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Thermoplastics pipes for industrial applications under pressure — Determination of the chemical resistance factor and of the basic stress —

Part 1 : Polyolefin pipes

Tubes en thermoplastiques pour les applications industrielles sous pression — Détermination du facteur de résistance chimique et de la contrainte de base — Partie 1 : Tubes en polyoléfines

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Contents

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 8584-1 was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids.*

ISO 8584 consists of the following parts, under the general title *Thermoplastics pipes for industrial applications under pressure — Determination of the chemical resistance factor and of the basic stress*:

— *Part 1: Polyolefin pipes*

— *Part 2: Pipes of halogenated polymers* [Technical Report]

Annex A forms an integral part of this part of ISO 8584. Annexes B to G are for information only.

Introduction

The design and the calculation of dimensions of pressure pipes intended for the transportation of liquids or gases is a complex task. It is necessary to take into consideration the influence of both the hydraulic properties of the liquid or gas and the material characteristics, both of which are more or less well defined and depend to a certain extent on one another. Application techniques use simplified rules which, by iterative methods, permit the best choice of the type of material and of the dimensions of the pipes, and provide an estimate of the permissible continuous pressures in the pipeline.

The resistance of a pipe to the fluids being transported by it may be expressed as a long-term chemical resistance under constant operating conditions (e.g. the type and concentration of the fluids, the temperature and the pressure).

In accordance with ISO 161-1, this part of ISO 8584 defines the development in time t of the permissible stress in the pipe wall, due to the action of a static internal pressure, as the "basic stress function":

$$\sigma_{B,\ \text{fluid, temperature, pressure}} = f(t)$$

The materials suitable for pressure pipes are divided into classes according to their nominal stress σ_N. This nominal stress corresponds to the basic stress σ_B, extrapolated to 50 years, for the case where the fluid is water at 20 °C, under nominal pressure (PN):

$$\sigma_N = \sigma_{B,\ 50,\ \text{water},\ 20\ °C,\ PN}$$

In addition to their designation according to the material and the nominal stress, pipes may be designated by a pipe series number S which corresponds to the series of wall thicknesses given in the table in ISO 4065. The definition of S is as follows:

$$S = \frac{d_e - \delta}{2\delta} = \frac{\sigma}{p}$$

where

d_e is the nominal outside diameter;

δ is the nominal wall thickness;

p is the operating pressure.

Using the nominal values, this equation then becomes

$$\sigma_N = PN \times S$$

or

$$PN = \frac{\sigma_N}{S}$$

For example, a polyethylene-based pipe designated by σ_N = 5 MPa and S5 has a nominal pressure

PN = 5/5 = 1
(corresponding to 1 MPa or 10 bar).

The design of a pressure pipe system is determined according to the differences in level, the maximum rate of discharge of fluid and other requirements of the design. The flow speed may, as a general rule and within certain limits, be chosen freely. The appropriate choice of the cross-section of the pipes (the cross-section multiplied by the speed gives the discharge of fluid), i.e. the inside diameter of the pipes in a system, enables the determination of the necessary pressure and thus the requirements for the long-term resistance of the pipes.

Once the operating pressure p as required by the hydraulic conditions, valid for all diameters, has been determined it is recommended that one chooses the series of pipe wall thicknesses which is likely to be suitable. Following this assumption, and according to the formula given above, the operating stress σ_S has the following value:

$$\sigma_S = p\mathrm{S}$$

The requirements of the material itself are then defined according to the operating stress. This stress shall be admissible for the fluid being transported at the given temperature and for the given period of time, and it is the essential criterion for the choice of the material.

The pipe series and the type of material chosen are suitable for carrying out a given project if the operating stress σ_S is equal to or less than the basic stress σ_B, as determined under the conditions specified in this part of ISO 8584:

$$\sigma_S \leqslant \sigma_B$$

If this inequality is not satisfied, it means, initially, that the choice of the pipe series is incorrect.

It is also possible to make other assumptions, starting from the basis of different data. One may make selections, for example, on the basis of the pipe series as well as on the material, or one may increase the pipe diameter so that the pipe system works at a lower pressure.

