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# Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation

*Systèmes de canalisations et de gaines en matières plastiques — Détermination de la résistance hydrostatique à long terme des matières thermoplastiques sous forme de tubes par extrapolation*



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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.

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

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

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

ISO 9080 was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, Subcommittee SC 5, *General properties of pipes, fittings and valves of plastic materials and their accessories — Test methods and basic specifications*.

This second edition cancels and replaces the first edition (ISO 9080:2003), which has been technically revised. The following changes have been made:



— all references to lifetime have been removed, as this standard only deals with the mathematics for extrapolation and the calculation of long-term strength;

— a more accurate description of the number and distribution of the observations and of the use of the extrapolation has been included;

— the observations in the example of Annex C have been modified in order to comply with the specifications of this standard and, consequently, the results of the regression calculations have been updated;

— a second set of observations has been added in Annex D in order to provide an evaluation according to the 3-parameter model (see Annex C), and according to the 4-parameter model (see Annex D);

— a second software package has been evaluated and included in Annex E.

 

# Introduction

## 0.1 General

This Standard Extrapolation Method (SEM) is meant to be used to evaluate the long-term hydrostatic strength of a material in pipe form. Product standards have specific requirements for the physical and mechanical properties of the material used for the intended application. It is emphasized that the Standard Extrapolation Method (SEM) described in this document is not intended to be used to disqualify existing procedures for arriving at design stresses or allowable pressures for pipelines made of plastics materials, or to disqualify pipelines made of materials proven by such procedures, for which experience over many years has been shown to be satisfactory.

Software packages have been developed for the SEM analysis as described in Annex A and Annex B. Windows-based programmes are commercially available (see Annex E). Use of these software packages is recommended.

## 0.2 Principles

The suitability of a plastics material for a pressure pipe is determined by its long-term performance under hydrostatic stress when tested in pipe form, taking into account the envisaged service conditions (e.g. temperature). For design purposes, it is conventional to express this by means of the hydrostatic (hoop) stress which a plastics pipe made of the material under consideration is expected to be able to withstand for 50 years at an ambient temperature of 20 °C using water as the internal test medium. The outside test environment can be water or air. This method is not intended to imply service life. In certain cases, it is necessary to determine the value of the hydrostatic strength at either shorter design times or higher temperatures, or on occasion both. The method given in this International Standard is designed to meet the need for both types of estimate. The result obtained will indicate the lower prediction limit (LPL), which is the lower confidence limit of the prediction of the value of the stress that can cause failure in the stated time at a stated temperature.



This International Standard provides a definitive procedure incorporating an extrapolation method using test data at different temperatures analysed by multiple linear regression analysis. The results permit the determination of material-specific design values in accordance with the procedures described in the relevant product standards.

This multiple linear regression analysis is based on the rate processes most accurately described by $\log_{10}$(stress) versus $\log_{10}$(time) models.

In order to assess the predictive value of the model used, it has been considered necessary to make use of the estimated 97,5 % lower prediction limit (LPL). The 97,5 % lower prediction limit is equivalent to the lower 97,5 % confidence limit for the predicted value. This convention is used in the mathematical calculations to be consistent with the literature. This aspect necessitates the use of statistical techniques.

The method can provide a systematic basis for the interpolation and extrapolation of stress rupture characteristics at operating conditions different from the conventional 50 years at 20 °C (see 5.1.5).

Thermoplastic materials in pipe form such as mineral filled thermoplastic polymer, fibre reinforced thermoplastics, plasticized thermoplastics, blends and alloys may have further considerations with regards to prediction of long term strength which have to be taken into account in the corresponding product standards.

It is essential that the medium used for pressurizing the pipe does not have an adverse effect on the pipe. In general, water is considered to be such a medium.

Long consideration was given to deciding which variable should be taken as the independent variable to calculate the long-term hydrostatic strength. The choice was between time and stress.

The basic question the method has to answer can be formulated in two ways, as indicated below:

a) What is the maximum stress (or pressure) that a given material in pipe form can withstand at a given temperature for a defined time?

 

b) What is the predicted time to failure for a material in pipe form at a given stress and temperature?

Both questions are relevant.

If the test data for the pipe under study does not show any scatter and if the pipe material can be described perfectly by the chosen empirical model, the regression with either time independence or stress independence will be identical. This is never the case because the circumstances of testing are never ideal nor will the material be 100 % homogeneous. The observations will therefore always show scatter. The regressions calculated using the two optional independent variables will not be identical and the difference will increase with increasing scatter.

