Detailed engineering guide based on ISO 18488:2015 and ISO 18489:2015

Strain Hardening Modulus (SHM) and Cracked Round Bar (CRB) test methods for PE piping مادهs, لولهs, and اتصالs.

Executive Technical Summary .1

s. It isماده Slow crack growth (SCG) is one of the principal long-term fracture mechanisms relevant to polyethylene piping can remain below its short-term yield strength and still اتصال or لوله a :بارfundamentally different from immediate ductile over experience progressive crack extension from a defect, notch, scratch, inclusion, or highly stressed local region. For this reason, long-term polyethylene performance cannot be assessed from yield stress or short-term tensile strength alone.

ISO 18488 determines .مقاومت ISO 18488:2015 and ISO 18489:2015 provide two complementary ways of characterizing SCG the strain hardening modulus, <Gp>, from the post-draw tensile response of compression-moulded polyethylene at 80 ing to generate slow crack growthبار and cyclic tensile نمونه آزمون °C. ISO 18489 uses a circumferentially notched cylindrical and records the number of cycles to failure as a function of stress range.

ing history, and primary output. ISO 18488 is anبار ,دما ,geometry نمونه آزمون ,The two standards differ in physical approach characterization method based on the molecular deformation response after the natural draw ratio. ISO 18489 ماده intrinsic is a fracture-based method that deliberately introduces a sharp crack-like notch and evaluates crack propagation under ranking, product evaluation, ماده ,ing. Used together, they provide a powerful framework for resin screeningبار cyclic grades. لوله research and development, and technical comparison of PE

Engineering Background: Slow Crack Growth in Polyethylene .2

piping combines crystalline lamellae with amorphous regions containing molecular tie chains and فشار Polyethylene used in may form ماده entanglements. Under long-term localized stress, deformation can concentrate near a flaw or crack tip. The carrying capacity in a narrow process zone. Crack-بار fibrillar structures, undergo chain orientation, and progressively lose growth can therefore proceed slowly over a long period before final failure.

as related to the lifetime of polyethylene products and links strain مقاومت The introduction to ISO 18488 describes SCG hardening behavior to the ability of the molecular network, particularly tie molecules, to resist disentanglement. ISO 18489 to crack initiation مقاومت emphasizes the need for accelerated methods because modern PE grades can exhibit such high ing regime areبار and SCG that older methods may require impractically long test periods. The CRB geometry and cyclic without relying on stress-cracking دما intended to accelerate the relevant failure process at application-relevant ambient liquids.

formulation and molecular architecture, but measured ماده is affected by مقاومت From an engineering perspective, SCG and data ,دما ,ing modeبار ,preparation, orientation, residual stresses, notch quality نمونه آزمون results are also sensitive to preparation and test execution. نمونه آزمون treatment. This is why both standards contain detailed controls on

Ductile failure versus slow-crack-growth failure 2.1

Ductile failure is characterized by extensive plastic deformation and gross yielding before rupture. SCG failure, by contrast, is dominated by localized crack advance and typically produces a relatively brittle-looking fracture region. In ISO 18489, this s are excluded from data evaluation because theنمونه آزمون distinction is not merely descriptive: predominantly ductile CRB .بارtest is intended to characterize slow crack growth, not ductile over

Why accelerated SCG methods are needed 2.2

s can survive traditional long-duration tests for very long periods.مقاومت لوله مادهModern PE80, PE100, and high-SCG- Accelerated tests must therefore shorten the experimental time while preserving a failure mechanism that remains technically meaningful. ISO 18488 accelerates characterization by measuring a deformation property that correlates with .ingبار geometry and cyclic نمونه آزمون SCG behavior. ISO 18489 accelerates crack propagation through controlled

Relationship Between Molecular Structure, Strain Hardening, and SCG .3

The strain hardening region occurs after yielding and neck propagation, when the polymer chains in the highly drawn zone of the molecular network to continued deformation produces an increasing true stress مقاومت become strongly oriented. The with increasing draw ratio. ISO 18488 quantifies this behavior through <Gp>. The informative annex links the strain-hardening response to the underlying entanglement network and describes it using a Neo-Hookean constitutive model.

The CRB method does not directly calculate molecular entanglement density. Instead, it subjects a sharp, controlled crack ing. The crack-tip process zone repeatedly experiences stress and deformation, making theبار geometry to cyclic tensile number of cycles to failure a direct fracture-based response. Consequently, the tests should not be expected to produce system, but both are relevant to the broader engineering problem of slow crack ماده identical rankings in every possible growth.

Standards Architecture and Normative References .4

ISO 18488 and ISO 18489 are both test-method standards prepared within ISO/TC 138, SC 5 for plastics piping systems. Each
preparation, procedure, data treatment, and reporting requirements. نمونه آزمون ,standard defines its own scope, apparatus
extensometry, standard ,آزمون, نیرو اندازه‌گیری Their normative references provide additional requirements for tensile
atmospheres, and machining.

Standard	Normative references explicitly identified	Function in the method
ISO 18488:2015	ISO 527-1; ISO 7500-1; ISO 9513	system verification; extensometer-نیرو ;Tensile principles calibration.
ISO 18489:2015	ISO 291; ISO 2818	.sآزمون نمونه atmospheres; machining of plastic آزمونConditioning/

Principle, and Terminology ,دامنه کاربرد – ISO 18488:2015 .5

5.1 دامنه کاربرد

ISO 18488 specifies a method for determining the strain hardening modulus of polyethylene and uses that modulus as a
to slow crack growth. The modulus is obtained from stress-strain curves measured on مقاومت measure related to
preparation, test execution, نمونه ,s. The method includes requirements for equipment, precisionنمونه compression-moulded
and calculation.

applications and is اتصال and لوله s used forماده STANDARD REQUIREMENT: The method is intended for polyethylene described as applicable independently of manufacturing technology, comonomer, or catalyst type.

Principle 5.2

Test pieces cut or punched from compression-moulded sheet are tensile-tested at 80 °C. The stress-strain curve must extend sufficiently beyond the natural draw ratio. The strain hardening modulus is then determined from the post-draw region of the true-stress response using the Neo-Hookean treatment specified in the standard.

Key terms and symbols 5.3

Term	Symbol	Unit / expression	Technical meaning
Gauge length	l0	mm	نمونه Initial distance between gauge marks in the central part of the آزمون.
ضخامت	h	mm	Smaller initial dimension of the rectangular cross-section.
Width	b	mm	Larger initial dimension of the rectangular cross-section.
سرعت Test	v	mm/min	Rate of separation of the gripping jaws.
Length	l	mm	Instantaneous distance between gauge marks.
Engineering stress	σ	MPa	divided by original cross-sectional area. نیرو Normal
Stress at yield	σy	MPa	Stress corresponding to the strain at yield.
True stress	σtrue	MPa	Draw ratio multiplied by engineering stress under the volume-conservation treatment.

Strain	ε	dimensionless or %	Increase in length divided by original gauge length.
Strain at yield	εy	dimensionless or %	First occurrence of increasing strain without increasing stress.
Draw ratio	λ	dimensionless	Current gauge length divided by original gauge length.
Strain hardening modulus	;lt;Gp&gt&	MPa	Slope parameter of the Neo-Hookean representation over the prescribed high-draw region.

6. ISO 18488 – دستگاه Metrology and الزامات

6.1 Tensile-آزمون دستگاه

STANDARD REQUIREMENT: The tensile-آزمون دستگاه must comply with ISO 527-1 and be capable of maintaining a test سرعت of 20 ± 2 mm/min.

The دستگاه must provide stable large-deformation tensile بارing while operating inside or through an 80 °C دما chamber. Grip design is especially important because the نمونه آزمون undergoes very large draw ratios and any slippage directly invalidates the strain اندازه‌گیری.

6.2 بار cell

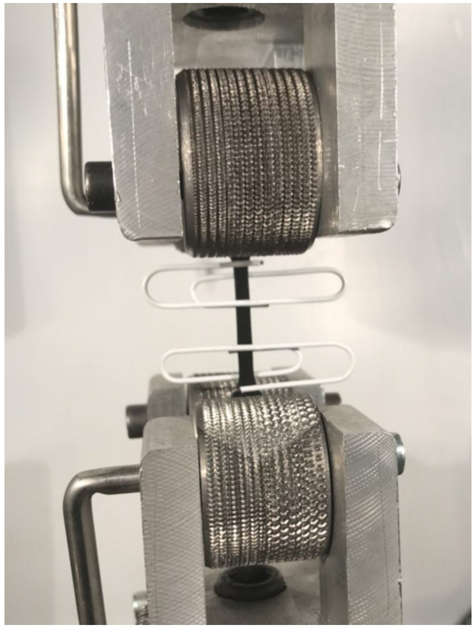
STANDARD REQUIREMENT: The بار cell must meet Class 1 as defined in ISO 7500-1.

The standard identifies نیرو ranges that the system must measure accurately: approximately 40 N for 0.30 mm نمونه آزمونs cell capacity should therefore not be unnecessarily high,-بار s. The selectedنمونه آزمون and approximately 120 N for 1.0 mm because excessive capacity can reduce useful resolution.

