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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

Reference number
ISO 9080:2003(E)

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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*.

It cancels and replaces ISO/TR 9080:1992, which has been technically revised.

Introduction

General

ISO/TR 9080, upon which this International Standard is based, is the result of considerable discussion within working group 10 of subcommittee 5 of technical committee 138 of the International Organization for Standardization (ISO) (referred to hereafter as ISO/TC 138/SC 5/WG 10), which was entrusted with the development of the standard, which represents an agreed compromise incorporating features of several accepted national procedures.

Furthermore, it is emphasized that the standard extrapolation method (SEM) described 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, which long years of experience have shown to be satisfactory. This SEM is meant to be used to qualify a material in pipe form prior to the introduction of such a material on the market.

A software package has been developed for the SEM analysis as described in Annex A and Annex B. A Windows-based programme is available on diskette (see Annex D).

NOTE Use of this software package is recommended.

Principles

The suitability for use of a plastics pressure pipe is first of all determined by the performance under stress of its material of construction, taking into account the envisaged service conditions (e.g. temperature). 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 environment can be water or air.

In certain cases, it is necessary to determine the value of the hydrostatic strength at either shorter lifetimes 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 (the ultimate stress).

NOTE The MRS value (at 20 °C) is usually based on data obtained using water as the internal and external test medium. It is obvious that indeed all data are used for validation of regression curves at higher temperatures (e.g. 70 °C), including the data obtained with air as the external medium (e.g. at 110 °C).

This International Standard provides a definitive procedure incorporating an extrapolation 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 system 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 confidence limit of the 95 % confidence interval of 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. Taking into account the extrapolation factors (see 5.1.4), the extrapolation time limit can go up to 100 years.

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 follows.

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

b) How long will a pipe system last when subjected to a defined stress (or pressure) at a given 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.

Use of the methods

This extrapolation method is designed to meet the following two requirements:

a) To estimate 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.

b) To estimate the value of the lower prediction limit (at 97,5 % probability level) of the stress, either at different lifetimes or at different temperatures, or on occasion both.

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 type A and type B crack behaviour) is found or not (see Annex B).

The materials have to be 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.

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

INTERNATIONAL STANDARD **ISO 9080:2003(E)**

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 describes a method for estimating 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. The dimensions of the pipes to be tested may be specified in the relevant product/system standards and, if so, are included in the test report.

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, *Thermoplastics pipes for the conveyance of fluids — Resistance to internal pressure — Test method*

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

ISO 3126:—[2], *Plastics piping systems — Plastics piping components — Measurement and determination of dimensions*

ISO 3146:2000, *Plastics — Determination of melting behaviour (melting temperature or melting range) of semi-crystalline polymers by capillary tube and polarizing-microscope methods*

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, in bars, exerted by the medium in the pipe

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[2] To be published. (Revision of ISO 3126:1974)

3.2
stress

σ

force per unit area, in megapascals, in the wall of the pipe in the hoop (circumferential) direction due to internal pressure

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;

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

3.3
test temperature

T_{t}

temperature, in degrees Celsius, at which stress rupture data have been determined

3.4
maximum test temperature

$T_{\text{t,max}}$

maximum temperature, in degrees Celsius, at which stress rupture data have been determined

3.5
service temperature

T_{s}

temperature, in degrees Celsius, at which the pipe will be used

3.6
failure time

t

time, in hours, to occurrence of a leak in the pipe

3.7
long-term hydrostatic strength

σ_{LTHS}

quantity, in megapascals, with the dimensions of stress, which represents the predicted mean strength at a temperature T and time t

3.8
lower confidence limit of the predicted hydrostatic strength

σ_{LPL}

quantity, in megapascals, 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

NOTE It is given by

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

3.9
knee

transition point between two modes of failure, which can be represented by a change in slope of a $\log_{10}$(stress) versus $\log_{10}$(time) plot of hydrostatic stress rupture data

3.10

branch

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

3.11

extrapolation time factor

k_e

factor for calculation of the extrapolation time limits

4 Acquisition of test data

4.1 Test conditions

The pipe stress rupture data shall be determined in accordance with ISO 1167. 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.

In cases of dispute, pipes of one diameter selected from the range 25 mm to 63 mm shall be tested. The pipes tested shall be made from the same batch of material and come from the same extrusion run.

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, regularly spread over at least five internal pressure levels. For statistical reasons, it is required that more than one observation be recorded at each internal pressure level. 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 5.1.4). In the event of the presence of a knee, a statistically adequate number of observations shall be collected for both branches, in order to ensure sufficient precision of the result.

