
Plastics — Determination of the transient extensional viscosity of polymer melts

*Plastiques — Détermination de la viscosité élongationnelle transitoire
des polymères à l'état fondu*





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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 5, *Physical-chemical properties*.

This second edition cancels and replaces the first edition (ISO 20965:2005), which has been technically revised.

The main changes compared to the previous edition are as follows:

- figures have been updated and figure keys have been introduced;
- calibration period in 5.6 has been clarified.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Plastics — Determination of the transient extensional viscosity of polymer melts

1 Scope

This document specifies the general principles of a method for determining the transient extensional viscosity of polymer melts. The procedure details the measurement of polymer melt specimens stretched uniaxially under conditions of constant strain rate and constant temperature.

The method is capable of measuring the transient extensional viscosity of polymer melts at Hencky strain rates typically in the range $0,01 \text{ s}^{-1}$ to 1 s^{-1} , at Hencky strains up to approximately 4 and at temperatures up to approximately 250 °C (see NOTES 1 and 2). It is suitable for measuring transient extensional viscosity values typically in the range from approximately $10^4 \text{ Pa}\cdot\text{s}$ to $10^7 \text{ Pa}\cdot\text{s}$ (see NOTE 3).

NOTE 1 Hencky strains and strain rates are used (see [Clause 3](#)).

NOTE 2 Values of strain, strain rate and temperature outside these limiting values can be attained.

NOTE 3 The operating limit of an instrument, in terms of the lowest transient extensional viscosity values that can be measured, is due to a combination of factors, including the ability of the specimen to maintain its shape during testing and the resolution of the instrument.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 472, *Plastics — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

Hencky strain

ε

strain given by the natural logarithm of the elongation ratio given by [Formula \(1\)](#)

$$\varepsilon = \ln(l/l_0) \quad (1)$$

where

l is the specimen length and

l_0 is the original specimen length

Note 1 to entry: It is also referred to as the natural or true strain.

Note 2 to entry: It is dimensionless.

3.2 Hencky strain rate

ε

rate of change of Hencky strain with time, given by [Formula \(2\)](#)

$$\varepsilon = 1/l \times \partial l / \partial t \quad (2)$$

where t is the time

Note 1 to entry: It is independent of the original specimen length l_0 .

Note 2 to entry: It is expressed in reciprocal seconds.

3.3 net tensile stress

σ_E

for tensile uniaxial extension, stress given by [Formula \(3\)](#)

$$\sigma_E = \sigma_{11} - \sigma_{22} = \sigma_{11} - \sigma_{33} = \sigma_{zz} - \sigma_{rr} \quad (3)$$

where σ_{ii} is a stress tensor in either rectangular or axisymmetric co-ordinates

Note 1 to entry: The tensile stress growth function is indicated by σ_E^+ where the $+$ indicates start-up of flow.

Note 2 to entry: Net tensile stress is expressed in pascals.

3.4 tensile stress growth coefficient

η_E^+

ratio of the net tensile stress to the Hencky strain rate, given by [Formula \(4\)](#)

$$\eta_E^+(t, \varepsilon) = \sigma_E / \varepsilon \quad (4)$$

for tensile uniaxial extension, where t is time and $+$ indicates start-up of flow

Note 1 to entry: It is also known for the purposes of this document as “transient extensional viscosity”.

Note 2 to entry: It is a transient term.

Note 3 to entry: It is expressed in pascal seconds.

3.5 tensile viscosity

η_E

term given by [Formula \(5\)](#)

$$\eta_E(t, \varepsilon) = \lim_{t \rightarrow \infty} [\eta_E^+(t, \varepsilon)] \quad (5)$$

Note 1 to entry: It is the limiting tensile stress growth coefficient value and represents an equilibrium extensional viscosity if a steady value is achieved. However, for materials that do not exhibit a steady-state behaviour, the use of an “equilibrium extensional viscosity” such as this is not appropriate.

Note 2 to entry: It is expressed in pascal seconds.