The long-term creep strength (or resistance) of thermoplastics pipes subject to internal pressure due to water has been the subject of very detailed investigation for decades. As the results show, the long-term creep strength may be represented mathematically by a regression curve of the form

$$\lg \sigma = a - b \lg t$$

In this case, the regression curve is a straight line. If the tests are performed over a long period of time at high temperatures and/or under the action of aggressive fluids, the slope of the regression curve becomes steeper. This part of ISO 8584 is applicable to the case where the long-term creep strength can be represented by a bilinear model, i.e. by a curve consisting of two straight line portions with different gradients, where each of the two straight line portions of the curve may be represented mathematically by a regression line of the form:

$$\lg \sigma = a_i - b_i \lg t$$

The first straight line portion has constants a_1 and b_1 and the second portion, with a steeper gradient, has constants a_2 and b_2. If the temperature of the water is taken as a parameter, a group of regression curves is obtained which enables one to determine the creep strength as a function of time for a given pipe material (see figure 1).

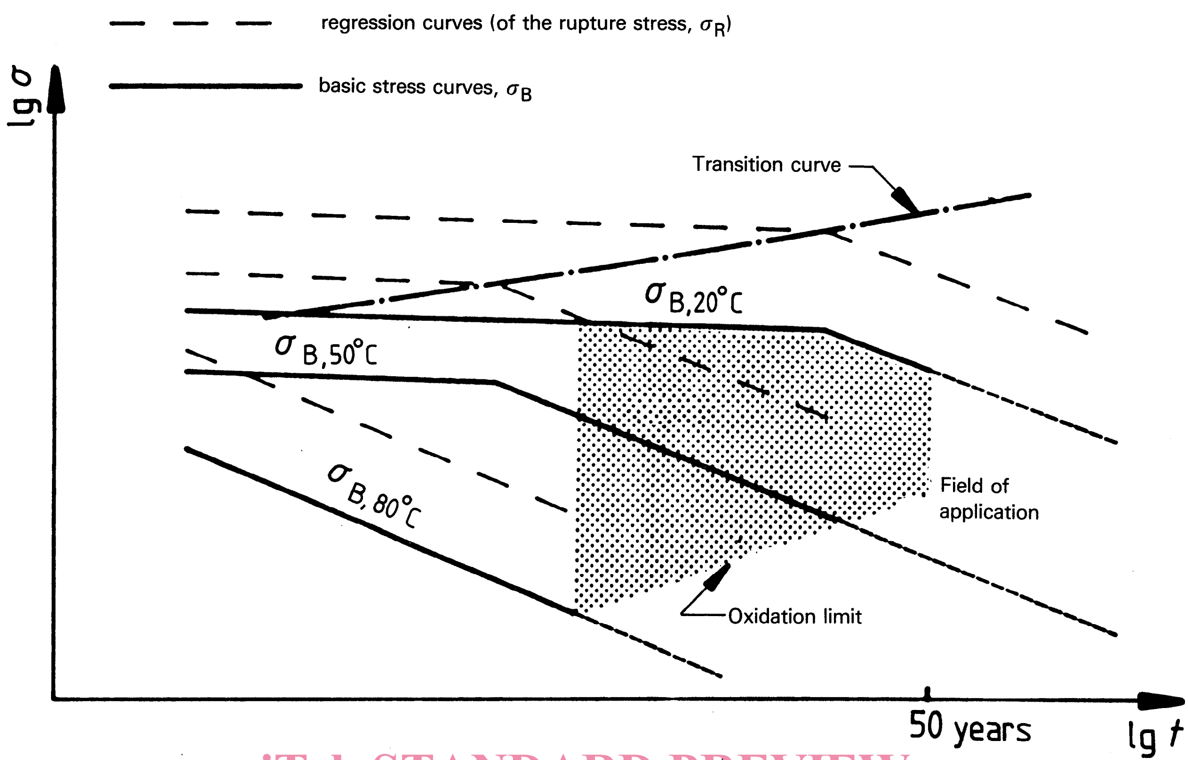

Figure 1 — Group of regression curves

The curve which connects the points of change in gradient or "transition points" of the group of regression curves, called the transition curve, represents the development of these transition points with time and temperature. The transition point is therefore located at longer times for lower temperatures.

The basic stress for an industrial application is determined from the group of rupture stress curves σ_R found by experimental tests. The corresponding values are extrapolated by taking into account the lower dispersion limit and safety factors which are fixed by agreement. The field of industrial applications (the shaded area in figure 1) is situated below the transition curve. Furthermore, it is limited by oxidation phenomena which may occur during long periods of usage at high temperatures[1].

By way of example, diagrams of such basic stresses of pipes are shown in annexes D to G. These types of long-term hoop stresses are necessary for the choice of the pipe series and the calculation of the dimensions of the pipes.

