Technical Bulletin: Standards governing the performance of plastic pipes

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1 Introduction.

This bulletin presents a summary of the international standards that govern the evaluation, classification and use of plastics - with a special interest in polyethylene - for the manufacture of pipes. The review was specifically oriented towards the ISO standard, by including the main standards that define the testing procedures, statistical analysis and classification nomenclature of plastic materials for the manufacture of pipes, as well as the inclusion of some of the auxiliary standards, whose relevance in the application of the main rule requires devoting space for its explanation.
From the revision of the ISO standard, the fundamental standards for the evaluation of plastic materials dedicated to the manufacture of pipes and the standards specifically dedicated to polyethylene pipes were identified, namely:

- **ISO 12162**: Thermoplastic materials for pipes and connections for pressure applications - Classification and designation - Global design coefficient.
- **ISO 9080**: Thermoplastic pipes for the transport of fluids. Extrapolation methods of hydrostatic stress data at rupture to determine the long-term hydrostatic strength of thermoplastic materials for pipes.
- **ISO 1167:** Thermoplastic pipes for the transport of fluids - Resistance to internal pressure - Test method.
- **ISO 4427:** Polyethylene pipes for water supply - Specifications.
- **ISO 4437:** Buried polyethylene pipes for the supply of gaseous fuels - Metric series - Specifications.
- **ISO 13477**: Thermoplastic pipes for the transport of fluids - Determination of resistance to rapid crack propagation (RCP, Rapid Crack Propagation) - Small-scale tests in steady state (test S4).
- **ISO 10837**: Determination of the thermal stability of polyethylene (PE) for use in gas pipes and connections.
- **ISO 11420**: Method for the evaluation of the degree of dispersion of carbon black in pipes, connections and compounds made with polyolefins.
- **ISO 13478**: Thermoplastic pipes for the transport of fluids - Determination of resistance to rapid crack propagation (RCP) - Full-Scale Tests (FST, Full-Scale Test).
- **ISO 13479**: Polyolefin pipes for the transport of fluids - Determination of resistance to crack propagation - Test method for slow growth of cracks in grooved pipes (slot test).
- **ISO 13949**: Method for the evaluation of the degree of dispersion of pigments in pipes, connections and compounds made with polyolefins.

2 General principles and standards that govern the performance of plastic pipes.

The feasibility of using a pressurized plastic pipe is determined, in the first instance, by the performance under stress of the construction material, taking into account the expected conditions of service (for example, high temperature, pressure levels, etc.).

2.1 ISO 12162 standard

This is the standard that regulates the classification and designation of thermoplastic materials used in the manufacture of pipes and connections for pressure applications. This standard also provides a method for calculating design stress.

The classification, material designation and calculation method are based on the resistance to internal pressure with water at 20°C for a period of 50 years, derived by extrapolation using the method specified in ISO 9080.

2.1.1 Standards of reference

ISO 3: Preferred Numbers - Preferred Number Series.

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- **ISO 497**: Guide to the Selection of Preferred Number Series and Series Containing More Rounded Values of Preferred Numbers. $\sigma_S =$

- **ISO 1043-1**: Plastics - Symbols - Part 1: Basic polymers and their special characteristics.

- **ISO 9080**: Thermoplastic pipes for the transport of fluids - Methods of extrapolation of hydrostatic stress rupture data to determine the long-term hydrostatic resistance of pipe materials.

2.1.2 Definitions:

a) Long-term resistance at 20°C for 50 years, σ_{LTHS}: Quantity, with stress dimensions in MPa, that can be considered as a material property and represents the 50% lower confidence limit for long-term strength. σ_{LTHS} is equal to the mean strength or the predicted mean strength at 20°C for 50 years with internal pressure with water.

b) Lower confidence limit at 20°C for 50 years, σ_{LCL}: Quantity, with stress dimensions in MPa, that can be considered a property of the material and representing the lower limit of the confidence interval at 97.5% long-term average stress at 20°C for 50 years with internal pressure with water.