The variable that is assumed to be most affected by the largest variability (scatter) is the time variable and it has to be considered as a dependent variable (random variable) in order to allow a correct statistical treatment of the data set in accordance with this method. However, for practical reasons, the industry prefers to present stress as a function of time as an independent variable.

## 0.3 Use of the methods

The purpose of this extrapolation method is to estimate the following:

a) The lower prediction limit[1)] (at 97,5 % probability level) of the stress which a pipe made of the material under consideration is able to withstand for 50 years at an ambient temperature of 20 °C using water or air as the test environment. In accordance with ISO 12162, the categorised value of this lower prediction limit is defined as MRS and is used for classification of the material.

b) The value of the lower prediction limit (at 97,5 % probability level) of the stress, either at different design times or at different temperatures, or on occasion both. In accordance with ISO 12162, the categorised value of this lower prediction limit is defined as CRS $\theta_{,t}$ and is used for design purposes.



There are several extrapolation models in existence, which have different numbers of terms. This SEM will use only models with two, three or four parameters.

Adding more terms could improve the fit but would also increase the uncertainty of the predictions.

The SEM describes a procedure for estimating the lower prediction limit (at 97,5 % probability level) whether a knee (which demonstrates the transition between data type A and type B) is found or not (see Annex B).

The materials are tested in pipe form for the method to be applicable.

The final result of the SEM for a specific material is the lower prediction limit (at 97,5 % probability level) of the hydrostatic strength, expressed in terms of the hoop stress, at a given time and a given temperature.

For multilayer pipes, the determination of the long-term hydrostatic pressure strength of the products is carried out in accordance with ISO 17456.

For composite and reinforced thermoplastics pipes, guidance on the use of this method is given in the product standards.

Guidance for the long-term strength of a specific material with reference lines is given in the appropriate product standard.

1) In various ISO documents, the lower prediction limit (LPL) is defined incorrectly as the lower confidence limit (LCL), where LCL is the 97,5 % lower confidence limit for the mean hydrostatic strength.

 

# Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation

## 1 Scope

This International Standard specifies a method for predicting the long-term hydrostatic strength of thermoplastics materials by statistical extrapolation. The method is applicable to all types of thermoplastics pipe at applicable temperatures. It was developed on the basis of test data from pipe systems.

## 2 Normative references

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

ISO 1167-1, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 1: General method*

ISO 1167-2, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 2: Preparation of pipe test pieces*



ISO 2507-1:1995, *Thermoplastics pipes and fittings — Vicat softening temperature — Part 1: General test method*

ISO 3126, *Plastics piping systems — Plastics piping components — Measurement and determination of dimensions*



ISO 11357-3, *Plastics — Differential scanning calorimetry (DSC) — Part 3: Determination of temperature and enthalpy of melting and crystallization*

ISO 12162, *Thermoplastics materials for pipes and fittings for pressure applications — Classification, designation and design coefficient*

ISO 17456, *Plastics piping systems — Multilayer pipes — Determination of long-term strength*

## 3 Terms and definitions

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

**3.1**
**internal pressure**
$p$
force per unit area exerted by the medium in the pipe, in bars

**3.2**
**stress**
$\sigma$
force per unit area in the wall of the pipe in the hoop (circumferential) direction due to internal pressure, in megapascals

NOTE It is derived from the internal pressure using the following simplified equation:

$$\sigma = \frac{p(d_{\text{em}} - e_{\text{y,min}})}{20 e_{\text{y,min}}}$$

where

$p$ is the internal pressure, in bars;

$d_{em}$ is the mean outside diameter of the pipe, in millimetres;

$e_{y,min}$ is the minimum measured wall thickness of the pipe, in millimetres.

