INTERNATIONAL STANDARD

ISO 13760

First edition
1998-05-15

Plastics pipes for the conveyance of fluids under pressure — Miner's rule — Calculation method for cumulative damage

Tubes en matières plastiques pour le transport des fluides sous pression — Règle de Miner — Méthode de calcul du cumul des dommages

Reference number
ISO 13760:1998(E)

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 voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 13760 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.*

Annexes A, B and C of this International Standard are for information only.

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

Printed in Switzerland

Plastics pipes for the conveyance of fluids under pressure — Miner's rule — Calculation method for cumulative damage

1 Scope

This International Standard specifies a method for calculating the maximum allowable hoop stress applicable to pipes exposed to varying internal pressures and/or temperatures during their expected lifetime. This method is generally known as Miner's rule.

It is necessary to apply Miner's rule to each failure mechanism separately. Thus, for mechanical failure due to internal pressure, other failure mechanisms, such as oxidative or dehydrochlorinative degradative failure mechanisms, are to be neglected (assuming, of course, no interaction). A material may be used only when it is proven to conform to all failure mechanism criteria.

NOTE — Miner's rule is an empirically based procedure, and is only a first approximation to reality.

2 Normative reference

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

ISO 10508:1995, *Thermoplastics pipes and fittings for hot and cold water systems.*

3 Symbols and abbreviated terms

For the purposes of this International Standard, the following symbols and abbreviations apply:

a_i fraction of a year, expressed as a percentage, when referring to set of conditions "*i*";

t_i lifetime under a specified set of conditions "*i*" (i = 1, 2, 3, etc.) expressed in years;

t_m lifetime at malfunction temperature T_m as defined in ISO 10508;

t_{max} lifetime at maximum operating temperature T_{max} as defined in ISO 10508;

t_o lifetime at operating temperature T_o as defined in ISO 10508;

t_x maximum permissible time of use under varying conditions, expressed in years;

TYD total yearly damage, expressed as a percentage.

4 Principle

Miner's rule is based on the following assumptions:

a) The total damage a material or product is allowed to suffer from a certain type of attack is constant (100 %).

b) Under constant conditions, the damage done is proportional to the duration of the attack. The material or product will last till the 100 % damage level has been reached. The time needed for this is called t_i, in this context expressed in years. Per year, the amount of damage done is $\frac{100}{t_i}$ % .

This is the **proportionality rule**.

NOTE — The amount of damage is not necessarily visible or measurable; it may, e.g., also be the passing of an induction time.

c) If a material is exposed to attack for only part of a year (say a_i % of the year, instead of 100 % of the year), the yearly damage is not $\frac{100}{t_i}$ % but $\frac{a}{t_i}$ %. This follows from the proportionality rule.

d) In the case of damage of the same type but under varyious sets of conditions (differing severity, temperature, pressure, stress, etc.), one after the other, the total damage per year will be the combined effect of the various sets of conditions. The **additivity rule** states that the separate amounts of damage may be added. The result is the **cumulative damage** under varying conditions.

5 Procedure

Calculate the total yearly damage (TYD) using the following equation:

$$\mathrm{TYD} = \sum \frac{a_i}{t_i} \tag{1}$$

expressed as a percentage of the total permissible damage.

Calculate the maximum permissible time of use t_x, in years, using the following equation:

$$t_x = \frac{100}{\mathrm{TYD}} \tag{2}$$

NOTE — See annex A for example calculations and annex B for the assessment of oxidative stability.

Annex A
(informative)

Examples of the use of Miner's rule

A.1 Example of varying conditions

An illustrative example is provided by the calculation of the expected service life of hot-water pipes, viz: class 2 as defined in ISO 10508.

This International Standard specifies, during a 50-year service life, a temperature profile consisting of 49 years at the standard operating temperature T_0 of 70 °C, 1 year at the maximum operating temperature T_{max} of 80 °C and 100 h at the malfunction temperature T_m of 95 °C to allow for heater control faults.

To derive the proper wall thickness (or rather the ratio SDR, i.e. the diameter/wall thickness ratio), it is necessary to know the maximum permissible hoop stress in the pipe wall that will withstand the given conditions. However, the proposed class specifications state that, in the case of polybutylene for instance, a safety factor of 1,5 is to be applied to the stress at T_0, a safety factor of 1,3 to the stress at T_{max} and a safety factor of 1,0 to the stress at T_m (this already being a safety factor in itself).

For the actual calculation, an educated guess is made of the acceptable design stress σ and the expected lifetime t_0 determined when the pipe is exposed continuously to 1,5 $\times$ σ and a temperature T_0 of 70 °C, and likewise t_{max} determined at 1,3 $\times$ σ and T_{max} = 80 °C and t_m at σ and T_m = 95 °C.

These expected lifetimes t_i are determined graphically or calculated from equations such as those given in ISO/TR 9080.

The factors a_i are 98 %, 2 % and 0,022 8 %, respectively. Substituting these and the values for t_i (the subscript "i" standing for the three components of the temperature curve) in equation (1) yields the TYD.

The maximum time that the pipe may be used is given by $t_x = \dfrac{100}{\text{TYD}}$ years.

If this time t_x is higher or lower than required (in this case 50 years), the operating stress σ may be chosen to be higher or lower. Selection of a new operating stress requires a complete recalculation, until by successive approximations the correct value of t_x has been found.