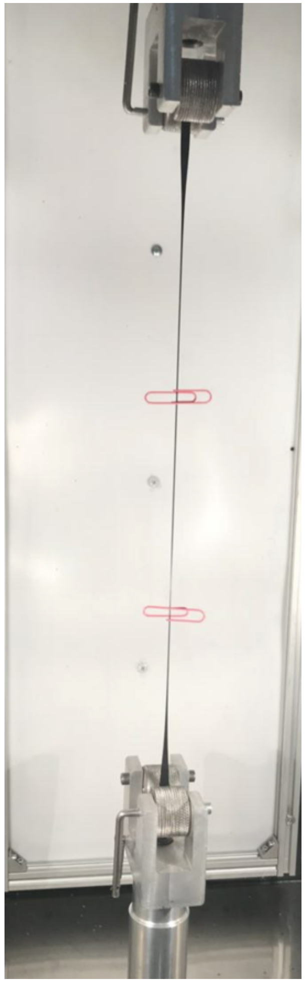
Extensometer 6.3

traverse displacement دستگاه STANDARD REQUIREMENT: The extensometer must comply with Class 1 as defined in ISO 9513. must not be used as the measure of strain.

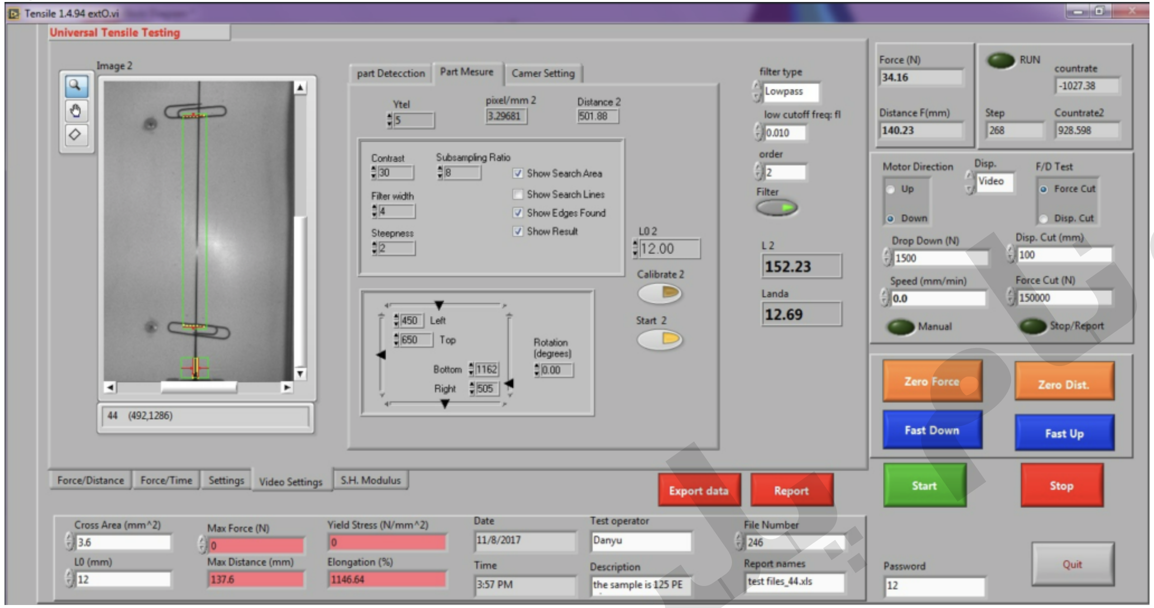
is particularly اندازه‌گیری s, the standard prefers a non-contact extensometer. Optical strainنمونه آزمون For 0.30 mm becomes highly drawn and thin, and mechanical contact can disturb the deformation نمونه آزمون advantageous because the or lose tracking at large extension.



Tensile Grips with Clips for Video Extensometer



نمونه After Extension in the Region of Strain Hardening



Ytel: 5
pixel/mm 2: 3.29681
Distance 2: 501.88
Contrast: 30
Subsampling Ratio: 8
Filter width: 4
Steepness: 2
☑ Show Search Area
☐ Show Search Lines
☑ Show Edges Found
☑ Show Result
Left: 450
Top: 650
Bottom: 1162
Right: 505
Rotation (degrees): 0.00
L0 2: 12.00
44 (492,1286)
filter type: Lowpass
low cutoff freq: fl: 0.010
order: 2
L 2: 152.23
Landa: 12.69
Force (N): 34.16
Distance F(mm): 140.23
countrate: -1027.38
Step: 268
Countrate2: 928.598
Motor Direction: ○ Up ● Down
Disp.: Video
F/D Test: ● Force Cut ○ Disp. Cut
Drop Down (N): 1500
Disp. Cut (mm): 100
Speed (mm/min): 0.0
Force Cut (N): 150000
Cross Area (mm^2): 3.6
L0 (mm): 12
Max Force (N): 0
Max Distance (mm): 137.6
Yield Stress (N/mm^2): 0
Elongation (%): 1146.64
Date: 11/8/2017
Time: 3:57 PM
Test operator: Danyu
Description: the sample is 125 PE
File Number: 246
Report names: test files_44.xls
Password: 12

Automatic اندازه‌گیری of Elongation Using Video Extensometer

6.4 دما chamber

STANDARD REQUIREMENT: The test دما is 80 ± 1 °C.

The chamber must maintain the نمونه آزمون and اندازه‌گیری zone within this range. Remote operation of the grips is recommended so the chamber does not need to be opened during the clamping sequence.

Test is Done inside دما Controlled Test Chamber

6.5 Dimensional اندازه‌گیری

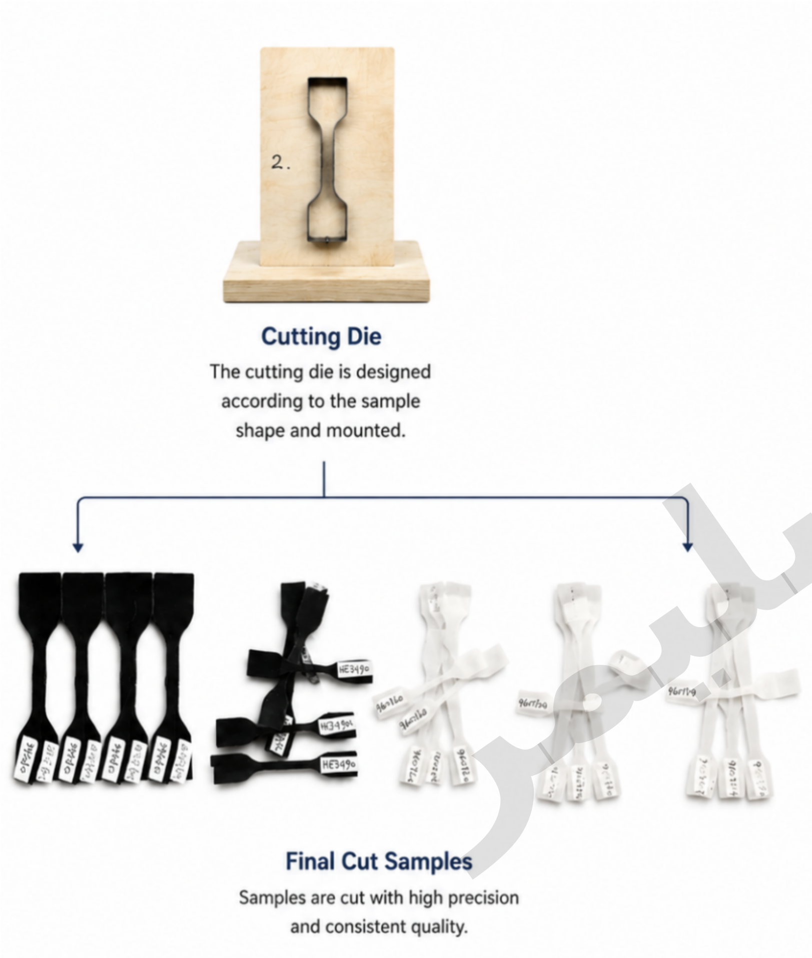
STANDARD REQUIREMENT: ضخامت must be measured with a device having 0.005 mm accuracy and a contact dimension width. Width must be measured with 0.01 mm accuracy. نمونه آزمون smaller than the 4.0 mm parallel

as a way to avoid اندازه‌گیری ISO 18488 recommends microscope .نمونه آزمون should not deform the thin اندازه‌گیری The width
during width determination. نمونه آزمون compressing or distorting the

Punch knife 6.6

is prepared using a punch knife matching the geometry defined by the standard. The cutting edge and نمونه آزمون The
edges because edge flaws can cause premature failure نمونه آزمون punching process must preserve smooth, undamaged
before the required draw-ratio range is reached.

Pneumatic نمونه Press and Cutter



Cutting Die

The cutting die is designed according to the sample shape and mounted.

Final Cut Samples

Samples are cut with high precision and consistent quality.

