***
2	3,54	7,07	10,61	14,14
3	2,89	5,77	8,66	11,55
4	2,50	5,00	7,50	10,00
5	2,24	4,47	6,71	8,94
6	2,04	4,08	6,12	8,16
7	1,89	3,78	5,67	7,56
8	1,77	3,54	5,30	7,07
9	1,67	3,33	5,00	6,67
10	1,58	3,16	4,74	6,32
11	1,51	3,02	4,52	6,03
12	1,44	2,89	4,33	5,77
13	1,39	2,77	4,16	5,55
14	1,34	2,67	4,01	5,35
15	1,29	2,58	3,87	5,16
16	1,25	2,50	3,75	5,00
17	1,21	2,43	3,64	4,85
18	1,18	2,36	3,54	4,71
19	1,15	2,29	3,44	4,59
20	1,12	2,24	3,35	4,47
21	1,09	2,18	3,27	4,36
22	1,07	2,13	3,20	4,26
23	1,04	2,09	3,13	4,17
24	1,02	2,04	3,06	4,08
25	1,00	2,00	3,00	4,00
26	0,98	1,96	2,94	3,92
27	0,96	1,92	2,89	3,85
28	0,94	1,89	2,83	3,78
29	0,93	1,86	2,79	3,71
30	0,91	1,83	2,74	3,65
40	0,79	1,58	2,37	3,16
50	0,71	1,41	2,12	2,83
60	0,65	1,29	1,94	2,58
70	0,60	1,20	1,79	2,39
80	0,56	1,12	1,68	2,24
90	0,53	1,05	1,58	2,11
100	0,50	1,00	1,50	2,00

Annex C
(informative)

Development of factor '*t*' of the Student distribution for different levels of confidence

NOTE 'n' is the number of samples. A standard deviation can be determined only by a minimum number of two samples, (because of the definition of '*s*'). By definition *df* = *n*-1, the degree of freedom in the sampling.

Number of samples	Degree of freedom (*n* – 1)	Student's *t*-Distribution, (two-tailed)				
		Confidence Intervals				
n	*df*	80 %	90 %	95 %	99 %	99,9 %
2	1	3,078	6,314	12,706	63,657	636,619
3	2	1,886	2,920	4,302	9,925	31,599
4	3	1,638	2,353	3,182	5,841	12,924
5	4	1,533	2,132	2,776	4,604	8,610
6	5	1,476	2,015	2,570	4,032	6,869
7	6	1,440	1,943	2,446	3,707	5,959
8	7	1,415	1,895	2,364	3,499	5,408
9	8	1,397	1,860	2,306	3,355	5,041
10	9	1,383	1,833	2,262	3,250	4,781
11	10	1,372	1,812	2,228	3,169	4,587
12	11	1,363	1,796	2,200	3,106	4,437
13	12	1,356	1,782	2,178	3,055	4,318
14	13	1,350	1,771	2,160	3,012	4,221
15	14	1,345	1,761	2,144	2,977	4,140
16	15	1,341	1,753	2,131	2,947	4,073
17	16	1,337	1,746	2,119	2,.921	4,015
18	17	1,333	1,740	2,109	2,898	3,965
19	18	1,330	1,734	2,100	2,878	3,922
20	19	1,328	1,729	2,093	2,861	3,883
21	20	1,325	1,725	2,085	2,845	3,850
22	21	1,323	1,721	2,079	2,831	3,819
23	22	1,321	1,717	2,073	2,819	3,792
24	23	1,319	1,714	2,068	2,807	3,768
25	24	1,318	1,711	2,063	2,797	3,745
26	25	1,316	1,708	2,059	2,787	3,725
27	26	1,315	1,706	2,055	2,779	3,707
28	27	1,314	1,703	2,051	2,771	3,690
29	28	1,313	1,701	2,048	2,763	3,674
30	29	1,311	1,699	2,045	2,756	3,659
31	30	1,310	1,697	2,042	2,750	3,646
41	40	1,303	1,684	2,021	2,704	3,551
61	60	1,296	1,671	2,000	2,660	3,460
121	120	1,289	1,658	1,980	2,617	3,373
	∞	1,282	1,645	1,960	2,576	3,291

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