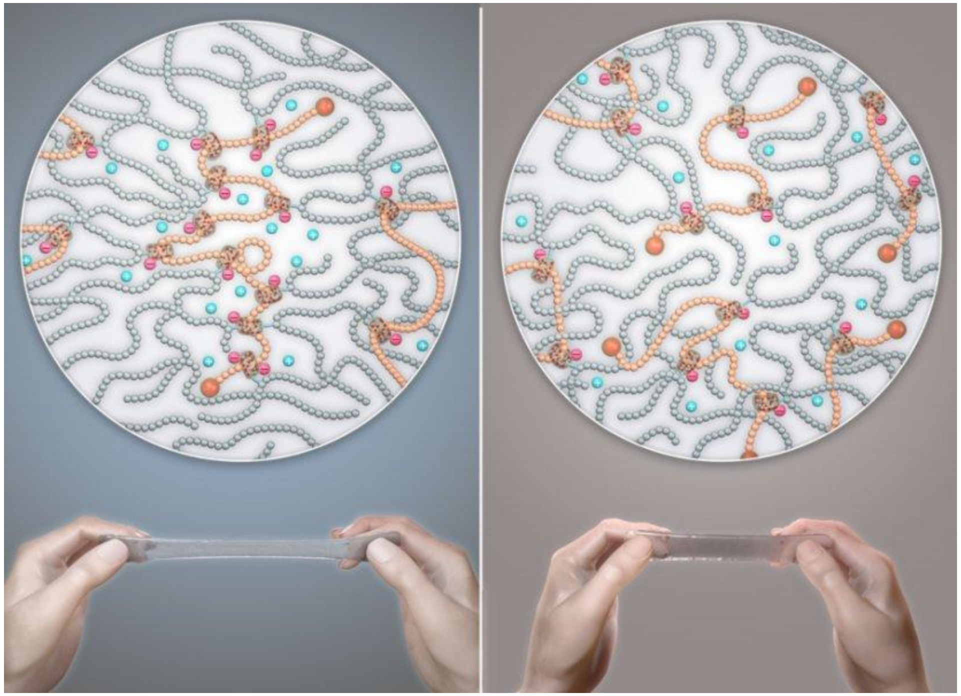
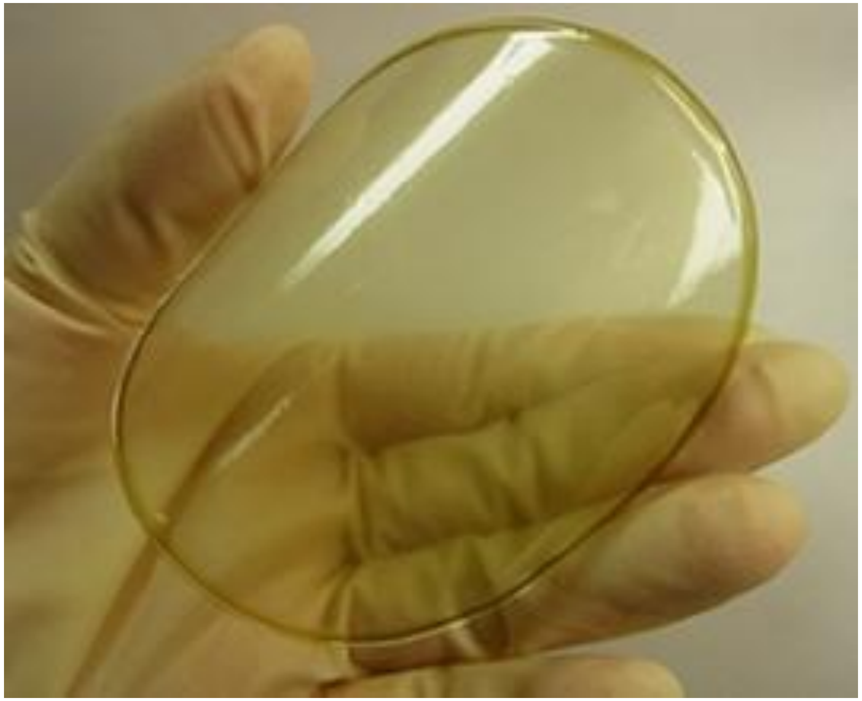
The Mechanical Properties of Polymers





Date: 14/07/2018

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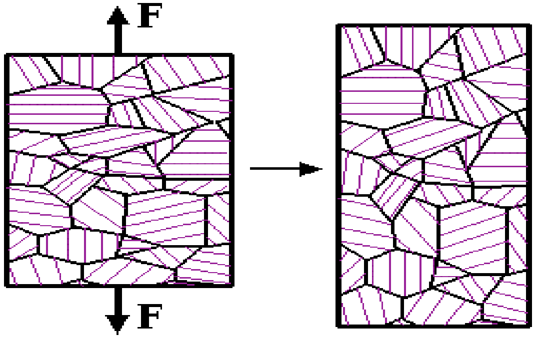
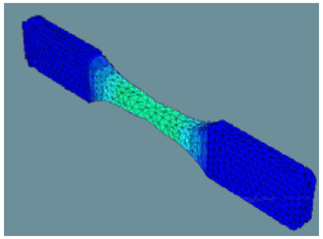
Behavior Of Material Under Mechanical Loads = Mechanical Properties.