Geometry and Preparation نمونه آزمون – ISO 18488 .7

dimensions نمونه آزمون 7.1

Designation	Description	Requirement
L	Start length between clamps	0.5 mm ± 30.0
l0	Gauge length	0.1 mm ± 12.5
l1	Length of narrow parallel-sided portion	1.0 mm ± 16.0
l2	Length between parallel portions of clamp area	1.0 mm ± 46
l3	Minimum overall length	70 mm minimum
R1	Radius	0.5 mm ± 10.0
R2	Radius	0.5 mm ± 8.0
b1	Width of narrow parallel section	0.1 mm ± 4.0
b2	Width at ends	1.0 mm ± 20.0
h	ضخامت	0.30 mm (+0.05/-0.03) or 1.0 ± 0.1 mm

does not slip while the gauge section undergoes very large extension. نمونه آزمون A large clamping area is required so the The standard notes that greater overall length may be necessary with some grips so only the wide end tabs contact the grips and shoulder breaks are avoided.

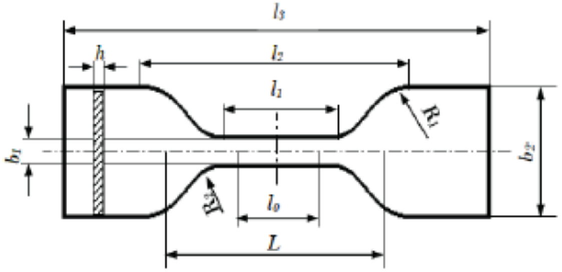


Figure 1 — Test specimen

Table 1 — Dimensions of test specimens

Dimension		Size mm
L	Start length between clamps	30,0 ± 0,5
l_0	Gauge length	12,5 ± 0,1
l_1	Length of narrow parallel sided portion	16,0 ± 1,0
l_2	Length between the parallel portions of the clamp area	46 ± 1,0
l_3	Minimum overall length[a]	70
R_1	Radius	10,0 ± 0,5
R_2	Radius	8,0 ± 0,5
b_1	Width at narrow parallel sided portion	4,0 ± 0,1
b_2	Width at ends	20,0 ± 1,0
h	Thickness	0,30 + 0,05/- 0,03 or 1,0 ± 0,1

[a] A greater overall length may be necessary to ensure that only the wide end tabs come into contact with the machine grips, thus avoiding "shoulder breaks".

7.2 Compression moulding conditions

Hot Press for Making Sheet from Raw ماده

ضخامت Sheet	دما Moulding	Average cooling rate	Preheating time	فشار Full time	فشارFull-
or 1.0 mm 0.30	180 °C	2 °C/min ± 15	to 15 min 5	5 MPa	1 min ± 5

Annealing 7.3

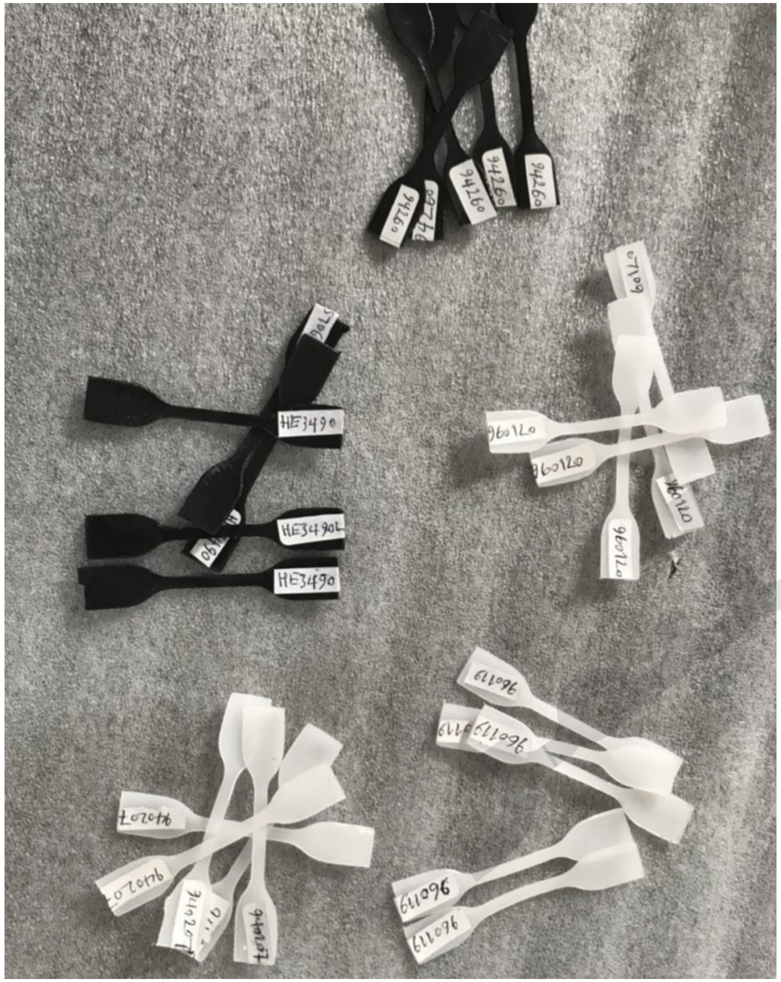
STANDARD REQUIREMENT: After compression moulding, the sheet is conditioned for 1 h at 120 ± 2 °C and then cooled with an average cooling rate below 2 °C/min. Free movement of the sheet must be allowed. دما slowly to room

The slow cooling step is intentionally different from the faster cooling used during moulding. It reduces the influence of
s are produced.نمونه آزمون uncontrolled thermal history before

sنمونه آزمون Punching and number of 7.4

STANDARD REQUIREMENT: Five test pieces are punched from the prepared sheet. The punching process must not introduce
deformation, crazes, or other irregularities.

is rejected because of slippage or early failure, the نمونه آزمون s to be tested. If aنمونه آزمون The standard requires at least five
result is discarded and the test must be repeated so that the valid dataset remains compliant.


94260
HE3490
HE3490L
HE3490
960120
960120
960119
961097
611096
611096

نمونه Are Punch Cut from The Sheets Prepared From Raw ماده

width, and gauge marks ,ضخامت 7.5

is measured at three points in the parallel region. The lowest of the three measured ضخامت :STANDARD REQUIREMENT values is used in data analysis. ضخامت

midpoint so that the specified initial gauge length l0 is maintained. نمونه آزمون Gauge marks are applied equidistant from the These marks are the reference for the extensometer and the draw-ratio calculation.

روش اجرای آزمون ISO 18488 – Detailed .8

اندازه‌گیریs Pre-test dimensional 8.1

h to 0.005 mm accuracy for every individual ضخامت STANDARD REQUIREMENT: Measure width b to 0.01 mm accuracy and نمونه آزمون.

to--نمونه آزمون This prevents sheet-to-sheet or .نمونه آزمون The original cross-sectional area is calculated separately for each dimensional variation from being hidden in the final modulus. نمونه آزمون

بارing Thermal conditioning before 8.2

chamber at 80 ± 1 °C before the test starts. دما for at least 30 min in the نمونه آزمون STANDARD REQUIREMENT: Condition the

8.3 Clamping sequence

1. Clamp the test piece in the upper grip using a clamping system that prevents damage and slippage.
2. Close the دما chamber.
3. After the نمونه آزمون has reached 80 ± 1 °C, clamp the lower end.
4. Keep the نمونه آزمون between the grips for at least 1 min before applying بار and beginning the اندازه‌گیری.

ENGINEERING IMPLEMENTATION NOTE: The staged clamping sequence minimizes thermal disturbance and reduces the risk of introducing an uncontrolled initial بار while the نمونه آزمون is still stabilizing at دما.

8.4 Pre-stress and tensile بارing

STANDARD REQUIREMENT: Apply a pre-stress of 0.4 MPa at a سرعت of 5 mm/min. During the test, measure both بار and elongation. Then extend the نمونه آزمون at a constant traverse سرعت of 20 mm/min.

8.5 Required data range

STANDARD REQUIREMENT: Collect data from λ = 8.0 until λ = 12.0 or until نمونه آزمون breakage. Reject a نمونه آزمون that breaks before λ = 8.5.

The analysis region is therefore deliberately far beyond initial yield. The strain-hardening modulus is not a conventional small-strain elastic modulus; it represents the slope of the highly drawn polymer response.

8.6 Validity conditions

- s are required.نمونه آزمون At least five valid
- slippage in the grips is discarded and repeated. نمونه آزمون Any test affected by
- breaking before λ = 8.5 is rejected. نمونه آزمون A
- The true-stress/Neo-Hookean fit must achieve R² > 0.9 during data analysis.

ISO 18488 – Calculations and Neo-Hookean Data Analysis .9

Original cross-sectional area 9.1

value used for ضخامت calculate the original cross-sectional area from the measured width and the ,نمونه آزمون For each :analysis

$$A = b \times h$$

ly affect calculated stress. This is why the standard specifies bothماده errors ضخامت is thin, even small نمونه آزمون Because the .ضخامت resolution and use of the lowest measured اندازه‌گیری

Draw ratio 9.2

:The draw ratio is calculated as

$$\lambda = l / l0 = 1 + \Delta l / l0$$

where l0 is the initial gauge length, l is the instantaneous gauge length, and Δl is the increase in gauge length.