As the observed scatter of test results is high, the tests, extrapolations and classifications of each type of pipe are performed using statistical methods. A suitable method is the "standard extrapolation method", which will form the subject of ISO/TR 9080. Within the temperature ranges for each type of material, it is necessary to carry out tests at several temperatures, where any two temperatures are separated by 10 K to 20 K, for at least five stresses and for at least five test pieces per test, so that some time periods are at least 10^4 h.

1) See Gaube, Gebler, Müller, Gondro, Zeitstandfestigkeit und Alterung von Rohren aus HDPE, *Kunstoffe* **75** (1985) p. 7.

ISO 4433 describes a method of determining the resistance of polyolefin pipes to industrial products and other chemical fluids using an immersion test and provides a system for preliminary classification. The results only apply directly to non-pressure pipes. For pipes containing fluids under pressure, this method only enables one to reveal the incompatibilities between the fluid and the pipes. The resulting classification of "satisfactory resistance" or "limited resistance" shall be confirmed by tests of the long-term creep strength under pressure.

The present test method, intended for the determination of the chemical resistance factor f_{CR}, gives examples of characteristic values of creep strength which express, for a given stress and temperature, the resistance of a pipe to the fluid considered in comparison with its resistance to water.

The aim of this test method is

a) to determine the chemical resistance factor f_{CR} and the basic stress function $\sigma_B = f(t, T)$ with fluids more aggressive than water;

b) to make test periods as short as possible and to keep costs as low as possible.

In view of the countless number of fluids, concentrations and mixtures used in various industries, it is absolutely essential to have a test method and a method of extrapolation simpler than those given in ISO 1167 and by the "standard extrapolation method" respectively which are valid for water and other wide-ranging applications.

The reduction in the cost of a test is not achieved by a reduction in the number of necessary statistical tests or by applying high stresses in the area situated above the transition curve for water. The simplification sought is achieved

— by carrying out the tests at high temperatures, and

— by determining the median of the time to failure (this method consists of stopping the tests as soon as half the test pieces have failed).

The function of the basic stress with water is to enable extrapolation of the f_{CR} values. Examples of diagrams of such basic stresses are given, for information, in annexes D to G. When the results are applied to pipes of greater wall thickness, the differences in the structure and the internal stresses induced in the walls of such pipes are taken into account.

The basic stress σ_B estimated from the tests and extrapolation serves as a basis for the calculation of the permissible stress. By definition, σ_B does not take into account

a) additional loads and various influences due to the fluids and temperatures which, depending on the case in hand, may exert a stress in addition to that of the pressure;

b) the physical or chemical influence of the environment, or any special safety requirements.

It is up to experts to estimate the influence of these additional factors and to introduce them into the calculations.

Thermoplastics pipes for industrial applications under pressure — Determination of the chemical resistance factor and of the basic stress —

Part 1 : Polyolefin pipes

1 Scope

1.1 This part of ISO 8584 defines the basic stress σ_B as the reference value for determining the series S of polyolefin pressure pipes and makes use of the classification of pipes according to their nominal stress σ_N.

1.2 For applications in the water industry, this part of ISO 8584

— gives examples of the possible basic stress as a function of time and temperature for polyolefin pipes and

— provides the design engineer with a method to study the field of application of each class of pipes and how the basic stress can develop, with the aid of diagrams and tables.

1.3 As far as applications in the chemical industry are concerned, this part of ISO 8584

— defines the chemical resistance factor f_{CR},

— specifies the test method to determine f_{CR},

— specifies a method of extrapolation to estimate the development of the basic stress in the case of an aggressive fluid, and

— illustrates in annex A a simplified laboratory apparatus, resistant to corrosion, for use on pipes of 12 mm and 8 mm in diameter.

1.4 This part of ISO 8584 may be applied in a similar manner to pipes made of other materials whose regression curves can be represented by a bilinear model. The method of extrapolation assumes knowledge of the basic stress function $\sigma_B = f(t, T)$ with water.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 8584. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 8584 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 3:1973, *Preferred numbers — Series of preferred numbers.*

ISO 161-1:1978, *Thermoplastics pipes for the transport of fluids — Nominal outside diameters and nominal pressures — Part 1: Metric series.*

ISO 1167:1973, *Plastics pipes for the transport of fluids — Determination of the resistance to internal pressure.*

ISO 3126:1974, *Plastics pipes — Measurement of dimensions.*

ISO 4065:1978, *Thermoplastic pipes — Universal wall thickness table.*

ISO 4433:1984, *Polyolefin pipes — Resistance to chemical fluids — Immersion test method — System for preliminary classification.*

ISO/TR 9080: —[1], *Plastics pipes for the transport of fluids — Standard extrapolation method for the long term resistance to constant internal pressure.*

3 Definitions

3.1 basic stress, σ_B: Stress sustained in continuous operation, without failure and with an appropriate safety factor, during a given period by the wall of a pipe exposed to a fluid under static pressure.