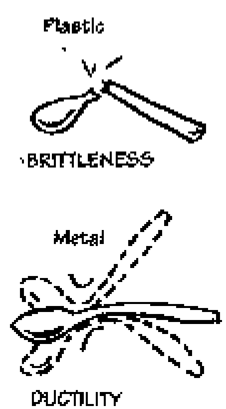
Term to address here…



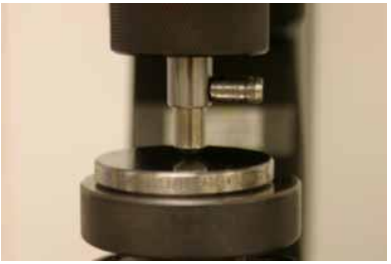
- Stress and strain:
  - These are size-independent measures of load and displacement, respectively.
- Elastic behavior:
  - Recoverable Deformation of small magnitude



- Plastic behavior:
  - This permanent deformation behavior occurs when the tensile (or compressive) uniaxial stress reaches σ_y.
- Toughness and ductility:
  - Defining how much energy that a material can take before failure.

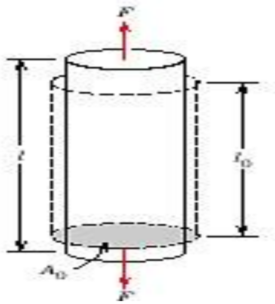


- Hardness:
  - The property of being rigid and resistant to pressure; not easily scratched.

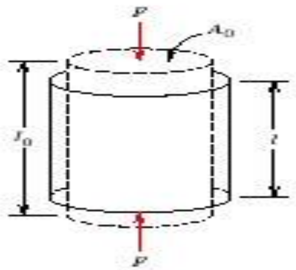


Types of Stresses/Load-Strain/Displacement

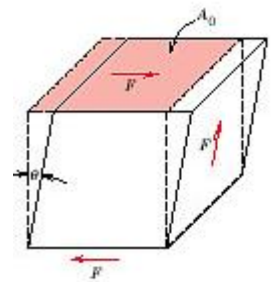
Tensile



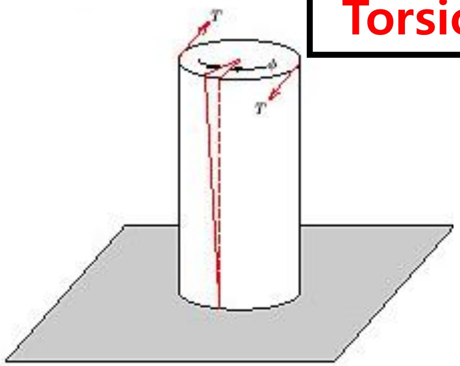
Compressive



Shear



Torsion



Stress: $\sigma = F / A_o$ (MPa @ N/mm^2),

F: is load (N)

A_0: cross-sectional area (m^2 or mm^2)

Strain: $\varepsilon = \Delta l / l_o$ ($\times$ 100 %)

Δl: change in length

l_o: original length (m or mm)

Shear stress: $\tau = F / A_o$

F is applied parallel to upper and lower faces each having area A_0

Shear strain: $\gamma = \tan\theta$ ($\times$ 100 %)

θ is strain angle

Torsion: like shear.

Load: applied torque, T

Strain: angle of twist, ϕ.