True stress 9.3

The standard assumes conservation of volume between the gauge marks. The true stress is therefore calculated from :and draw ratio as نیرو measured

$$\sigma true = \lambda \times F / A$$

and A is the initial cross-sectional area. نیرو where F is the measured tensile

9.4 Neo-Hookean constitutive model

:ISO 18488 represents the high-draw response with a Neo-Hookean form

$$\sigma true = (\text{<Gp>} / 20) \times (\lambda^2 – 1/\lambda) + C$$

In this expression, <Gp> is the reported strain hardening modulus and C is a mathematical intercept parameter associated with extrapolated yield behavior. The model converts the nonlinear large-deformation response into a relationship from which a slope parameter can be determined.

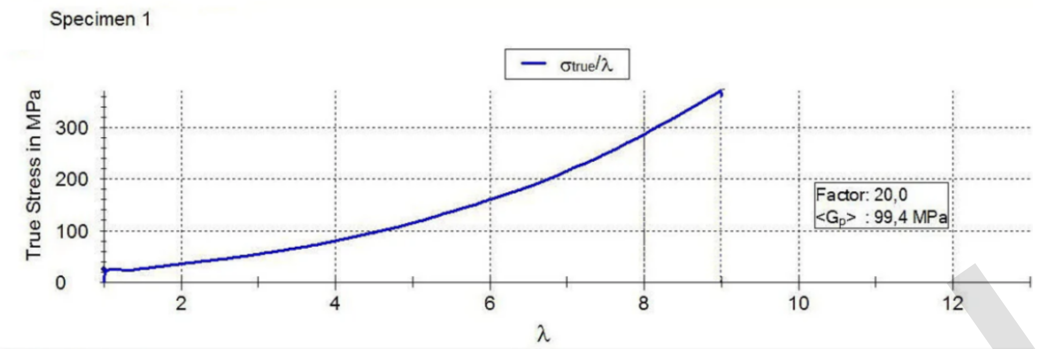
Analysis interval and regression quality 9.5

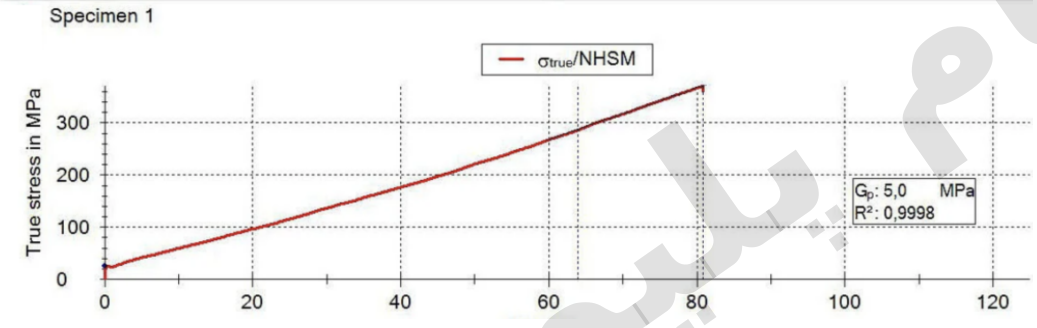
STANDARD REQUIREMENT: The model is fitted to the high-draw data for the prescribed region between approximately λ = 8 and λ = 12, and the fit must have R^2 greater than 0.9.

The informative annex explains the underlying linear-regression concept and associates the strain-hardening response with The primary engineering value is the reproducible slope in the highly .مقاومت molecular entanglement and fibril deformation oriented region, not the initial elastic or yield response.

;Interpretation of <Gp&gt 9.6

A higher .مقاومت discrimination parameter related to SCG ماده Within the context of ISO 18488, <Gp> is used as a of the molecular network to the deformation and مقاومت strain-hardening response generally indicates greater disentanglement mechanisms that accompany crack growth. The standard does not convert <Gp> into a direct service-.لوله life value for a





ISO 18488 – Result Validation, Rejection Criteria, and Test Report .10

Reasons for rejection or repetition 10.1

Observed issue Required / appropriate action **Reason**

Insufficient high-draw region for valid strain-hardening analysis.	Reject نمونه آزمون	Break before λ = 8.5
Measured elongation no longer represents gauge-section strain.	Discard result and repeat	Grip slippage
Neo-Hookean fit quality does not meet the standard criterion.	Do not accept fit as compliant	$R^2 \leq 0.9$
Preparation defect may cause premature failure.	Do not use damaged نمونه آزمون	Visible punching damage or crazing
Specified test condition was not maintained.	Investigate/repeat as necessary	دما outside 80 ± 1 °C

Test report content 10.2

The ISO 18488 test report includes the following information. The list below preserves the substance of the standard while using original wording for this guide:

- Reference to ISO 18488:2015.
- Complete identification of the tested ماده and test-piece origin, including type, source, manufacturer designation, manufacturing method, and production date where relevant.
- Minimum ضخامت of each نمونه آزمون.
- Mean width of each نمونه آزمون.
- Identification/number of each tested نمونه آزمون.
- Yield stress for each نمونه آزمون.
- Mean and standard deviation of yield stress for the full نمونه آزمون set.

- Calculated strain hardening modulus for each نمونه آزمون.
- Mean strain hardening modulus and coefficient of variation for the full نمونه آزمون set.
- Test دما and any recorded variation.
- Identification of rejected/replaced نمونه آزمونs and reasons for rejection or آزمون of nonconforming نمونه آزمونs.
- Any incident or operating detail that may have affected the result.
- Date of اندازه‌گیری.

11. ISO 18489:2015 – دامنه کاربرد, Principle, and Terminology

11.1 دامنه کاربرد

ISO 18489 specifies a method for determining مقاومت to slow crack growth of polyethylene مادهs, لولهs, and اتصالs. نمونهs may be دستگاهd from compression-moulded sheet, extruded لوله, or injection-moulded اتصالs, provided adequate ضخامت is available for the CRB geometry.

STANDARD REQUIREMENT: The method is intended for accelerated fracture-mechanics characterization at ambient دما around 23 °C and is particularly identified for PE80 and PE100 لوله مادهs.

11.2 Principle

A cylindrical نمونه آزمون containing a circumferential razor-sharp notch is subjected to cyclic tensile بارing with constant بار range. The بار is selected to generate slow crack growth rather than predominantly ductile failure. The number of cycles to final failure, Nf, is recorded as a function of the applied stress range, Δσ0, corresponding to the measured initial crack length.

The geometry creates high constraint and limited global plastic deformation near the crack tip. This promotes relatively rapid crack initiation and shortens the overall test time. The standard notes that crack initiation may also be monitored with extensometers if desired.

Terms and symbols 11.3

Term	Symbol	Unit / relationship	Meaning
Crack length	a	mm	Depth from external surface to crack tip at any time.
Cycle	N	–	time or stress-time function.-بار Smallest repeated segment of the
Failure cycle number	Nf	cycles	failure. نمونه آزمون Total cycles from test start to
Frequency	f	Hz	Number of cycles per second.
Initial crack length	aini	mm	Measured crack depth at the beginning of the test, determined from the fracture surface after the test.
Initial ligament diameter	Dini	mm	.Remaining inner diameter after notching: Dini = D – 2aini
بار ratio	R	Fmin/Fmax	.بار to maximum بار Ratio of minimum
بار range	ΔF	N	Difference between Fmax and Fmin.
بار Maximum	Fmax	N	in one cycle. بار Highest
بار Minimum	Fmin	N	in one cycle. بار Lowest

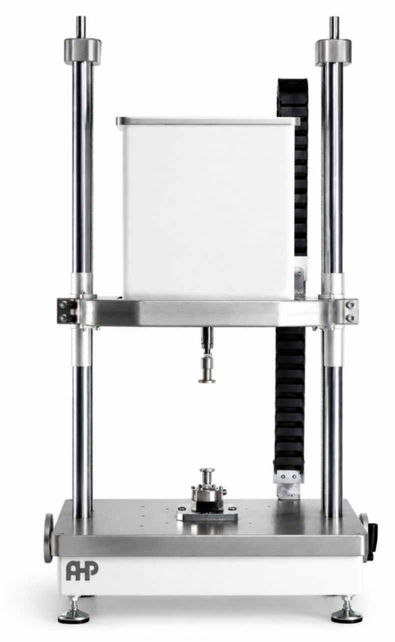
Notch distance	Lmin	mm	Minimum distance from the notch to the clamping system.
Target initial crack length	*aini	mm	Target razor-notch depth before the test.
Target initial ligament diameter	*Dini	mm	Target remaining diameter after notching.
Target stress range	*Δσ0	MPa	Target difference between maximum and minimum stress at test start.
diameter نمونه آزمون	D	mm	.نمونه آزمون Diameter of the cylindrical CRB
length نمونه آزمون	L	mm	length. نمونه آزمون Total
Stress range	Δσ0	MPa	Applied stress range corrected using the measured initial crack depth.
Waveform	–	–	time curve within one cycle.-بار Shape of

ing Systemبار and Cyclic دستگاه – ISO 18489 .12

ing systemبار 12.1

control mode between-بار in بار STANDARD REQUIREMENT: The system must impose and record a time-varying cyclic accurately defined limits and with a specified waveform.

s with electronic control are generally suitable, although mechanically driven systems may be usedدستگاه Servo-hydraulic when they meet all relevant requirements.