1) To be published.

It is calculated using

- the creep strength with water, determined experimentally according to the "standard extrapolation method" (see ISO/TR 9080),
- a conventional safety coefficient C, and
- a chemical resistance factor f_{CR} determined according to this part of ISO 8584 ($f_{CR} = 1$ for water).

The safety coefficient C takes into account the composition of the basic material (and its normal variation), any accidental differences in manufacturing conditions and, as a result, any variations in quality of a batch of pipes compared with the test results.

3.2 basic stress function, $\sigma_B = f(t, T)$: The variation in σ_B with time of a pipe in continuous operation under the influence of a given fluid, and with the temperature as a parameter.

The group of curves thus defined represents the entire behaviour of a pipe under internal pressure, as a function of time and temperature, under the influence of a given fluid.

3.3 chemical resistance factor, f_{CR}: For a given test stress σ_e and temperature T, the ratio of the median failure times of two series of 10 test pieces taken from the same pipe and filled respectively with water and a chemical fluid, i.e.

$$f_{CR} = \frac{t_{M,\,fluid}}{t_{M,\,water}}$$

where

$t_{M,\,fluid}$ is the median failure time of the test pieces containing chemical fluid, in hours;

$t_{M,\,water}$ is the median failure time of the test pieces containing water, in hours.

NOTE — Extrapolation may be carried out only if the median failure times (and f_{CR} values) thus determined lie on the second straight line portion of the group of regression curves representing the basic stress versus time (see 3.2).

3.4 creep strength time, t_R, until failure: Time interval between the application of pressure and the appearance of a leak (failure) which is due either to bursting or cracking under stress or to weeping.

3.5 mathematical model of the median failure time, $t_M = f(\sigma_e)$: The median failure times t_M of a series of test stresses σ_e follow the law of regression represented by the following model:

$$\lg \sigma_e = a_i - b_i \lg t_M$$

For polyolefins, as for other known thermoplastics, this regression curve comprises an initial linear straight line portion with a low gradient (a_1, b_1), a point of change in gradient followed by another linear straight line portion with a steeper gradient (a_2, b_2), i.e. $a_2 > a_1$ and $b_2 > b_1$.

NOTE — If the test results are not scattered, and if the pipe material can be perfectly described by the empirical model chosen, the regression $t_M = f(\sigma_e)$ is equivalent to that of $\sigma_e = f(t_M)$. However, this is never the case as the material is never 100 % homogeneous: the model is an ideal case for, in reality, the results are scattered.

The two regressions are therefore not equivalent, and the difference between them increases with the degree of scatter. In the "standard extrapolation method", the stress is chosen as an independent variable [$t_M = f(\sigma_e)$] and it is possible to show that the calculations made according to this method give less optimistic extrapolated results (see ISO/TR 9080).

3.6 median failure time, t_M: For a total of 10 test pieces of the same dimensions, which are subjected simultaneously to a given test stress σ_e, the geometric mean of the times to failure t_R of the fifth and sixth test pieces, i.e.

$$\lg t_M = \frac{\lg t_{R5} + \lg t_{R6}}{2}$$

The test for any particular pressure value is stopped as soon as the sixth test piece fails; the results which would be obtained for the remaining four test pieces are not necessary.

3.7 nominal stress, σ_N: The basic stress of a pipe containing water at 20 °C under the nominal pressure PN, extrapolated to 50 years.

3.8 test stress, σ_e: Circumferential stress (the axial stress is equal to half the circumferential stress) induced in the middle of the wall of a test piece which is closed at both ends and subject to internal pressure.

This conventional stress is calculated from the pressure according to the following equation taken from ISO 1167 :

$$\sigma_e = p_e \frac{\bar{d}_{max} - \delta_{min}}{2\delta_{min}}$$

where

σ_e is the test stress, in megapascals or newtons per square millimetre;

p_e is the test pressure, in megapascals;

$\bar{d}_{max}$ is the maximum value of the mean outside diameter, in millimetres (determined from the circumference divided by π);

δ_{min} is the minimum wall thickness of the test piece, in millimetres.