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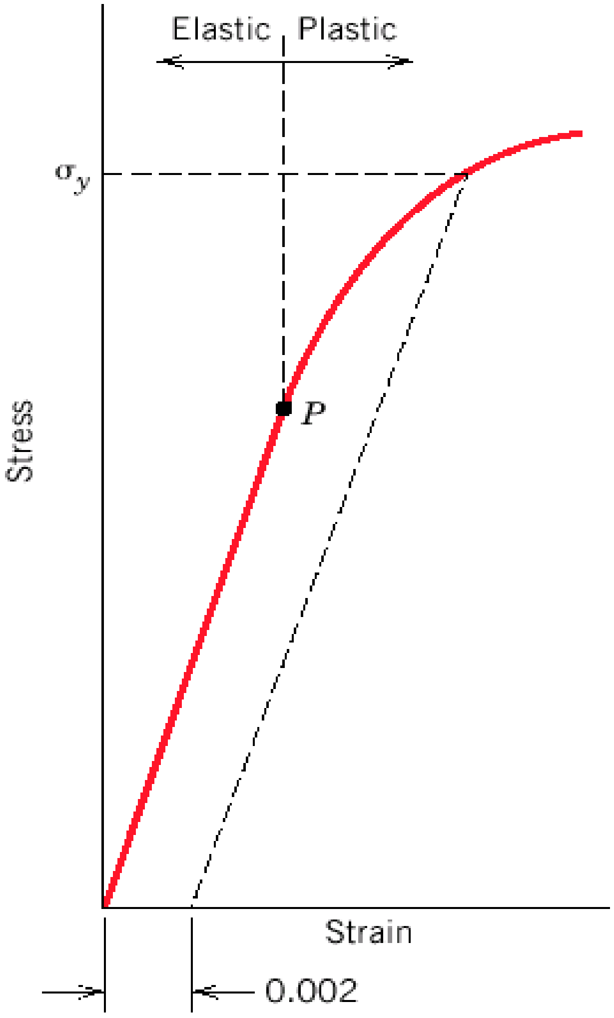
Stress-Strain Behavior



Elastic deformation

Reversible:

(For small strains)

Stress removed → material returns to its original size

Plastic deformation

Irreversible:

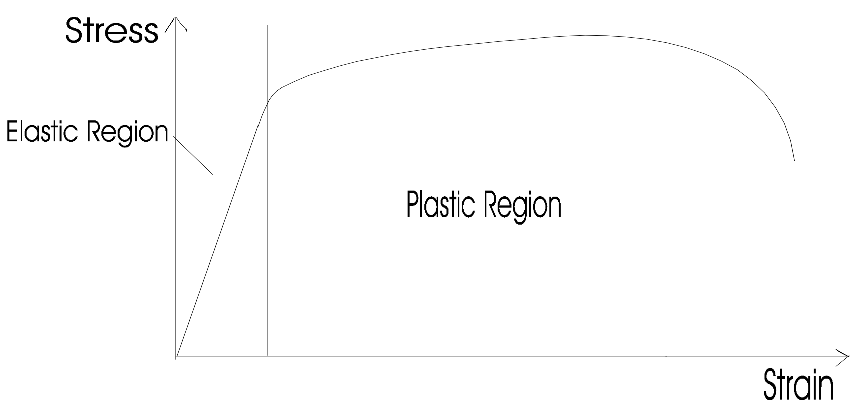
Stress removed → material does not return to its original dimensions.

Yield Strength (σ_y)

- **The stress at which plastic deformation becomes noticeable (0.2% offset).**
- ***P* the stress that divides the elastic and plastic behavior of the material.**

The Stress - Strain curve Divided into 2 regions

ELASTIC | **PLASTIC**



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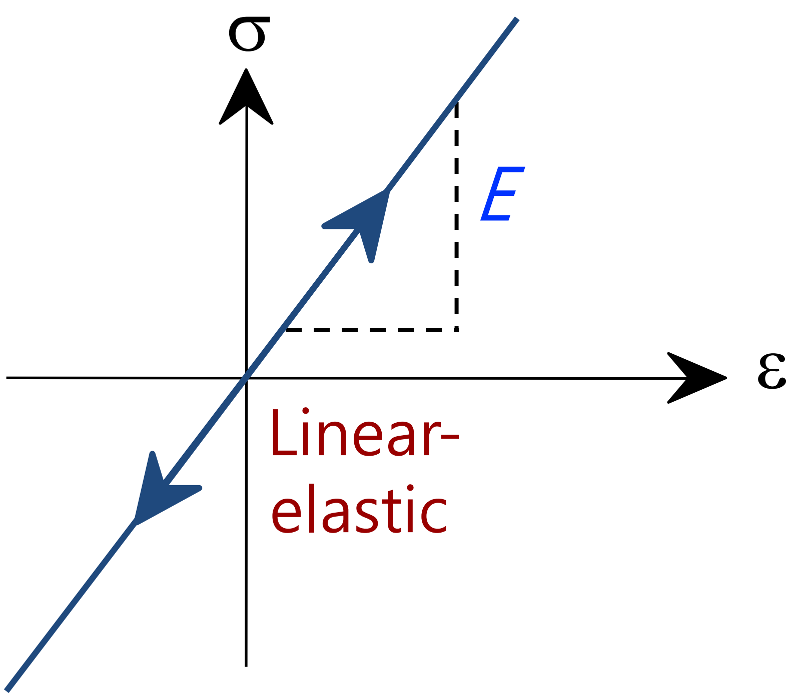
Linear: Elastic Properties