دستگاه Dynamic بارing

12.2 Waveform and بار stability

STANDARD REQUIREMENT: The cyclic بار is sinusoidal and is defined by Fmax and the بار ratio R. Maximum and minimum بارs must remain constant throughout the test within ±1%.

12.3 Frequency

cycle frequency must not exceed 10 Hz and must be controlled to 1 % accuracy.-بار STANDARD REQUIREMENT: The

At 10 Hz, hysteretic heating is normally not expected to significantly influence Nf according to the standard. If unusual heating near the crack tip is suspected, the frequency is reduced to 5 Hz or 1 Hz, again with 1 % accuracy.

Grips and alignment 12.4

must be aligned with the بار s and the appliedنمونه آزمون STANDARD REQUIREMENT: The grips must be suitable for cylindrical axis. نمونه آزمون

Bending or twisting changes the stress field at the circumferential notch and can create nonuniform crack growth. Alignment .آزمون is therefore a central validity issue in CRB

chamber دما 12.5

must have a suitable chamber/environmental system دستگاه s other than 23 ± 2 °C, theدما STANDARD REQUIREMENT: For s compatible with the test environment.ماده and uses دما within ±2 °C of the specified نمونه آزمون that maintains the

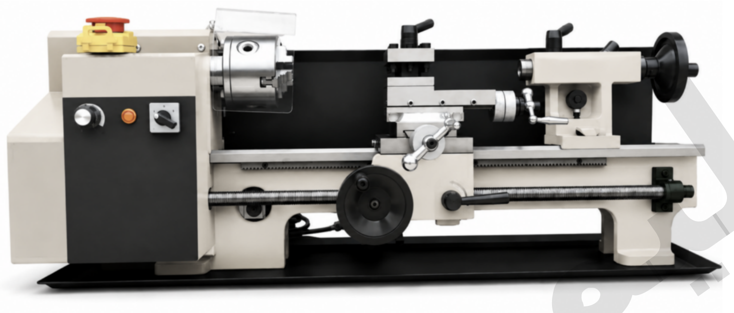
Microscope 12.6

STANDARD REQUIREMENT: Use a microscope or equivalent device with 0.01 mm accuracy to measure the initial crack length after completion of the cyclic test.

12.7 Notching apparatus

STANDARD REQUIREMENT: The notching device must produce a circumferential razor-sharp notch with a tip radius below 10 µm and maintain the notch perpendicular to the نمونه آزمون axis.

A conventional lathe with a razor-blade tool can be suitable. Blade bending must be prevented because it can distort notch geometry and create a nonuniform initial crack front.



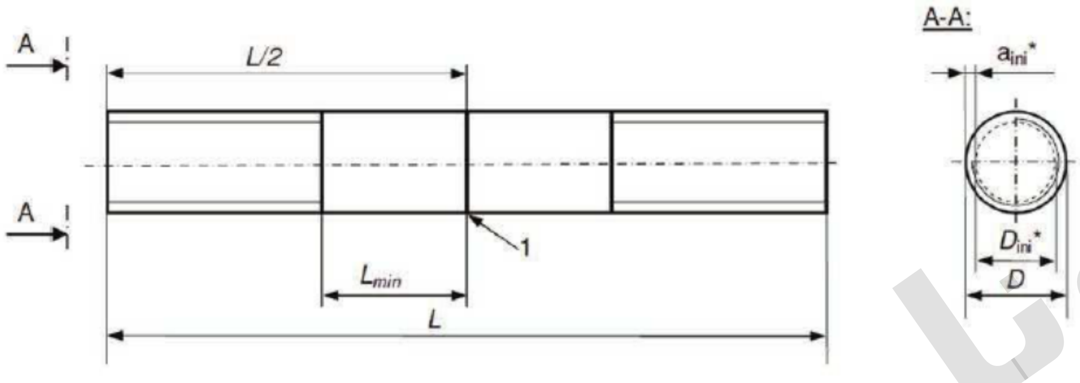
13. CRB – ISO 18489 نمونه آزمون Geometry, Machining, and Notching

Preferred CRB geometry 13.1

Parameter	Symbol	Preferred requirement
length نمونه آزمون	L	to 100 mm 80
diameter نمونه آزمون	D	14 mm
Target initial crack length	*aini	1.50 mm (+0.15/-0.00 mm)
Minimum notch-to-grip distance	Lmin	At least 20 mm
Optional thread	–	M14 × 1.0 metric fine thread may be used for clamping

The target initial ligament diameter .نمونه آزمون The notch is circumferential and located in the middle of the cylindrical
:diameter and target crack depth نمونه آزمون follows directly from the

Dini = D – 2aini



Key

L	specimen length
L_{min}	minimum distance between notch and clamping system
a_{ini}*	target initial crack length
D_{ini}*	target initial ligament diameter
D	specimen diameter
1	razor-sharp notch

Figure 1 — Principal configuration of CRB test specimen with optional metric fine thread

13.2 Source ماده and machining

CRB نمونه آزمون s can be دستگاه d from compression-moulded sheet, extruded لوله, or injection-moulded اتصال s. Machining is carried out in accordance with ISO 2818. The standard explicitly warns that different compression-moulding conditions can affect test results, so preparation history must be controlled when comparing ماده s.

13.3 Compression moulding conditions

ضخامت Moulded	دما Moulding	Average cooling rate	Preheating time	فشار Full	time فشارFull-
lt;10 mm&	180 °C	2 °C/min ± 15	20 min	5 MPa	10 min
to 16 mm 10	180 °C	0.5 °C/min ± 2	45 min	10 MPa	25 min

is used. فشار is below 40 °C. During preheating, only contact دما STANDARD REQUIREMENT: Demoulding

13.4 Notching conditions

.s at 23 ± 2 °Cنمونه آزمون STANDARD REQUIREMENT: Notch

and approximately 0.03 mm per سرعت The standard gives favorable practical values of approximately 80 to 100 rpm driving rotation razor-blade feed. The purpose is to avoid frictional heating, notch-tip blunting, and residual stresses.

STANDARD REQUIREMENT: Use each razor blade for no more than 10 notches.

axis. Any angular notch can create asymmetric crack propagation نمونه آزمون The notch must remain perpendicular to the .sنمونه آزمون and invalidate comparison with correctly prepared

روش اجرای آزمون ISO 18489 – Conditioning and Detailed .14

conditioning before test نمونه آزمون 14.1

s at ISO 291 condition 23/50, Class 2 beforeنمونه آزمون STANDARD REQUIREMENT: Unless otherwise specified, store notched
A minimum of 24 h preconditioning at this condition is recommended. .آزمون

is not highly significant, but recommends the 24 h آزمون The standard notes that the interval between notching and
preconditioning period as good practice within the method.

اندازه‌گیری Diameter 14.2

measure D on both sides of the notch at a distance of 1 to 2 mm from the notch, ,آزمون STANDARD REQUIREMENT: Before
s. Do not measure the diameter directly at the notch.اندازه‌گیری with at least 0.1 mm accuracy. Use the average of the two

mounting نمونه آزمون 14.3

s, bending, or twisting. Maintain sufficientنیرو without inducing additional نمونه آزمون STANDARD REQUIREMENT: Mount the
notch-to-grip distance Lmin to prevent clamping effects at the crack tip.

Test atmosphere 14.4

STANDARD REQUIREMENT: The preferred test atmosphere is ISO 291 condition 23/50, Class 2 unless a referring standard specifies otherwise.

for at least 2 h before دما at test نمونه آزمون ed mountedبارcondition the un ,دما آزمونSTANDARD REQUIREMENT: For elevated-بارing.

Selection of stress range 14.5

ratio R = 0.1 unless a referring standard specifies otherwise. بار STANDARD REQUIREMENT: Use a

Base-polymer density	***Typical target stress range Δσ0**
ρ ≤ 945 kg/m^3	to 12.5 MPa 10.5
ρ > 945 kg/m^3	to 13.5 MPa 11.5

STANDARD REQUIREMENT: Target stress ranges above 13.5 MPa should be avoided because they may produce ductile failure.

s are tested at each applied target stress range, with stress levels distributed through the applicableنمونه آزمون At least four s generate SCG rather thanبار preliminary tests are recommended to confirm that the selected ,ماده range. For an unknown ductile failure.

range. بار For a product specification, the standard notes that a single-point requirement may be established at one

14.6 Cyclic بار application

- Mount and condition the نمونه آزمون as required.
- Apply the cyclic بار immediately at the defined frequency without exceeding the calculated Fmax.
- Avoid static preبارing before the cyclic test because it may cause creep at the notch tip.
- Start the cycle counter simultaneously with the cyclic بار.
- Apply and record the cyclic بار continuously until نمونه آزمون failure.

14.7 Post-test crack-depth اندازه‌گیری

The actual initial crack depth aini is measured after the cyclic test from the fracture surface. The smooth ring-like surface produced by the razor notch can normally be distinguished from the surface created by subsequent fatigue/SCG crack extension. A microscope or equivalent device is used for this اندازه‌گیری.