c) Minimum resistance required (MRS): Value of σ_{LCL} rounded to the nearest smaller of the R10 series or the R20 series, in accordance with ISO 3 and ISO 497, depending on the value of σ_{LCL}.

d) Global service (design) coefficient, C: Global coefficient with a value greater than 1, which considers the service conditions, as well as the properties of the components of a piping system, in addition to those represented in the lower confidence limit.

e) Design effort, σ_s: Effort allowed for a given application. It is derived by dividing the MRS by the global service coefficient C, then rounding to the nearest lower value in the R20 series.

$$\sigma S = \frac{[MRS]}{C}$$

2.2 Use of the SEM method (Standard Extrapolation Method). ISO 9080 standard:

The standard extrapolation method (which we will call SEM to maintain the nomenclature of the norm), is used to satisfy two basic requirements:

- To estimate the average annular stress that the pipe material under consideration is capable of withstanding for 50 years at an ambient temperature of 20°C using water as the test environment (σ_{LTHS}).

- To estimate the value of the average annular stress at shorter lifetimes, higher temperatures, or both conditions combined.

The final result of the SEM method for a specific material is the value of σLTHS and/or the value of σLCL (lower limit of the confidence interval for σLTHS). The value of the maximum resistance required (MRS) is obtained from the value of σLCL. The SEM method does not establish the procedure to find the allowable design stress, nor does it specify the safety factors to be used.

The models used by the SEM are divided into type I and type II. Type I are the constant slope models, while Type II are discontinuous change, constant slope models.

2.2.1 Type I models

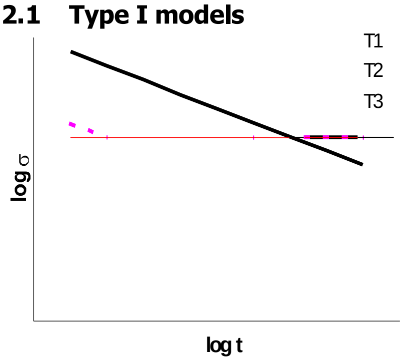

Figure 1. Schematic representation of the three-parameter Q1 model with constant slope.

The QI model equation consists of three parameters A, B and C, according to the following expression:

$$\log t = -A - \frac{B}{T}\log\sigma + \frac{C}{T}$$

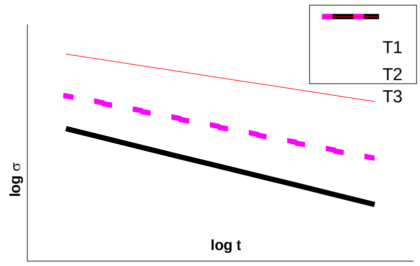

Figure 2. Schematic representation of the four-parameter RI model with constant slope.

2.2.2 Type II models

The RI model equation consists of four parameters A, B, C and D, according to the following expression:

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

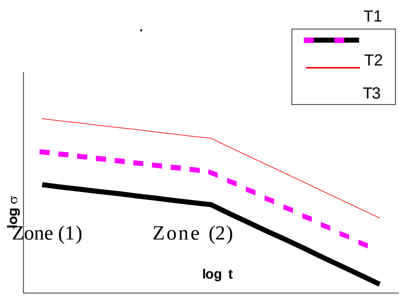

Figure 3. Schematic representation of the six-parameter QII model with discontinuous change of constant slope

The QII model equation consists of six parameters A_1, B_1, C_1, A_2, B_2 y C_2, according to the following expression:

$$\log t = -A_1 - \frac{B_1}{T}\log\sigma + \frac{C_1}{T}$$

for the area (1)

$$\log t = -A_2 - \frac{B_2}{T}\log\sigma + \frac{C_2}{T}$$

for the area (2).