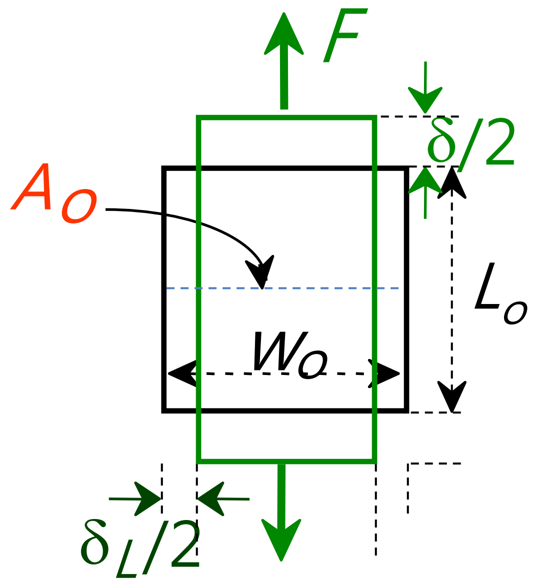
- **Modulus of Elasticity, *E* :**
  (also known as Young's modulus)

  - **Hooke's Law:** ut tensio, sic vis ("as the extension, so the force")

$$\sigma = E\,\varepsilon$$

Units:
E: [GPa] or [psi]
σ: in [Mpa] or [psi]
ε: [m/m or mm/mm] or [in/in]





Here: The Black Outline is Original, Green is after application of load

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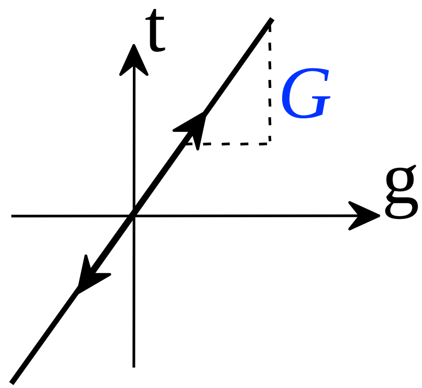
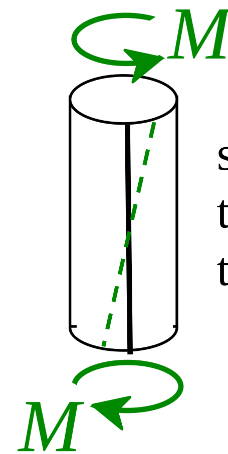
Other Elastic Properties