NOTE — For chemical resistance creep tests, the pipes contain the chemical fluid being used for the test and are placed in air or water.

3.9 transition curve, $(\sigma_l, t_l) = f(T)$: The curve representing the variation in (σ_l, t_l) as a function of the temperature, where (σ_l, t_l) are the coordinates of the point of change in gradient (or transition point) of the bilinear regression curves describing the long-term creep strength.

The position of the transition point moves towards shorter times and lower stresses as the temperature increases.

NOTE — The elaboration of a test method which enables extrapolation to industrial operating conditions is related to the fact that it is necessary to obtain a sufficient number of points beyond the transition curve (i.e. $t_M > t_l$).

The shape of the creep strength curve excludes the possibility of reducing the test period by applying stresses in the area above the transition curve for water. To reduce the test period, it is possible to take measurements at high temperatures as indicated in table 2.

4 Principle

Comparison, using creep strength tests on pipes taken from the same manufacturing batch, of the resistance of a pipe to chemical products with its resistance to water. The basic stress values of pipes containing water serve as a reference for the choice of test stresses to be used for pipes containing the fluid under consideration.

This part of ISO 8584 is thus based on the principle that to have a good resistance to chemical products, a pipe must have a good resistance to water.

This part of ISO 8584 gives examples of basic stress values of pipes containing water, classified according to the nominal stress (see introduction) and shows how such data can be used as a basis for establishing the dimensions of pressure pipes (see annexes D to G).

The determination of the stress resistance is carried out in accordance with ISO 1167. The liquid is introduced into sections of the pipe, which are themselves placed in air or water and subjected to a constant internal pressure at a constant temperature until failure. The tests are carried out at several stress levels and at two different temperatures, to determine the possible influence of these two parameters.

It is then possible to determine a correlation factor from the times to failure observed with a chemical product and with water for a given test stress and temperature. This correlation factor is called the "chemical resistance factor" f_{CR} (see 3.3). The chemical resistance factor f_{CR} varies from 0 to 1 depending on the chemical product. The value 1 corresponds to the case where water and the chemical reagent have the same behaviour.

For extrapolation to operating conditions, the basic stress function for pipes containing water is taken as the reference. The basic stress of a pipe containing a given fluid for an expected period of use and the pipe series may be determined from the value of f_{CR}.

5 Apparatus

The apparatus is in principle identical with that described in ISO 1167 and consists of the following parts.

5.1 Connections, fixed rigidly in the top of the pipe and enabling it to be attached to a pressure device [see ISO 1167 : 1973, figure 1a)].

These connections and the system for closing the bottom of the pipe shall be compatible with the chemical fluid and with the pipe under test. The leakproofness of the lower end of the pipe may be ensured by welding on a cap of suitable thickness.

5.2 Suitable pressure device, allowing the required pressure to be applied gradually and smoothly and to be maintained constant within ± 1 % throughout the test.

In the case of a set of pipes simultaneously put under pressure, the failure of one pipe shall not affect the others. Short interruptions are permitted, particularly to restore the level of the chemical fluid in the pipe.

5.3 Manometers, with suitable scales, to monitor the pressure of the test pieces and to permit a reading to ± 1 %.

5.4 Heating system, capable of heating the test pieces to the desired temperature and maintaining this temperature constant to within ± 1 K.

6 Test pieces

6.1 General requirements

The pipes shall fulfil the quality and dimensional tolerance requirements as specified in the relevant product standard. Comparative tests with water and the chemical fluid shall be carried out on pipes from the same manufacturing batch. The test pieces shall consist of sections of pipe, whose ends shall be smooth and cut square.

6.2 Sampling

The test pieces shall be taken either from batches of current production pipes, having a thickness close to that suitable for the proposed application, or from specially prepared and conditioned pipes having dimensions of 12 mm × 1 mm or 8 mm × 1 mm (see 6.5.2).

6.3 Free length

The free length of the test pieces between the connections shall comply with ISO 1167, i.e. it shall be greater than or equal to three times the outside diameter of the pipe, with a minimum value of 250 mm.

6.4 Number of test pieces

For the creep strength tests with water and the chemical fluid, the miminum number of test pieces per stress and temperature test shall be 10.