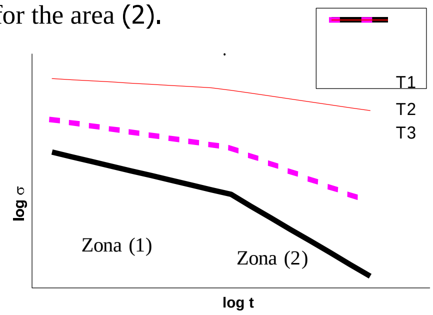

Figure 4. Schematic representation of the eight-parameter RII model with discontinuous change of constant slope

The RII model equation consists of eight parameters A_1, B_1, C_1, D_1, A_2, B_2, C_2 y D_2 according to the following expression:

$$\log t \; -A_1 - \frac{B_1}{T\,T}\log\sigma + \frac{C_1}{T} + D_1\log\sigma$$

for the area (1)

$$\log t = -A_2 - \frac{B_2}{T}\log\sigma + \frac{C_2}{T} + D_2\log\sigma$$

for the area (2)

Breaking stress data should be determined using **ISO 1167**, except in cases where there is conflict with the SEM method.

The liquid that exerts the internal pressure in the pipe can be water or any other liquid that does not chemically attack the pipe material or induce its degradation. The external environment of the pipe can be air, water or any other liquid with the previously exposed restrictions.

The internal and external temperatures must be kept within ±1°C of the set temperature value for the test.

The tube measurements (external diameter and wall thickness) must be taken in accordance with the provisions of **ISO 3126**.

2.2.3 Distribution of pressure levels

For each temperature value selected, there is a minimum of 25 stress-time failure points, according to the following table:

Table 1. Distribution of pressure levels for hydrostatic tests

Hours	Failure Data
10-100	At least 8
100-1000	At least 8
More of 1000	At least 9
More of 7000	At least 4
More of 9000	At least 1

2.2.4 Selection of data collection and analysis methods.

The **ISO 9080** standard presents two methods to obtain the long-term hydrostatic stress, ($\sigma LTHS$). These methods are called Method I and Method II.

Method I is the most complete to determine the characteristics of rupture under pressure. This method requires data collection at various temperatures and for time periods of one year or more and is applicable whether or not there is a change in the slope of the curve. The risk that the actual behavior deviates from the prediction of the extrapolation method is minimal, although it is not zero. **Method I is appropriate for determining the rupture characteristics of new materials.**

Method II requires a smaller range of experimental values than method I in the number of temperature levels evaluated and the data must not show any sign of change in slope. This method is most suitable for the evaluation of new varieties of well-known materials, in which the polymer has not been altered (for example, a material previously evaluated to which the proportion of some of its additives has been modified).

2.2.5 Description of Method I

Data are obtained, according to the procedure and conditions described above, for a minimum of three temperatures T1, T2, T3,.TN, where T1 < T2, < T3 < TN, with the following additional conditions:

- Each pair of adjacent temperatures must be separated by at least 10K.
- The highest temperature TMAX must no exceed the value of the glass transition temperature minus 20K in amorphous o predominantly amorphous materials or the value of the melting temperature minus 15 K in crystalline of o semi crystalline materials.
- The maximum temperature, TMAX, must be selected taking into account of the máximum temperature at which the material can be used, as well as the maximum possible temperature test.

2.2.6 Detection of slope change; data and model validation.

The **ISO 9080 standard** uses a mathematical linear regression test to determine the presence of a change in slope in the curve. Linear regression is applied to the data collected for each of the temperatures separately; the slope of the regression line is determined for each temperature and the stress for which 50% and 2.5% failure is predicted after 50 years (ie, the values of σLTHS and σLCL).

If at one or more temperatures the regression slope is positive, the data at that temperature are considered inadequate.

The method described in the standard for determining the change in slope is applied. If the presence of the slope change is confirmed, one of the type II models should be used. If the presence of a change in slope is not detected, one of the Type I models should be used. Once the type of model is selected, the selection of the appropriate model (Q or R) depends on the statistical test of lack of fit*, of which obtains the statistical value F and the model that provides the lowest value is chosen. If the value of F is greater than 20 for both cases, the model is considered inadequate.

2.2.7 Description of Method II

Data are obtained according to the procedure and conditions described above, at two temperatures T1 and T2, where T2 must be at least 40K greater than T1, the number of observations and the pressure distribution must be made according to Table 1. The rest of the procedure is similar to method I.