- **Elastic Shear modulus, *G*:**

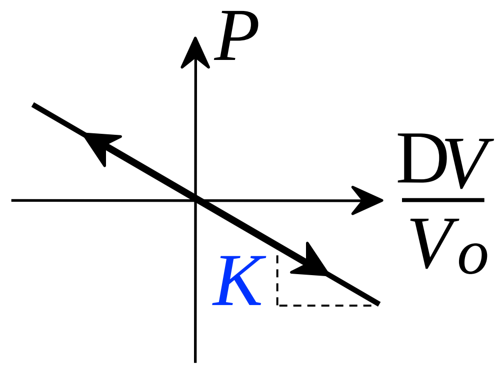
$$t = G\, g$$

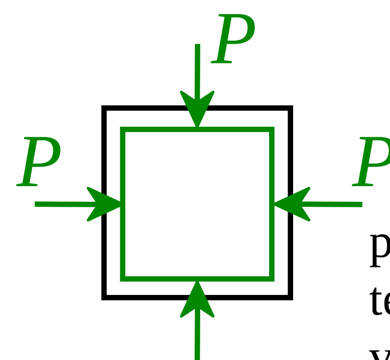




- **Elastic Bulk modulus, K:**

$$P = -K \frac{DV}{V_o}$$





pressure test: Init. vol $=V_o$. Vol chg. $= DV$

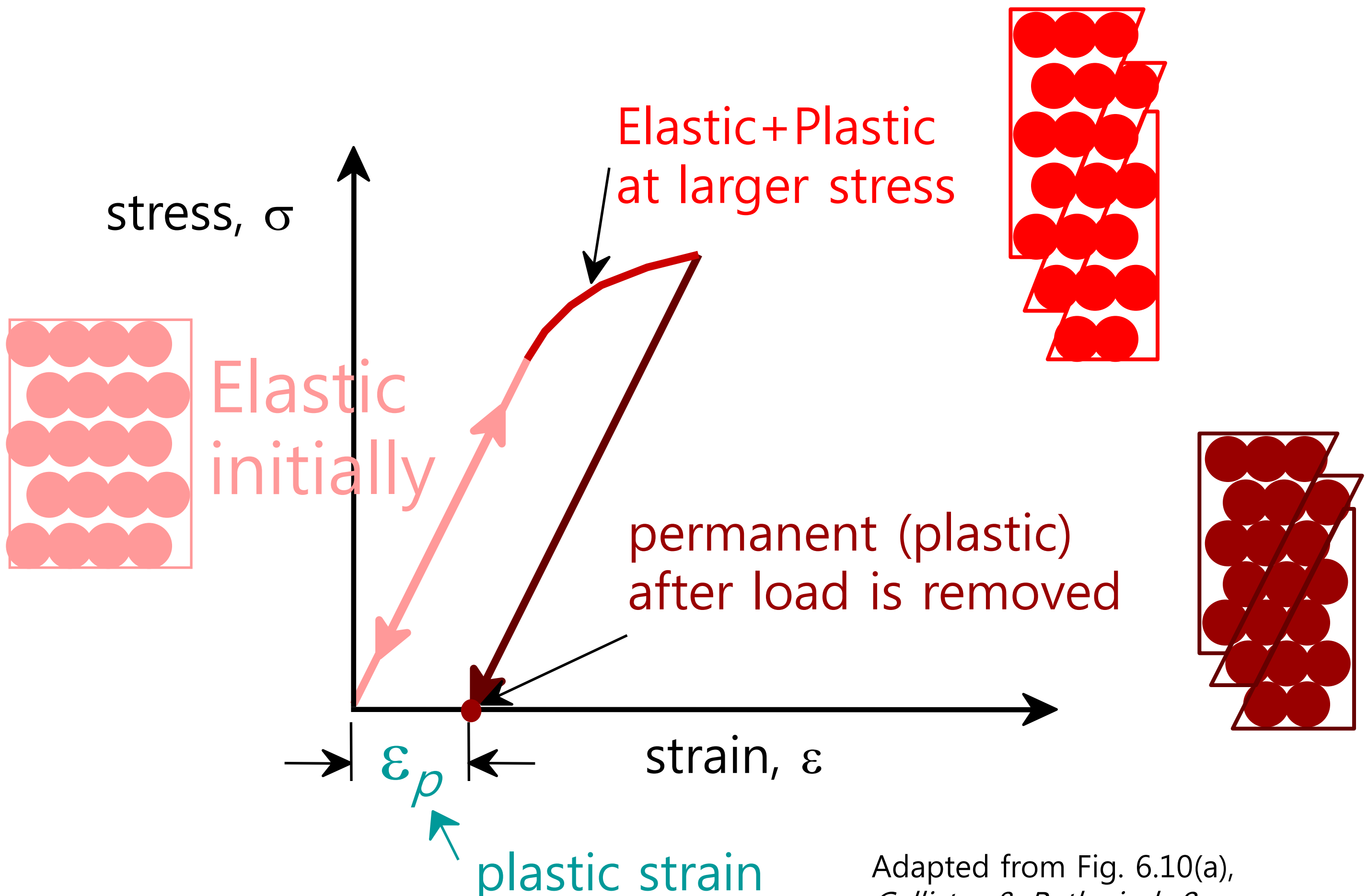
- **Special relations for *isotropic materials*:**