4 General principles

In contrast to shear flow where reference is normally made only to steady shear flow behaviour, extensional flow behaviour is best described as being transient. In describing the transient behaviour of materials in extension at constant strain rate, they may exhibit either an unbounded stress growth behaviour in which the stress continually increases with increasing strain until the material fails, or the stress reaches a steady value with increasing strain thus yielding a tensile or equilibrium extensional viscosity. The latter occurs typically at large strains. An equilibrium extensional viscosity is thus dependent on strain rate but not on strain or time. Normally, the extensional viscosity varies as a function of both strain and strain rate as well as temperature.

In describing and modelling plastics processing, the use of Hencky strain is preferred. The rate of Hencky strain of an element of fluid within a flow is independent of its original length and is determined only from the velocity field of that element. It is thus a more suitable characteristic of the flow. Strain and strain rate are taken by default herein to be Hencky values.

Stretching flow methods can be used to generate quantitatively accurate data on the extensional viscoelasticity of polymer melts. In carrying out extensional flow measurements, there are four types of measurement that are normally made: constant strain rate, constant stress, constant force and constant speed. This document describes the first of these: constant strain rate. In this method, the strain rate is uniform throughout the specimen and is held constant with time.

The basic principle behind stretching flow measurements is to subject a specimen to a tensile stretching deformation. By measurement of the force and deformation of the specimen, the stresses and strains and hence strain rate can be determined.

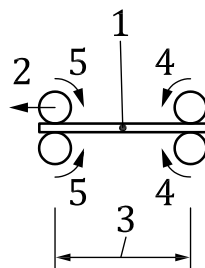
5 Apparatus

5.1 General description

The measuring apparatus shall consist of one of the following types, shown in [Figure 1](#) to [Figure 4](#). These types define the various instrument configurations. The notation used in these figures is defined in [8.1](#).

Type A: Two rotating clamps. Each clamp shall consist of either a single rotating element or a pair of rotating elements – only the pair arrangement is shown. The force exerted on the specimen can be measured at the fixed or rotating end.

NOTE It is likely that the force will be easier to measure, and will be measured with greater accuracy, on a fixed clamp rather than on a moving clamp as there will be fewer complications due, for example, to vibration and the inertia of the clamp which can introduce noise and errors into the force signal.

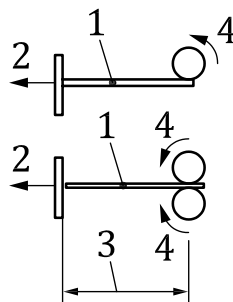


Key

- 1 specimen
- 2 force, F , expressed in N
- 3 original specimen length, l_0 , expressed in m
- 4 angular speed of rotating clamps of side 1, ω_1 , expressed in $\text{rad}\cdot\text{s}^{-1}$
- 5 angular speed of rotating clamps of side 2, ω_2 , expressed in $\text{rad}\cdot\text{s}^{-1}$

Figure 1 — Schematic diagram of type A test instrument

Type B: A single rotating clamp and a fixed clamp. The rotating clamp shall consist of either a single rotating element or a pair of rotating elements. The force exerted on the specimen is normally measured at the fixed end.

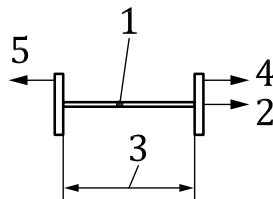


Key

- 1 specimen
- 2 force, F , expressed in N
- 3 original specimen length, l_0 , expressed in m
- 4 angular speed of rotating clamps, ω_1 , expressed in $\text{rad}\cdot\text{s}^{-1}$

Figure 2 — Schematic diagram of type B test instrument

Type C: Two translating (non-rotating) clamps.



Key

- 1 specimen
- 2 force, F , expressed in N
- 3 original specimen length, l_0 , expressed in m
- 4 speed of the ends of the specimen of side 1, V_1 , expressed in $\text{m}\cdot\text{s}^{-1}$
- 5 speed of the ends of the specimen of side 2, V_2 , expressed in $\text{m}\cdot\text{s}^{-1}$

Figure 3 — Schematic diagram of type C test instrument

Type D: Single translating (non-rotating) clamp.