2.3 ISO 1167 standard

This standard specifies the method for determining the resistance of thermoplastic pipes to internal water pressure at constant temperature. The tests that are carried out to determine the classification of PE pipes and their procedures are established in said standard.

The standard has an informative annex, which specifies **the recommended failure times** for each pressure level (or annular stress). Pipe failure times shall not be less than the minimum time specified in the table. However, Table 2 has a marginal note explaining that "if a material with an MRS value determined in accordance with ISO 9080 by the required series of tests does not meet the specified minimum test times, the test times may be modified and, for materials with a given MRS and that physically do not meet the specified requirements for 80°C, a lower stress value can be used, according to Table 3. ISO 1167 contains the detailed procedure for the execution of hydrostatic tests and indicates a series of tests of short and medium duration (up to 42 days) that, although they allow to establish in a preliminary way if the material has the characteristics of hydrostatic resistance desired in a material for pipes, they cannot be used for a definitive classification of the material

*Translation of lack-of-fit.

Table 2. Recommended failure times for PE pipes

Material	Test Effort (MPa)		
	100 h to 20°C	165 h to 80°C	1000 h to 80°C
PE 100	12.4	5.5	5.0
PE 80	9.0	4.6	4.0
PE 63	8.0	3.5	3.2
PE 40	7.0	2.5	2.0
PE 32	6.5	2.0	1.5

2.4 ISO 13479 Standard. Determination of crack propagation resistance - Test method for slow crack growth in grooved pipes (groove test).

In this test, pipes of a given length with four machined longitudinal grooves are subjected to constant hydrostatic pressure while submerged in a tank of water at 80°C. The failure time is recorded. The equipment and procedures used for the hydrostatic test are those stipulated in ISO 1167. The groove is manufactured by using a milling machine with a horizontal mandrel rigidly fixed to a support, to ensure that the pipe is fixed and thus achieve a groove. straight. The blade must have a 60° "V" angle, according to ISO 6108, and the cutting speed is 0.010±0.002 (mm/rev)/tooth. For example, a blade with 20 teeth rotating at 700 rpm, moving at a speed of 150 mm/min, has a cutting speed of 150/(20x700)=0.011 (mm/rev)/tooth.

with

$$p = \frac{10\sigma}{S}$$

or

$$p = \frac{20\sigma}{(SDR-1)}$$

With σ: hydrostatic stress (equivalent to annular stress), in MPa

S: tube series.

SDR: Standard ratio of dimensions: $\frac{d_n}{e_n}$

The standard recommends a minimum of three tests, in which failure should not occur within the minimum established time of 165 h, that is, 7 days.

There is the possibility of performing a slow crack growth test with specimens extracted from pipes, by means of a procedure described by Tränkner*, in which specimens of specific dimensions are subjected to a constant stress, following a principle similar to that of the PENT test, according to ASTM F 1473.

2.5 ISO 13477 Standard. Determination of resistance to rapid crack propagation (RPC) - Small-scale steady-state test (Test S4).

The principle of this test consists of subjecting a section of pipe, pressurized and maintained at a controlled temperature, to an impact near one of the ends, in order to initiate a fast-growing longitudinal crack. The equipment necessary to perform the test is described in the standard; It consists of a containment cage, to restrict radial expansion during fracture while allowing expansion during the internal pressurization stage, a measurement zone, some internal fins as an internal support zone, to prevent deformation of the tube wall during impact and crack initiation equipment, which is basically an impact blade with specific dimensions and characteristics.

The objectives of the test are:

a) Obtain the value of the critical pressure (or critical annular stress), at which rapid crack propagation occurs.

b) Obtain the critical crack propagation temperature. The critical temperature is defined as the lowest temperature that produces the crack arrest. A temperature slightly lower than the critical temperature will cause rapid crack propagation.