$$G = \frac{E}{2(1+n)} \qquad K = \frac{E}{3(1-2n)}$$

E is Modulus of Elasticity ν is Poisson's Ratio

Atomic Demo of Plastic (Permanent) Deformation

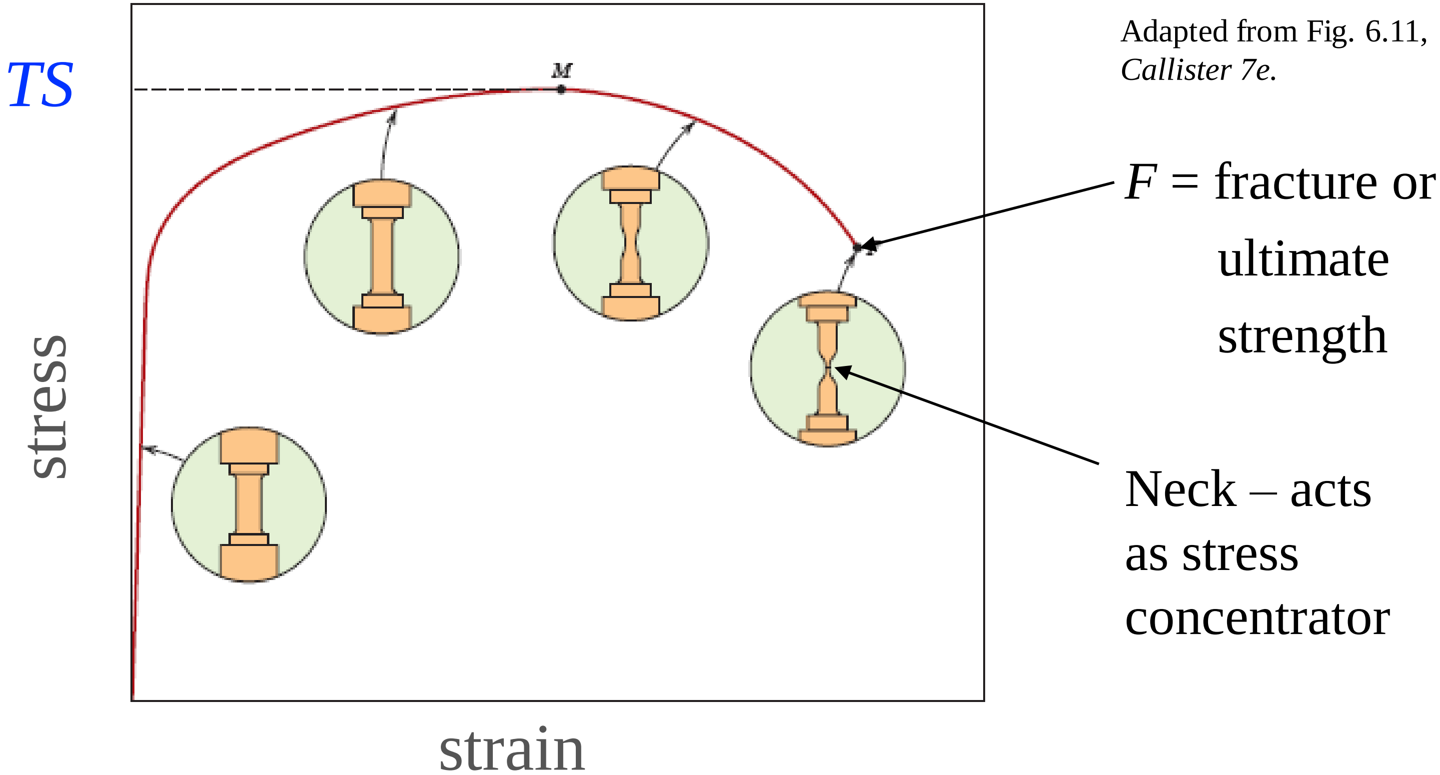
- Simple tension test:



Adapted from Fig. 6.10(a), *Callister & Rethwisch 8e.*

Tensile properties: Tensile Stress

- TS is Maximum stress on stress-strain curve.

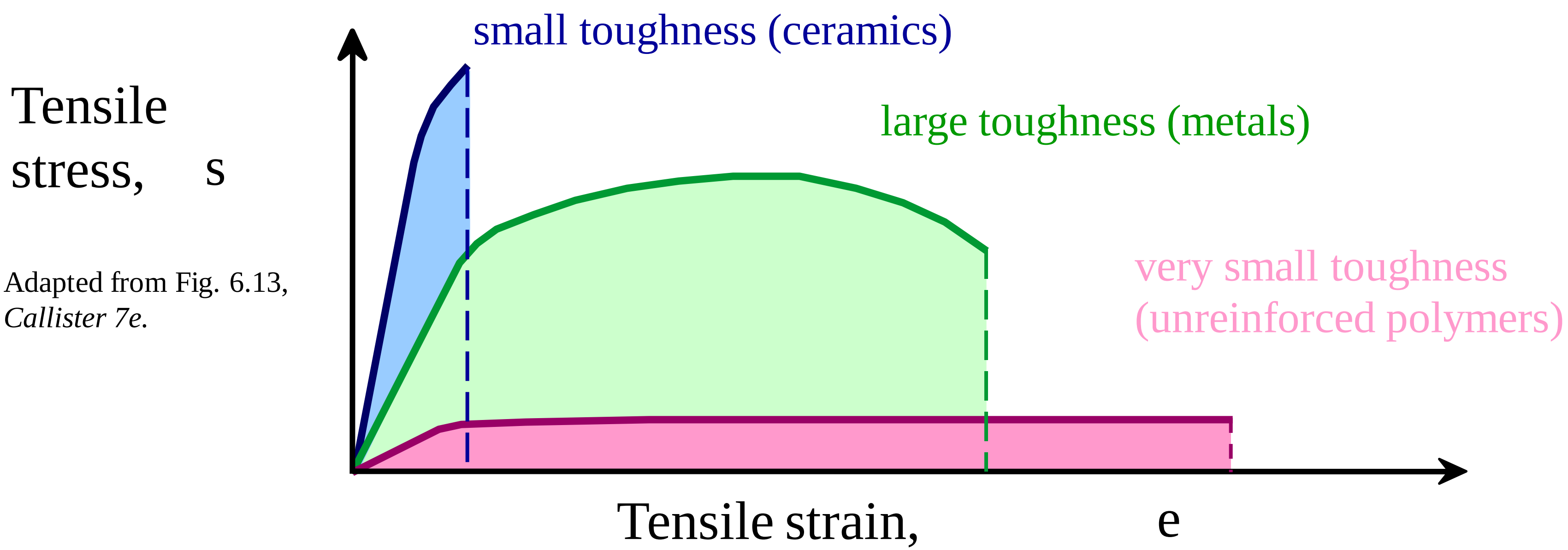


Adapted from Fig. 6.11, *Callister 7e.*

- Metals: occurs when noticeable necking starts.
- Polymers: occurs when polymer backbone chains are aligned and about to break.