15. ISO 18489 – بار and Stress Calculations

15.1 بار ratio and بار range

The بار ratio is:

R = Fmin / Fmax

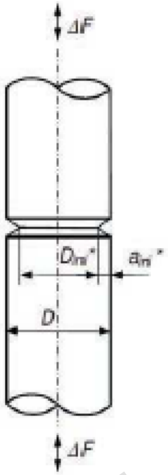
The cyclic بار range is:

ΔF = Fmax – Fmin

Target ligament diameter 15.2

:For the target notch depth, the remaining ligament diameter is

Dini = D – 2aini



Key

ΔF	load range
a_{ini}*	target initial crack length
D_{ini}*	target initial ligament diameter
D	specimen diameter

Figure 2 — Calculation of F_{max} and F_{min} for cyclic CRB test

15.3 Maximum and minimum بار

For the preferred geometry, the target stress range is applied to the circular ligament area. Rearranging the relationship between stress range and بار range gives the maximum بار:

$$\Delta F = F_{\max} - F_{\min}$$

$$F_{\max} = \frac{D_{\mathrm{ini}}{}^{2} \cdot \pi \cdot \Delta\sigma *}{4 - (1 - R)}$$

$$F_{\min} = F_{\max} \cdot R$$

نمونه آزمون and ΔF = Fmax – Fmin. These equations allow the test controller to be programmed from the measured/target
ratio. بار geometry, selected stress range, and

15.4 Corrected actual stress range

Because the exact razor-notch depth is determined after failure, the actual initial ligament diameter can differ from the
:target value. The applied stress range is therefore corrected using the measured aini

$$\Delta\sigma_0 = \frac{4 \cdot \Delta F}{\left(D - 2a_{\mathrm{ini}}\right)^2 \cdot \pi}$$

This corrected Δσ0, rather than only the target Δσ0*, is the stress range used in the final failure-cycle relationship.

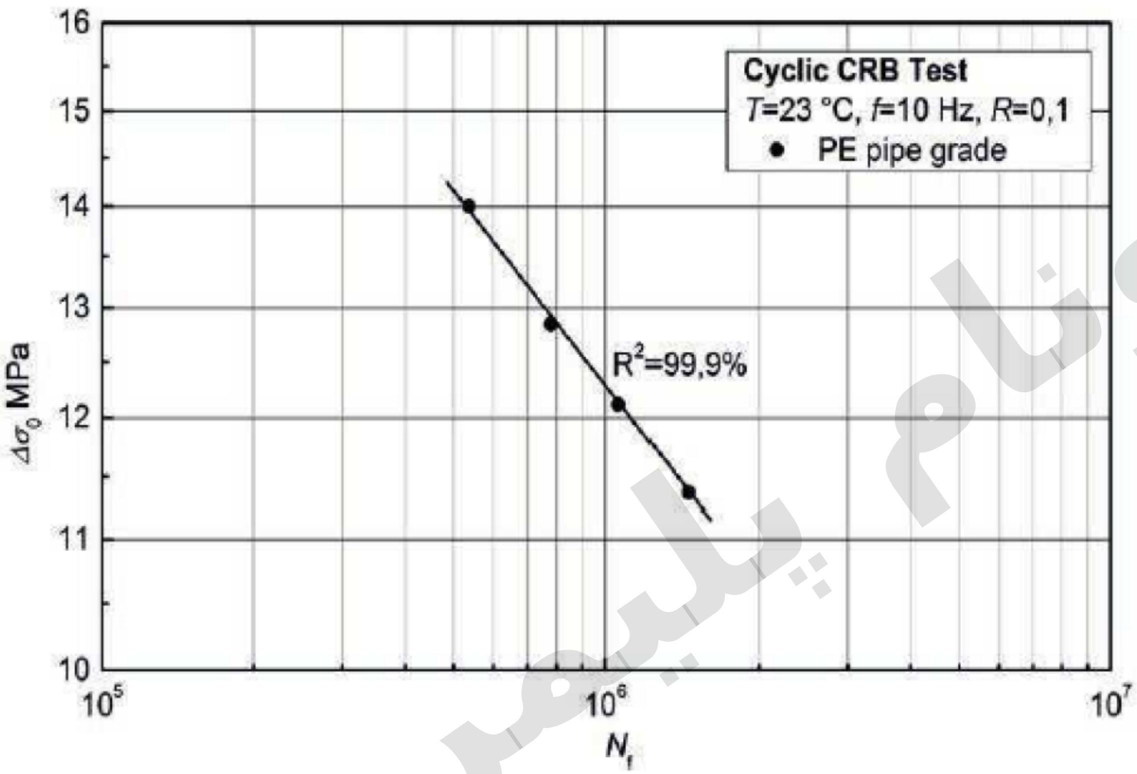


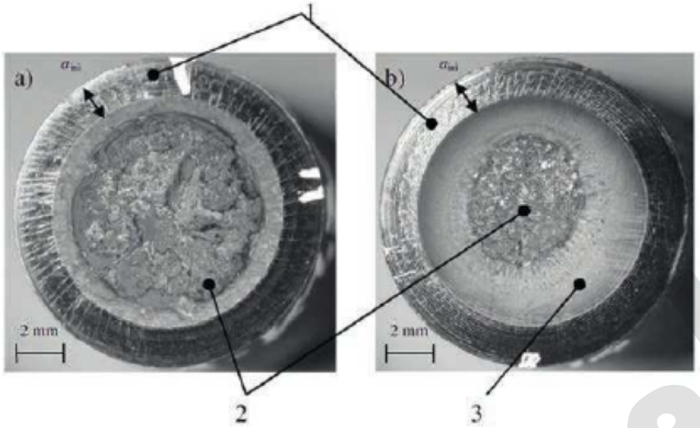
Figure 4 — Example of a diagram of $\Delta\sigma_0$ versus N_f

ISO 18489 – Fracture-Surface Assessment and Data Treatment .16

16.1 Fracture-mode validity

s showing predominantly brittle fracture are included in the data evaluation.نمونه آزمون STANDARD REQUIREMENT: Only

The fracture surface generally contains distinguishable regions: a smooth ring corresponding to the razor notch, a slow-
that failed نمونه آزمون crack-growth/brittle region, and a final ductile region when the remaining ligament becomes small. A
predominantly by ductile deformation indicates that the applied stress was too high for the intended SCG mechanism and
must be excluded from evaluation.



Key

1	razor blade notch
2	area with ductile failure
3	area with brittle failure

Figure 3 — Typical fracture surfaces of CRB specimens after testing

16.2 Failure cycle number

failure. Because the method is a نمونه آزمون ing until finalبار cycles from the beginning of cyclic بار Nf is the total number of fatigue-style test, Nf is strongly dependent on applied stress range; a single Nf value is therefore meaningful only together .دما geometry, frequency, R ratio, and نمونه آزمون ,with the corresponding Δσ0

Log-log failure relationship 16.3

STANDARD REQUIREMENT: Display Nf as a function of Δσ0 in a double-logarithmic (log-log) diagram.

STANDARD REQUIREMENT: The failure curve must show a linear correlation with an accuracy within at least a 98 % confidence interval. If a clear linear relationship is not obtained, additional tests at suitable stress ranges are performed.

cycle frequency, and R ratio. These variables are necessary-بار ,دما configuration, test نمونه آزمون The plot must also identify
and therefore the observed life. نیرو ing can alter the crack-drivingبار because changes in geometry or

16.4 Comparison limits

geometry and test parameters نمونه آزمون STANDARD REQUIREMENT: Direct comparison by stress range is allowed only when
are the same.

diameter differs from the preferred 14 mm configuration, the standard requires comparison through the نمونه آزمون When
stress-intensity-factor range rather than Δσ0 alone.

ISO 18489 – Alternative Diameters and Stress-Intensity-Factor .17 Approach

diameters from 10 mm to 14 mm. For such alternative sizes, the target نمونه آزمون The informative annex addresses CRB
diameter. Because a given nominal stress range does نمونه آزمون initial crack length may be taken as approximately 10 % of

not produce exactly the same crack-tip intensity in different geometries, Nf versus Δσ0 is not a valid direct comparison diameters. نمونه آزمون across different

STANDARD REQUIREMENT: For alternative-diameter comparison, use the stress-intensity-factor range ΔKI. The annex .نمونه آزمون indicates a ΔKI range of approximately 0.62 to 0.70 MPa·m^0.5 to avoid ductile failure in the CRB

The annex uses the Benthem-Koiter crack-geometry solution for a circumferential crack in a round bar. Its inputs include radius r, crack depth a, remaining ligament radius b = r – a, and a geometry function f(b/r). For نمونه آزمون ,range ΔF بار cyclic calculation software or formal conformity work, the exact Annex A equation and coefficients should be implemented directly from an authorized copy of ISO 18489.

ENGINEERING IMPLEMENTATION NOTE: This manual intentionally explains the calculation architecture without reproducing calculation worksheet should store the controlled formula آزمایشگاه the full copyrighted annex coefficient expression. A version and revision traceably.

الزامات ISO 18489 – Test Report .18

A complete CRB report includes substantially more information than Nf alone because the validity of the result depends ing conditions.بار preparation, notch geometry, fracture mode, and cyclic نمونه آزمون strongly on

- .Reference to ISO 18489:2015
- and operating person(s). آزمایشگاه Name of test
- such as PE base polymer or compound, product type, ,نمونه آزمون product and each/ماده Complete identification of

manufacturer, and production date.