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

4.2.3 At temperatures $\leqslant$ 40 °C, failure times up to 1 000 h may be neglected, provided that the number of remaining observations conforms to 4.2.1. In that case, all points under the selected time and temperature shall be discarded.

4.2.4 Test pieces which have not failed at the lowest internal pressure levels may be used as observations in the multiple regression computations and for the determination of the presence of a knee. Otherwise, they may be disregarded.

5 Procedure

5.1 Data gathering and analysis

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

5.1.1 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.

b) The highest test temperature $T_{\mathrm{t,max}}$ shall not exceed the Vicat softening temperature $\mathrm{VST}_{\mathrm{B.50}}$ determined in accordance with ISO 2507-1:1995 minus 15 °C for amorphous or predominantly amorphous polymers, or the melting temperature determined in accordance with ISO 3146:2000 minus 15 °C for crystalline or semi-crystalline polymers.

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

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

e) The data obtained at the lowest test temperature may be used down to 20 °C below this temperature, provided that there is no change of state of the material.

Any failures resulting from contamination shall be disregarded.

5.1.2 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, the other belonging to the second branch.

Fit the multiple linear regression as described in Annex A independently, using all first-branch failures for all temperatures and all second-branch failures for all temperatures.

When only using one temperature, the problem is reduced to simple linear regression analysis. In that case, the use of the extrapolation factor k_{e} (see 5.1.4) is not applicable.

NOTE 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 be discarded for the calculation of the creep rupture branch.

5.1.3 Visual verification

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

5.1.4 Extrapolation time limits and extrapolation time factor k_{e}

Determine the extrapolation time limits using the following information and procedures.

The time limits t_{e} for which extrapolation is allowed, are bound to temperature-dependent values. The extrapolation time factor k_{e} as a function of ΔT is based on the following equation:

$$\Delta T = T_{\mathrm{t}} - T$$

where

T_{t} is the test temperature to which the extrapolation time factor k_{e} is applied, $T_{\mathrm{t}} \leqslant T_{\mathrm{t,max}}$, in degrees Celsius;

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

T is the temperature for which the extrapolation time limit is calculated, $T_{\mathrm{s}} \leqslant T$, in degrees Celsius;

T_{s} is the service temperature, in degrees Celsius;.

Calculate the extrapolation time t_e, in hours, using the following equation:

$$t_e = k_e t_{max}$$

When t_{max} is equal to 8 760 h (1 year), k_e represents the maximum extrapolation time t_e in years, to be used only for extrapolation downwards in the temperature range. Obtain the maximum test time t_{max}, in hours, by averaging the logarithms of the five longest failure times, 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 "failures" for this purpose. All those points shall belong to the population with which all calculations are performed.

Examples of the application of the extrapolation time limits 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 factor k_e are assigned in 5.2 and 5.3.

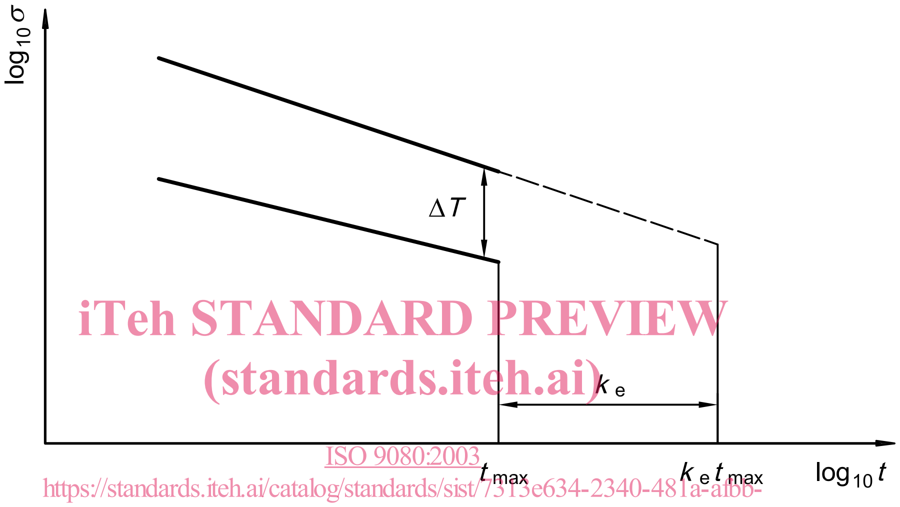

Figure 1 — Extrapolation time limits in the case of extrapolation without a knee at the highest test temperature