Tensile Stress :Toughness

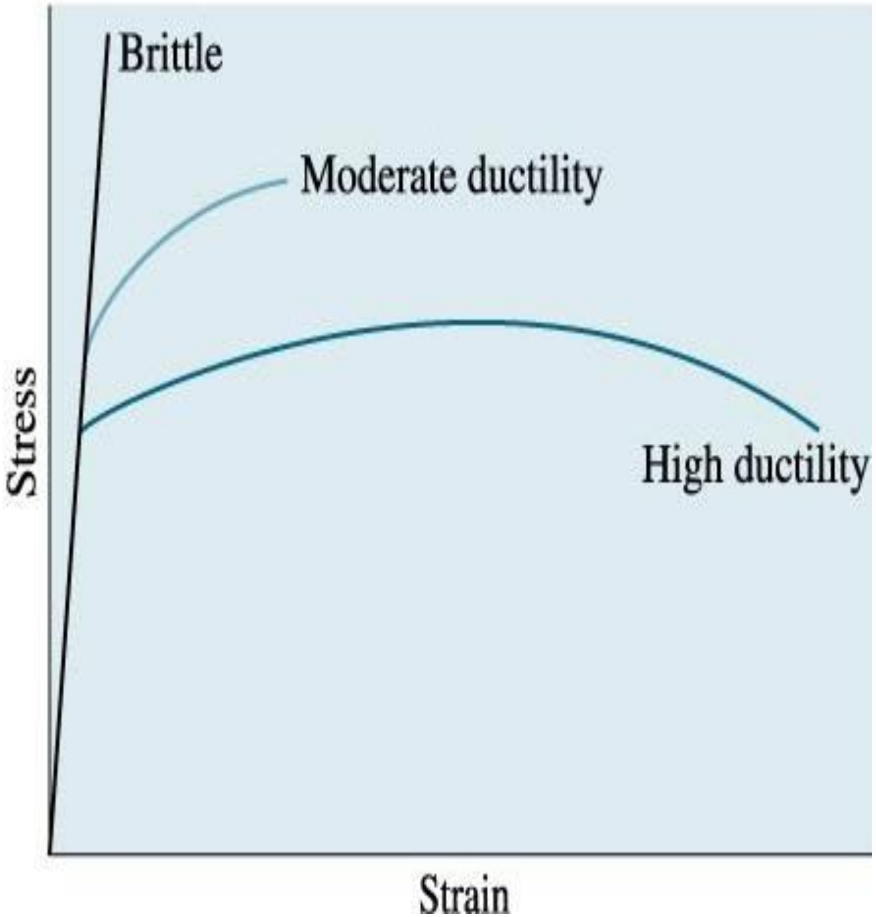
- Measure the energy to break a unit volume of material
- Approximate by the area under the tensile stress-strain curve.