* Tränkner, Tom as, "Slow Crack Growth Test as Ranking Method, Studsvik Polymer AB, published on the Bodycote website,www.bodycotepolymer.com

2.6 ISO 13478 standard. Determination of resistance to rapid crack propagation (RPC) - Full-scale test (FST).

The principle of this test is the same as that of the ISO 13477 standard test. A section of pipe made of thermoplastic material, maintained with an internal pressure and at a specific temperature, is subjected to an impact designed to initiate the formation of a crack. Unlike the 13477 standard, the ISO 13478 standard provides for the use of larger equipment for pipes of a minimum length of 14 meters. The objectives, as in the case of standard 13477, are:

a) Obtain the value of the critical pressure (or critical annular stress), at which rapid crack propagation occurs.

b) Obtain the critical crack propagation temperature. The critical temperature is defined as the lowest temperature that causes the crack to stop. A temperature slightly lower than the critical temperature will cause rapid crack propagation..

3 Summary.

The ISO 12162 standard establishes the criteria for classifying plastic materials for the manufacture of pipes, according to the MRS values determined following the procedure of the ISO 9080 standard. The procedure for determining the MRS requires the assembly of at least 25 hydrostatic tests ranging from a duration of a few hours to more than 9000 hours, that is, more than a year. The ISO 1167 standard contains the detailed procedure for the execution of hydrostatic tests, and indicates a series of tests of short and medium duration (up to 42 days) that, although they allow to establish in a preliminary way if the material has the characteristics of hydrostatic resistance desired in a piping material, cannot be used for a definitive classification of the material.

4 Bibliographic references

1. International Standard ISO 13949. Method for the assessment of the degree of pigment dispersion in polyolefin pipes, pipes and compounds.
2. International Standard ISO 13479. Polyolefin pipes for the conveyance of fluids - Determination of the resistance to crack propagation - Test method for slow crack growth on notched pipes (notch test)
3. International Standard ISO 13478. Thermoplastic pipes for the conveyance of fluids - Determination of the resistance to rapid crack propagation (RCP) - Full scale test (FST)
4. International Standard ISO 13477. Thermoplastic pipes for the conveyance of fluids - Determination of the resistance to rapid crack propagation (RCP) - Small-scale steady-state test (S4 test)
5. International Standard ISO 12162.Thermoplastic materials for pipes and fittings for pressure applications - Classification and designation - Overall service (design) coefficient.
6. International Standard ISO 4437. Buried polyethylene PE) pipes or he supply of gaseous fuels - Metric series - Specifications
7. International Standard ISO 4427. Polyethylene (PE) pipes for water supply - Specifications.
8. International Standard ISO 11420. Method for the assessment of the degree of carbon black dispersion in polyolefin pipes, fittings and compounds.
9. International Standard ISO 1167. Thermoplastic pipes for the conveyance of fluids - Resistance to internal pressure - Test method.
10. International Standard ISO 10837. Determination of the thermal stability of polyethylene (PE) for use in gas pipes and fittings.
11. International Standard ISO/TR 9080. Thermoplastic 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.
12. Tränkner, T. Slow crack growth test as a ranking method, Studsvik Polymer AB, Sweeden.
13. Ifwarson, M, Leijstrom, H, What controls the lifetime of plastic pipes and how can the lifetime be extrapolated. Studsvik Polymer AB, Sweeden.
14. ASTM Standard test method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials. Annual Book o ASTM Standards, 1992.
15. Solvay Polymers, ASTM vs. ISO Methodology for Pressure Design of Polyethylene Piping Materials.

TABLE 3. HYDROSTATIC RESISTANCE AT 80° - REPEAT TEST REQUIREMENTS.

PE 32		**PE 40**		**PE 63**		**PE 80**		**PE 100**	
Effort MPa	Minimum time of failure h	Effort MPa	Minimum time of failure h	Effort MPa	Minimum time of failure h	Effort MPa	Minimum time of failure h	Effort MPa	Minimum time of failure h
2,0	165	2,5	165	3,5	165	4,6	165	5,5	165
1,9	227	2,4	230	3,4	285	4,5	219	5,4	233
1,8	319	2,3	323	3,3	538	4,4	283	5,3	332
1,7	456	2,2	463	3,2	1000	4,3	394	5,2	476
1,6	667	2,1	675			4,2	533	5,1	688
1,5	1000	2,0	1000			4,1	727	5,0	1000
						4,0	1000		

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