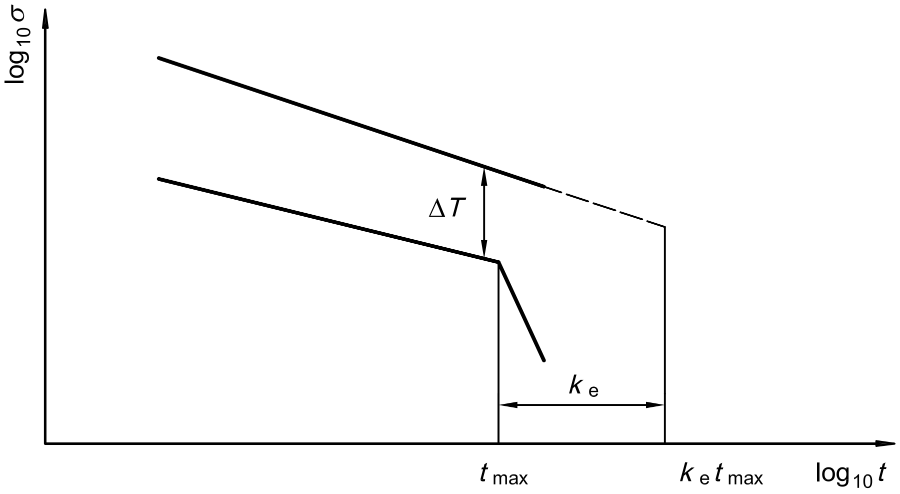

Figure 2 — Extrapolation time limits in the case of extrapolation with a knee only at the highest test temperature

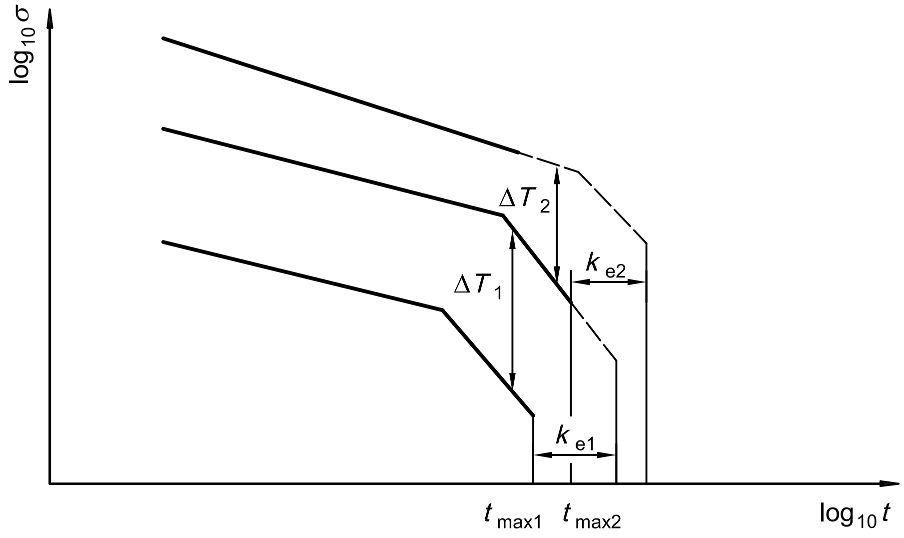

Figure 3 — Extrapolation time limits in the case of extrapolation with knees at different test temperatures

5.2 Extrapolation factors for polyolefins (crystalline or semi-crystalline polymers)

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

Table 1 — Relationship between ΔT (= $T_t - T$) and k_e for polyolefins

ΔT °C	k_e
$\geqslant$ 10 but < 15	2,5
$\geqslant$ 15 but < 20	4
$\geqslant$ 20 but < 25	6
$\geqslant$ 25 but < 30	12
$\geqslant$ 30 but < 35	18
$\geqslant$ 35 but < 40	30
$\geqslant$ 40 but < 50	50
$\geqslant$ 50	100

5.3 Extrapolation factors for glassy, amorphous vinyl chloride based polymers

For extrapolation of creep rupture data for vinyl chloride based polymers, the extrapolation time limits are based on an experimentally determined lifetime at the maximum test temperature, which is 15 °C below the Vicat softening temperature, and an Arrhenius equation for the temperature dependence, which employs the estimated activation energy calculated from the assumed second branch of the curve for vinyl chloride based polymers (which is 178 kJ/mol). This yields the extrapolation factors k_e given in Table 2.