**3.3**
**test temperature**
$T_t$
temperature at which stress rupture data have been determined, in degrees Celsius

**3.4**
**maximum test temperature**
$T_{t,max}$
maximum temperature at which stress rupture data have been determined, in degrees Celsius

**3.5**
**service temperature**
$T_s$
temperature at which the pipe will be used, in degrees Celsius

**3.6**
**time to failure**
$t$
time to occurrence of a leak in the pipe, in hours

**3.7**
**maximum test time**
$t_{max}$
time obtained by averaging the logarithms of the five longest times to failure, in hours



**3.8**
**extrapolation time**
$t_e$
time limit for which extrapolation is allowed, in hours

**3.9**
**long-term hydrostatic strength**
$\sigma_{LTHS}$
quantity with the dimensions of stress, which represents the predicted mean strength at a temperature $T$ and time $t$, in megapascals

**3.10**
**lower confidence limit of the predicted hydrostatic strength**
$\sigma_{LPL}$
quantity with the dimensions of stress, which represents the 97,5 % lower confidence limit of the predicted hydrostatic strength at a temperature $T$ and time $t$, in megapascals

NOTE It is given by

$$\sigma_{LPL} = \sigma(T, t, 0{,}975)$$

**3.11**
**knee, data type A, data type B**
point of intersection of two branches at the same temperature; data points used to calculate the first branch are designated as type A, data points used to calculate the second branch are designated as type B

**3.12**
**branch**
line of constant slope in the $\log_{10}$ (stress) versus $\log_{10}$ (time) plot representing the same failure mode

 

**3.13**
**extrapolation time factor**
$k_e$
factor for calculation of the extrapolation time

# 4 Acquisition of test data

## 4.1 Test conditions

The pipe stress rupture data shall be determined in accordance with ISO 1167-1 and ISO 1167-2. The determination of the resistance to internal pressure shall be carried out using straight pipes.

The mean outside diameter and minimum wall thickness of each pipe test piece shall be determined in accordance with ISO 3126.

For all calculations, the pipes tested shall be of the same nominal dimension and made from the same batch of material and come from the same production run.

For existing materials evaluated according to ISO/TR 9080:1992 or ISO 9080:2003, the initial data set may be complemented by additional data produced from other batches to meet the requirements of 4.2. In such case, the additional data should be spread regularly at each temperature and documented in the test report.

## 4.2 Distribution of internal pressure levels and time ranges



**4.2.1** For each temperature selected, a minimum of 30 observations shall be obtained, spread over the testing time. Internal pressure levels shall be selected such that at least four observations will occur above 7 000 h and at least one above 9 000 h (see also 5.1.5). In the event of prediction based on the second branch, a minimum number of 20 observations is required for the second branches, with a minimum of 5 observations per temperature.



**4.2.2** For all temperatures, times to failure up to 10 h shall be neglected.

**4.2.3** At temperatures ≤ 40 °C, times to failure up to 1 000 h may be neglected, provided that the number of remaining observations conforms to 4.2.1. In that case, at the selected temperature(s), all points below the selected time shall be discarded.

**4.2.4** Test pieces which have not failed above 1 000 h may be used as observations in the multiple linear regression computations and for the determination of the presence of a knee. Otherwise, they should be disregarded, provided that the number of remaining observations conforms to 4.2.1.

# 5 Procedure

## 5.1 Data gathering and analysis

### 5.1.1 General

The method is based on multiple linear regression and calculation details given in Annex A. It requires testing at two or more temperatures and times of 9 000 h or longer and is applicable whether or not indications are found for the presence of a knee.

### 5.1.2 Required test data

Obtain test data in accordance with Clause 4 and the following conditions, using two or more temperatures $T_1$, $T_2$, …, $T_n$:

a) Each pair of adjacent temperatures shall be separated by at least 10 °C and at most 50 °C.

b) One of the test temperatures shall be 20 °C or 23 °C.

c) The highest test temperature $T_{t,max}$ shall not exceed the Vicat softening temperature, $VST_{B50}$, determined in accordance with ISO 2507-1:1995 minus 15 °C for glassy amorphous polymers, or the melting temperature determined in accordance with ISO 11357-3 minus 15 °C for semi-crystalline polymers.

d) The number of observations and the distribution of internal pressure levels at each temperature shall conform to 4.2.

e) To obtain an optimum estimate of $\sigma_{LPL}$, the range of test temperatures shall be selected such that it includes the service temperature or range of service temperatures.

Failures resulting from contamination may be disregarded, provided that the number of remaining observations conforms to 4.2.1.

All valid data points shall be used in the calculations.

For most materials, the test environment and test temperatures are specified in the relevant product standards.

### 5.1.3 Detection of a knee and validation of data and model

Use the procedure given in Annex B to detect the presence of any knee.

After detecting a knee at any particular temperature, split the data set into two groups, one belonging to the first branch (data type A), the other belonging to the second branch (data type B).