The practice of successive approximations is most easily carried out with a computer. A spreadsheet is a convenient tool, especially when the expected failure times at different temperatures and hoop stresses can be calculated with a model, such as that used in ISO/TR 9080.

$$\lg t = A + \frac{B}{T} \lg\sigma + \frac{C}{T} + D \lg\sigma$$

Using the coefficients that describe lg t as a function of σ and T, a spreadsheet algorithm will easily give t_x as a function of σ.

A.2 Example of an actual calculation

Using for an actual calculation the hoop stress data for polybutylene pipes (ISO 1167 and ISO 12230), start with e.g. σ = 5,0 MPa and change this value to a higher one if the resulting time t_x is too long, and *vice versa*. The values for t (t_0, t_{max} and t_m) are obtained using the equations given in ISO 12230. The calculation is carried out using hours as the unit of time because that is the normal unit in hoop stress diagrams. The final result is converted into years.

A few steps in the calculation are shown in table A.1. For the actual calculation of t_x, more decimal places were used than are given here.

Table A.1 — Example of actual use of Miner's rule

σ MPa	$1,5 \times \sigma$ MPa	T_o °C	t_o h	a_o %	a_o/T_o %/h	$1,3 \times \sigma$ MPa	T_{max} °C	t_{max} h	a_{max} %	a_{max}/t_{max} %/h	T_m °C	t_m h	a_m %	a_m/t_m %/h	$\Sigma (a_i/t_i)$ %/h	t_x yrs
5,0	7,5	70	$5,5 \times 10^5$	97,98	$1,8 \times 10^{-4}$	6,5	80	$1,4 \times 10^5$	2	$1,4 \times 10^{-5}$	95	$10,5 \times 10^3$	0,022 8	$2,2 \times 10^{-6}$	$1,9 \times 10^{-4}$	58,9
5,1	7,65		$3,7 \times 10^5$		$2,6 \times 10^{-4}$	6,63		$1,0 \times 10^5$		$2,0 \times 10^{-5}$		$8,2 \times 10^3$		$2,8 \times 10^{-6}$	$2,9 \times 10^{-4}$	39,9
5,04	7,56		$4,7 \times 10^5$		$2,1 \times 10^{-4}$	6,55		$1,2 \times 10^5$		$1,6 \times 10^{-5}$		$9,5 \times 10^3$		$2,4 \times 10^{-6}$	$2,3 \times 10^{-4}$	50,4

The result is that, for a service life of 50 years, PB pipes may have a design stress of $\leqslant$ 5,04 MPa in order to conform to the requirements of class 2 as defined in ISO 10508.

Annex B
(informative)

Miner's rule and oxidative stability

The oxidative stability of polyolefins in the range 60 °C to 120 °C is usually very well described by a single Arrhenius equation:

$$t(T) = Ae^{E/RT} \tag{B.1}$$

where

t is the oxidative lifetime at temperature T;

T is the temperature, in kelvins;

A is a constant for a given reaction;

E is the activation energy;

R is the gas constant (≈ 8,32 J/mol·K).

The activation energies found so far for polyolefins between 60 °C and 120 °C all range around 110 kJ/mol.

In ISO/TR 9080, a time extrapolation factor K_e of 50 is applied going from 110 °C to 70 °C or 75 °C, which is equivalent to an activation energy of 107 kJ/mol or 125 kJ/mol. The extrapolation factor is for an extrapolation in time: 1 year at, say, 110 °C corresponds to K_e years at a lower temperature, where K_e is the extrapolation factor, which depends on the temperature difference.

It is recommended that the value of 110 kJ/mol be used unless experimental data indicate otherwise. This represents a conservative (safe) approach.

Equation B.1 enables extrapolation factors to be calculated at various temperatures (more precisely temperature differences, such as from 110 °C to 70 °C). When the oxidative life at a certain control point, say 110 °C, is known from experiment, multiplying by these extrapolation factors then yields the expected oxidative life at each lower temperature. These lifetimes can be inserted in Miner's equation, allowing the expected oxidative life to be derived for a given temperature profile.

Since all these lifetimes are proportional to the oxidative life at the control point, the result obtained using Miner's rule (the calculated lifetime for the temperature profile) is also proportional to $t_{110\ °C}$. The net result, therefore, is an extrapolation factor for the profile, and the oxidative life of a pipe or fitting for the profile is equal to the oxidative life at 110 °C multiplied by the extrapolation factor for that profile.

Consequently, when an oxidative extrapolation factor is used which is > 50, the oxidative life for the temperature profile concerned will be more than 50 years (the standard requirement for oxidative life at 110 °C is 1 year). Conversely, when an oxidative extrapolation factor is used which is < 50, a 110 °C lifetime of > 1 year is necessary for a design period of 50 years.

The oxidative extrapolation factor for the temperature profile corresponding to class 2 as defined in ISO 10508 is 52.

Annex C
(informative)

Bibliography

[1] ISO 1167:1996, *Thermoplastics pipes for the conveyance of fluids — Resistance to internal pressure — Test method.*

[2] ISO/TR 9080:1992, *Thermoplastics pipes for the transport of fluids — Methods of extrapolation of hydrostatic stress rupture data to determine the long-term hydrostatic strength of thermoplastics pipe materials.*

[3] ISO 12230:1996, *Polybutene (PB) pipes — Effect of time and temperature on the expected strength.*

[4] The original article by M.A. Miner, "*How cumulative damage affects fatigue life*" (Machine Design, December 1945, pp. 111-115), deals with fatigue analysis at various stress levels. Experimental verification has been carried out on an aluminium alloy.

[5] In Germany, Miner's rule is incorporated in Richtlinie (Guide) DVS 2205, Part 1 (November 1985), for thermoplastics pipes.