- preparation, including cutting and dimensions. نمونه آزمون Details of
- conditioning. نمونه آزمون Details of notching procedure and
- Details of the test equipment.
- Test atmosphere.
- information as applicable, R, Nf, frequency f, بارing variables including corrected stress range Δσ0, maximum stress/بار and cycle waveform.
- Measured notch depth aini from the fracture surface.
- .آزمون Photograph of the CRB fracture surface after
- Diagram of Δσ0 versus Nf.
- Any deviations, incidents, or operations outside the specified method that may affect results.
- Start and end dates of the test.

Side-by-Side Comparison of ISO 18488 and ISO 18489 .19

Technical aspect	ISO 18488:2015 – SHM	ISO 18489:2015 – CRB
Measured response	High-draw tensile strain hardening	ingبار Cycles to failure under cyclic crack
Primary result	lt;Gp> in MPa&	Nf as a function of corrected Δσ0; ΔKI when geometry differs

source نمونه آزمون	Compression-moulded PE sheet	or ,لوله Compression-moulded sheet, extruded اتصال injection-moulded
type نمونه آزمون	نمونه آزمون Thin dog-bone style tensile	Circumferentially notched cylindrical bar
دما Typical test	1 °C ± 80	s allowedدما Preferably 23/50 condition; other
ingبار	Monotonic tension	Sinusoidal cyclic tension
frequency/سرعت	capability; test at 20 دستگاه 2 mm/min ± 20 mm/min	Hz; reduce to 5 or 1 Hz if heating is suspected 10≥
sنمونه آزمون Number of	sنمونه آزمون At least five valid	s at each stress range forنمونه آزمون At least four curve generation
Core validity issue	Adequate draw range and no slippage	Predominantly brittle SCG failure, correct notch and alignment
Data quality criterion	Neo-Hookean fit R^2 > 0.9	Log-log linear relation with at least 98 % confidence requirement
Direct physical emphasis	Molecular network strain مقاومت hardening/disentanglement	Fracture propagation under a defined cyclic crack-نیرو driving
burden آزمون	s areنمونه آزمون Relatively rapid once prepared	,آزمون Higher: precision machining, notching, cyclic microscopy, multiple stress levels

What the two methods can and cannot be used for 19.1

ranking and SCG-related characterization, but neither standard by itself provides a complete ماده Both methods can support operating ,فشار geometry, internal لوله lifetime. Real service performance additionally depends on لوله prediction of installed s, and product manufacturing quality.بار installation damage, residual stresses, joints, chemicals, external ,دما

parameter is needed. ISO 18489 is especially useful when direct ماده ISO 18488 is especially useful when a rapid intrinsic development program, it is reasonable to use ISO 18488-ماده ing is required. In a بار fracture behavior under controlled cyclic as a fast screen and ISO 18489 for more detailed confirmation, provided this strategy is consistent with the governing product specification.

Control اندازه‌گیری Quality Assurance and آزمایشگاه .20

control تجهیزات 20.1

- range. نیرو systems whose calibration status is current and whose capacity is appropriate for the test نیرو-اندازه‌گیری Use
- For ISO 18488, verify extensometer calibration and tracking at large deformation; do not substitute crosshead displacement.
- .آزمون amplitude, R ratio, sinusoidal waveform, frequency, and cycle counter before بار For ISO 18489, verify cyclic
- rather than relying only on controller setpoint. نمونه آزمون دما Check environmental chamber stability and
- Inspect grips for wear, slippage, eccentricity, or damage that can introduce bending.
- .اندازه‌گیریs Control microscope calibration and image scale for CRB notch-depth

traceability نمونه آزمون 20.2

record should therefore assign a آزمایشگاه identification in the final report. A robust نمونه آزمون and ماده The standards require batch/lot, product type, manufacturing date, extraction location, orientation, ,ماده ID and preserve source نمونه آزمون unique data. These are implementation اندازه‌گیری moulding history, machining history, notching details, operator, and recommendations that strengthen traceability without changing the formal test method.

Environmental records 20.3

,دما excursions. For CRB tests at elevated دما conditioning start/end time, and any ,دما Record chamber setpoint, measured For SHM tests, document the minimum 30 .نمونه آزمون ed mountedبارdocument the minimum 2 h conditioning time of the un min pre-test conditioning at 80 ± 1 °C.

Data integrity 20.4

cycle data should be retained so calculations can be independently reproduced. Calculated-نیرو and elongation or نیرو Raw information system. Any manual exclusion آزمایشگاه results should be linked to a controlled spreadsheet, validated script, or should carry a documented reason consistent with the standard validity rules. نمونه آزمون of a

Common Sources of Error and Troubleshooting .21

Problem	Likely cause	Technical consequence	Corrective action
نمونه آزمون ISO 18488 breaks early	Edge damage, poor punching, ماده ,unsuitable clamping behavior	Insufficient λ range	Inspect edges and die; review grip .نمونه آزمون contact; replace damaged

ISO 18488 strain data inconsistent	Extensometer tracking loss or grip slippage	;Incorrect λ and <Gp&gt	Verify gauge marks, optical contrast, .فشار alignment, and grip
ISO 18488 poor R²	Noisy strain data, irregular deformation, insufficient valid range	Invalid model fit	Review raw curve and tracking; repeat when necessary.
CRB failure is ductile	Stress range too high	Not SCG-dominated; result excluded	Reduce Δσ0* and repeat preliminary range selection.
CRB crack grows eccentrically	Angular notch, bending, misalignment	Nonuniform crack-driving نیرو	Correct notching perpendicularity and fixture alignment.
CRB notch appears blunted	feed/سرعت Excessive notching or worn blade	Reduced crack severity and altered Nf	Reduce frictional heating; use fresh blade within usage limit.
heats نمونه آزمون CRB strongly	High cyclic dissipation	response may be ماده altered	Reduce frequency to 5 Hz or 1 Hz as directed by the standard.
CRB log-log data are not linear	Stress levels poorly selected, mixed failure mode, scatter	Failure curve not acceptable	Review fracture modes and add tests at suitable stress ranges.

Strategy آزمون Development, Qualification, and Product ماده .22

Resin development 22.1

preparation, نمونه آزمون development because its duration is governed mainly by ماده ISO 18488 is well suited to iterative rather than by waiting for a slow crack to propagate for a long time. It can سرعت thermal conditioning, and tensile-test therefore provide relatively fast feedback on changes in molecular architecture that affect the high-draw response.

s can then be evaluated using ISO 18489 to determine whether improved intrinsic strain-hardening behavior isماده Candidate
This two-stage strategy is an engineering workflow, not a mandatory .مقاومت accompanied by stronger cyclic crack-growth
sequence stated by the standards.

evaluation اتصال and لوله 22.2

لوله d from extrudedدستگاه s can beنمونه آزمون ISO 18489 has an important advantage for finished-product evaluation because
s. This allows the final processed morphology to be included in the test response. When comparingاتصال or injection-moulded
s, extraction position and orientation should therefore be held constant and documented.نمونه آزمون product

Product specifications and acceptance criteria 22.3

ed standard establishes a universal acceptance limit for all PE80, PE100, or PE100-RC products. AcceptanceبارNeither up
qualification ماده criteria must come from the relevant product specification, customer requirement, regulatory document, or
range. بار scheme. ISO 18489 explicitly notes that a product specification can establish a single-point requirement at one
This manual does not invent pass/fail limits that are absent from the supplied standards.

Example Calculation Workflows .23

The following examples are illustrative engineering calculations. They demonstrate how the standard equations are applied
but are not standard test results and must not be used as acceptance criteria.

ISO 18488 illustrative calculation 23.1

$h = 0.305$ mm. The original cross- ضخامت has mean width $b = 4.02$ mm and the lowest measured نمونه آزمون Assume a :sectional area is

$$A = 4.02 \times 0.305 = 1.2261 \text{ mm}^2$$

:$F = 3.20$ N نیرو At a measured draw ratio $\lambda = 9.00$ and

$$\sigma\text{true} = \lambda \times F / A = 9.00 \times 3.20 / 1.2261 \approx 23.49 \text{ MPa}$$

The same calculation is performed for the complete data series in the prescribed high-draw interval. True stress is regressed against the Neo-Hookean strain measure ($\lambda^2 - 1/\lambda$). The fitted slope is then converted to <Gp> according to the .standard model, and the regression must satisfy R^2 > 0.9

calculation بار ISO 18489 illustrative 23.2

target notch depth aini* = 1.50 mm, target stress range $\Delta\sigma0^* = 12.0$ MPa, نمونه آزمون Assume the preferred $D = 14.00$ mm :and $R = 0.10$. The target ligament diameter is

$$D\text{ini}^* = 14.00 - 2(1.50) = 11.00 \text{ mm}$$

range is approximately $95.03 \times 12.0 = 1140.4$ N. بار The ligament area is $\pi(11.00^2)/4 \approx 95.03$ mm^2. The required cyclic :($\text{Because } \Delta F = F\text{max}(1 - R$