Fit the multiple linear regression as described in Annex A independently, using all first-branch (type A) data points for all temperatures and all second-branch (type B) data points for all temperatures.



When studying the data for the occurrence of a knee, attention should be paid to the occurrence of a degradative failure. Such data (usually characterized by a nearly stress-independent line and visually recognizable) should not be considered for the calculation, but should only be used for determination of the extrapolation time (see 5.1.5).



If the automatic knee detection does obviously not correspond with the visual examination of the diagram, then the data points type A and type B in the region of the predicted knee can be manually reclassified to better align the knee point position with the data. In this case all data points at higher stresses than the stress level of the reclassified transition from type A to type B data points shall be declared type A and all data points at lower stresses shall be declared type B. The extrapolation shall be performed again without automatic knee detection. It is recommended in this case that more data points beyond the time of the predicted knee are obtained.

The reasons for following the manual procedure and details of the changes made for the analysis shall be justified and included in the test report, see Clause 7.

### 5.1.4 Visual verification

Plot the observed data points, the $\sigma_{LTHS}$ linear regression lines and the $\sigma_{LPL}$ curves as a graph on a $\log_{10}\sigma$ / $\log_{10}$ (time) scale.

### 5.1.5 Extrapolation time and extrapolation time factor

Determine the extrapolation time $t_e$ using the following information and procedures.

The time limits $t_e$ for which extrapolation is allowed, are bound to be temperature-dependent values. The extrapolation time factor $k_e$ as a function of $\Delta T$ is based on the following equation:

$$\Delta T = T_t - T$$

where

$T_t$ is the test temperature to which the extrapolation time factor $k_e$ is applied, $T_t \leq T_{t,max}$, in degrees Celsius;

$T_{t,max}$ is the maximum test temperature, in degrees Celsius;

$T$ is the temperature for which the extrapolation time is calculated, $T_s \leq T$, in degrees Celsius;

$T_s$ is the service temperature, in degrees Celsius.

Calculate the extrapolation time $t_e$, using the following equation:

$$t_e = k_e \, t_{max}$$

Obtain the maximum test time $t_{max}$, by averaging the logarithms of the five longest times to failure, which are not necessarily at the same stress level, but at the same temperature. Test pieces that have not yet failed may be considered as data points for this purpose. All those points shall belong to the population with which all calculations are performed.

If the data at the maximum test temperature are not used for determination of the regression model, these data are only used for the determination of the maximum test time $t_{max}$ and consequently for the extrapolation time $t_e$. Such choices of calculation shall be justified and reported. Extrapolation is not permitted above the temperature range of the regression model.



The data obtained may be used for predicting the strength down to 20 °C below the lowest test temperature, provided that there is no change of state of the material, e.g. glass transition.

NOTE It is recommended that test data be generated at the lowest predicted temperature to demonstrate performance.

Examples of the application of the extrapolation time factor are presented in Figures 1 to 3. Figure 2 represents the case that a knee has been detected only at the highest temperature. Figure 3 refers specifically to the case that a knee has been detected at higher temperatures. Values of the extrapolation time factor $k_e$ are assigned in 5.2 and 5.3.

NOTE In cases like Figure 2, $t_{max}$ is positioned at the time of the knee point.

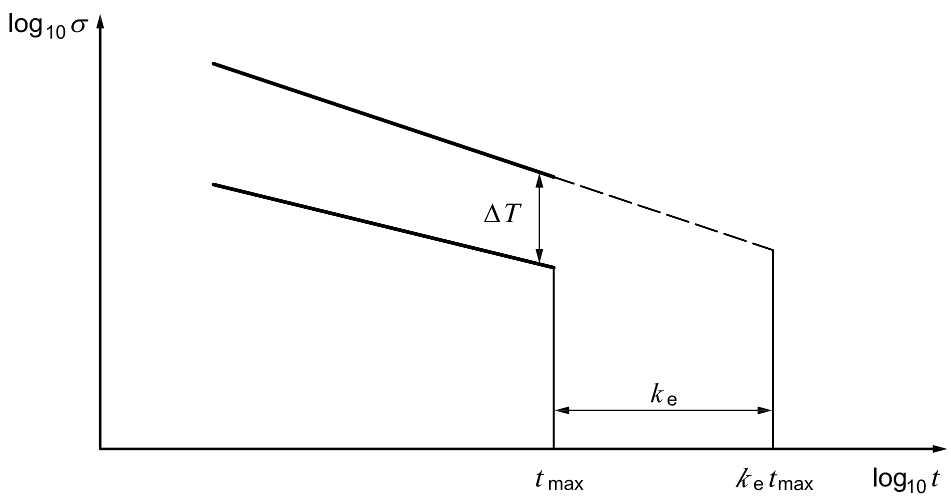


**Figure 1 — Extrapolation time in the case of extrapolation without a knee at the highest test temperature**

 