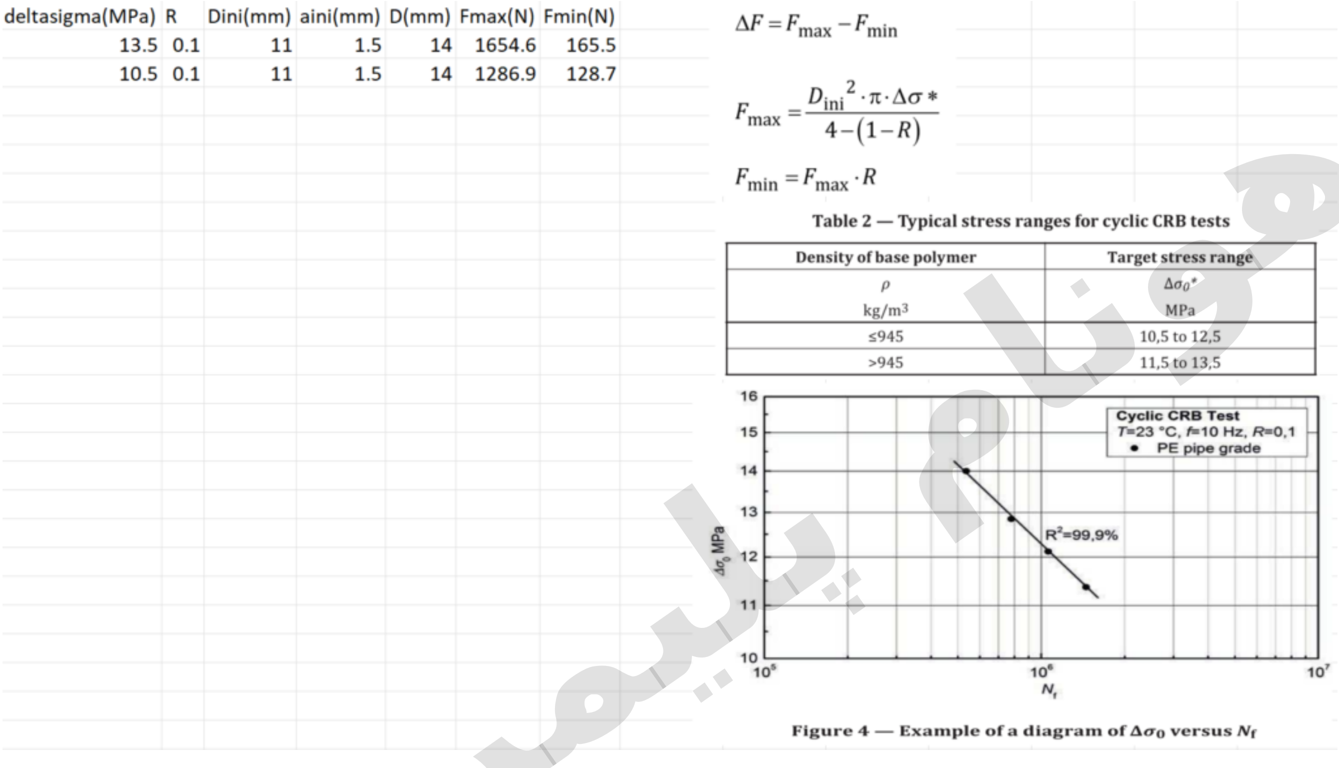
$F_{max} \approx 1140.4 / 0.90 \approx 1267$ N

$F_{min} = 0.10 \times 1267 \approx 127$ N

After fracture, suppose the measured actual crack depth is 1.58 mm. The corrected ligament diameter becomes 14.00 – 2(1.58) = 10.84 mm, and the corrected stress range is calculated from the actual ligament area using $\Delta\sigma_0 = 4\Delta F/[\pi(D - 2a_{ini})^2]$. The corrected value, not merely the target value, is used in the final Δσ0-Nf relationship.

ENGINEERING IMPLEMENTATION NOTE: For a public website, avoid reproducing figures or long verbatim passages from the ISO documents unless your organization has appropriate publication rights. Original explanatory diagrams and original tables based on engineering interpretation are preferable.

Lets see another نمونه calculation according to above standard:



deltasigma(MPa)	R	Dini(mm)	aini(mm)	D(mm)	Fmax(N)	Fmin(N)
13.5	0.1	11	1.5	14	1654.6	165.5
10.5	0.1	11	1.5	14	1286.9	128.7

$$\Delta F = F_{\max} - F_{\min}$$

$$F_{\max} = \frac{D_{\mathrm{ini}}{}^{2} \cdot \pi \cdot \Delta\sigma *}{4-(1-R)}$$

$$F_{\min} = F_{\max} \cdot R$$

Table 2 — Typical stress ranges for cyclic CRB tests

Density of base polymer ρ kg/m3	Target stress range $\Delta\sigma_0{}^*$ MPa
≤945	10,5 to 12,5
>945	11,5 to 13,5

Figure 4 — Example of a diagram of $\Delta\sigma_0$ versus N_f

Appendix A. ISO 18488 Parameter Checklist

Control item	Requirement / target	Check

ضخامت	Moulded sheet 0.30 mm or 1.0 mm; 0.30 mm in case of dispute ;nbsp&
دما Moulding	180 °C ;nbsp&
Average moulding cooling rate	2 °C/min ± 15 ;nbsp&
Preheat	to 15 min 5 ;nbsp&
فشار Full	5 MPa ;nbsp&
time فشارFull-	1 min ± 5 ;nbsp&
دما Demoulding	lt;40 °C& ;nbsp&
Annealing	1 h at 120 ± 2 °C ;nbsp&
Annealing cooling rate	lt;2 °C/min& ;nbsp&
Number of test pieces	نمونه آزمونs At least 5 valid ;nbsp&
Gauge length l0	0.1 mm ± 12.5 ;nbsp&
Narrow width b1	0.1 mm ± 4.0 ;nbsp&
Width accuracy	0.01 mm ;nbsp&
accuracy ضخامت	0.005 mm ;nbsp&
Pre-test conditioning	30 min at 80 ± 1 °C≤ ;nbsp&
Pre-stress	0.4 MPa at 5 mm/min ;nbsp&
سرعت Tensile	capability 20 ± 2 mm/min دستگاه ;20 mm/min ;nbsp&
Analysis data range	λ = 8 to 12 or break ;nbsp&
Early-break rejection	Reject if break before λ = 8.5 ;nbsp&
Slippage	Discard and repeat ;nbsp&

Regression quality	R^2 > 0.9 ;nbsp&

Appendix B. ISO 18489 Parameter Checklist

Control item	Requirement / target	Check
Preferred D	14 mm ;nbsp&	
Preferred L	to 100 mm 80 ;nbsp&	
*Target aini	1.50 mm (+0.15/-0.00) ;nbsp&	
Lmin	20 mm≤ ;nbsp&	
دما Notching	2 °C ± 23 ;nbsp&	
Notch tip radius	lt;10 µm& ;nbsp&	
سرعت Favorable notching	to 100 rpm 80 ;nbsp&	
Favorable blade feed	0.03 mm/rotation~ ;nbsp&	
Blade usage	notches per blade 10≥ ;nbsp&	
Preconditioning	50 Class 2; 24 h recommended/23 ;nbsp&	
اندازه‌گیری D	Two sides, 1-2 mm from notch, ≥0.1 mm accuracy ;nbsp&	
Preferred test atmosphere	50 Class 2/23 ;nbsp&	
conditioning دماElevated-	edبار2 h after mounting, un≤ ;nbsp&	
R	0.1 ;nbsp&	
Frequency	Hz, 1 % accuracy 10≥ ;nbsp&	

Frequency reduction if heating	or 1 Hz 5 ;nbsp&
stability بار	% Fmax and Fmin constant within ±1 ;nbsp&
Target Δσ0* for ρ ≤945	to 12.5 MPa 10.5 ;nbsp&
Target Δσ0* for ρ >945	to 13.5 MPa 11.5 ;nbsp&
*Avoid target Δσ0	gt;13.5 MPa& ;nbsp&
Replicates	s per stress rangeنمونه آزمون At least 4 ;nbsp&
ing waveformبار	Sinusoidal ;nbsp&
ingبارStatic pre	Avoid ;nbsp&
اندازه‌گیری Crack-depth	After fracture, 0.01 mm microscope accuracy ;nbsp&
Accepted failure mode	Predominantly brittle ;nbsp&
Failure plot	log Δσ0 vs log Nf ;nbsp&
Correlation requirement	Linear within at least 98 % confidence interval ;nbsp&

https://مقاومتahp-makina.com/iso-18489-determination-of--بارto-slow-crack-growth-under-cyclic-ing-cracked-round-bar-test-method-equipment/
https://مادهahp-makina.com/iso-18488-polyethylene-pe-s-for-piping-systems-determination-of-strain-hardening-modulus-in-آزمونrelation-to-slowcrack-growth--equipment/
https://مقاومتahp-makina.com/iso-18488-iso-18489-strain-hardening--to-slow-crack-growth-scg-esc/

Tensile Tester with Video Extensometer (Strain Hardening Tester for Polymers-ISO 18488) https://نیروahp-makina.com/shop/dynamic-tensile-tester-for-iso-18489-2kn--50mm-travel/