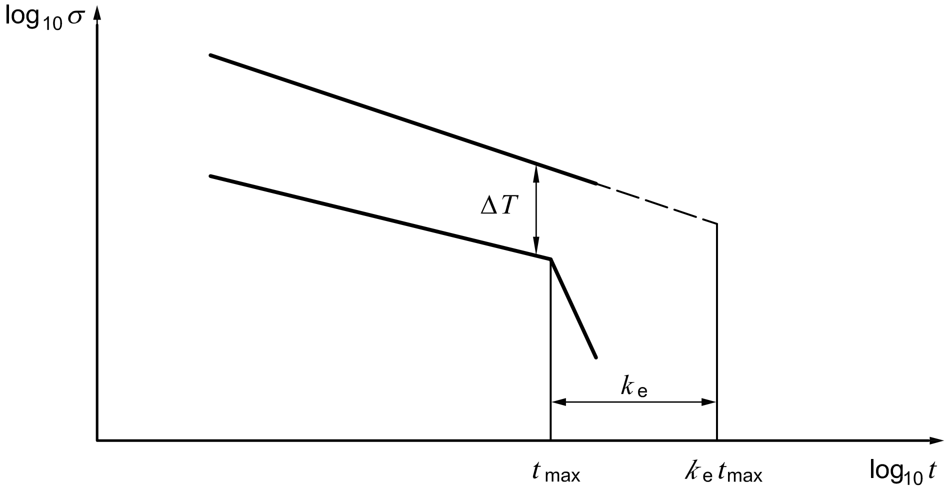


**Figure 2 — Extrapolation time in the case of extrapolation with a knee only at the highest test temperature**

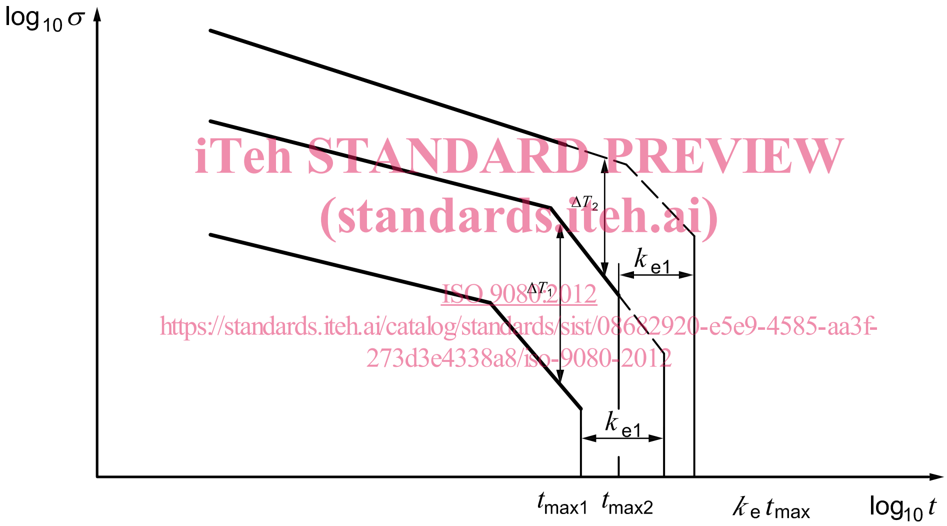




**Figure 3 — Extrapolation time in the case of extrapolation with knees at different test temperatures**

### 5.2 Extrapolation time factors for polyolefins (semi-crystalline polymers)

For extrapolation of stress rupture data of polyolefins, the extrapolation time is based on an experimentally determined time to failure at the relevant maximum test temperature and an Arrhenius equation for the temperature dependence using the apparent activation energy calculated from the third (degraded) branch of the curve for stabilized polyolefins (which is 110 kJ/mol, i.e. a conservative value for the activation energy from the third branch). This yields the extrapolation time factors $k_e$ given in Table 1.

 