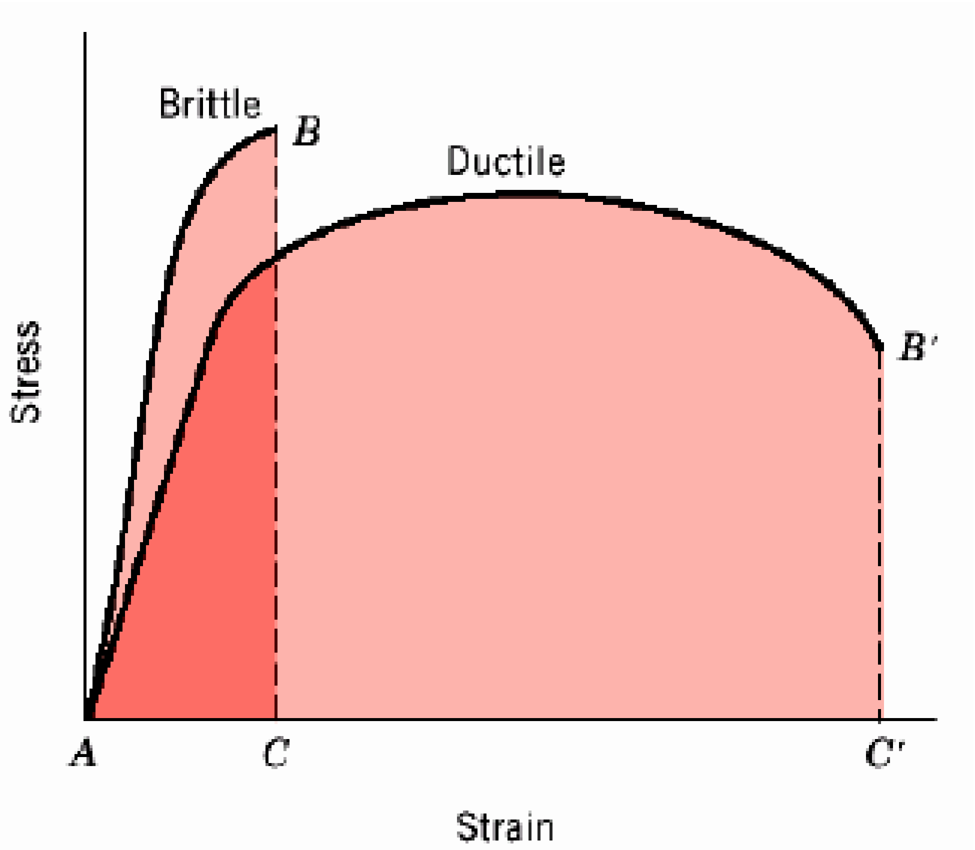


Adapted from Fig. 6.13, *Callister 7e.*

Brittle fracture: elastic energy
Ductile fracture: elastic + plastic energy

Tensile properties: Ductility

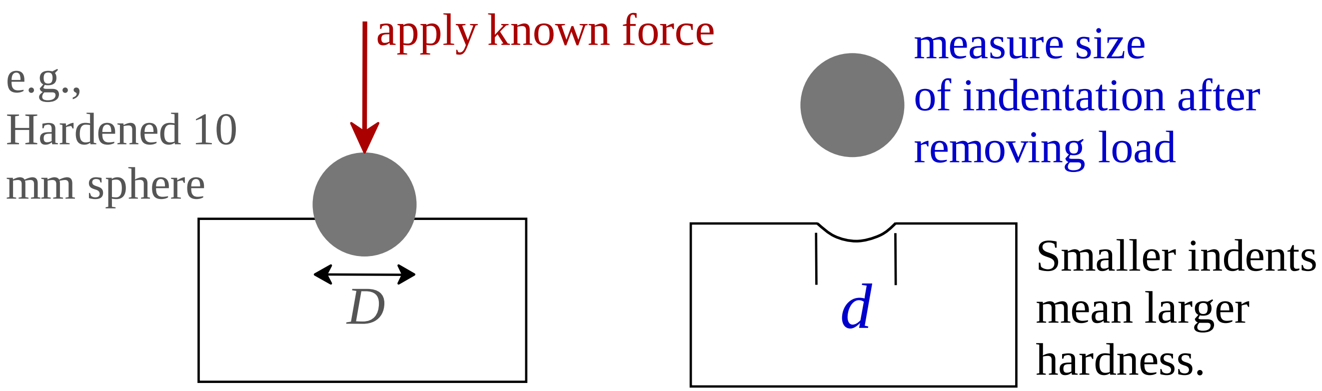


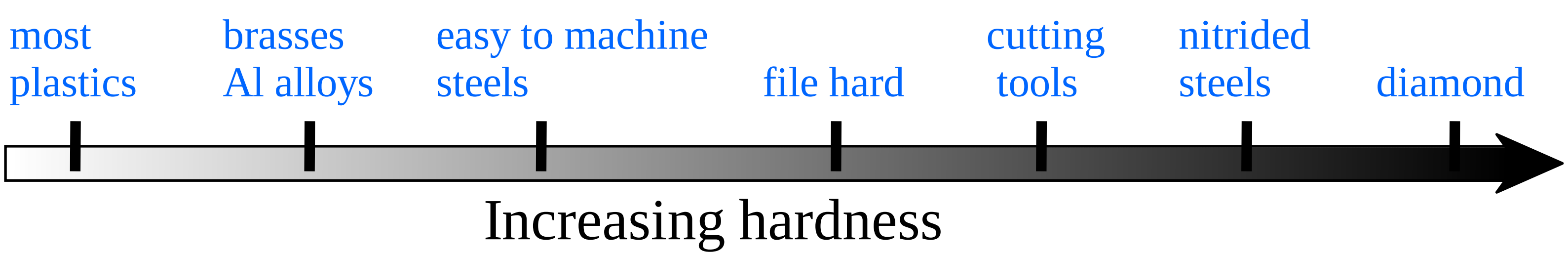


The total elongation of the specimen due to plastic deformation, neglecting the elastic stretching (the broken ends snap back and separate after failure).

Tensile Properties: Hardness

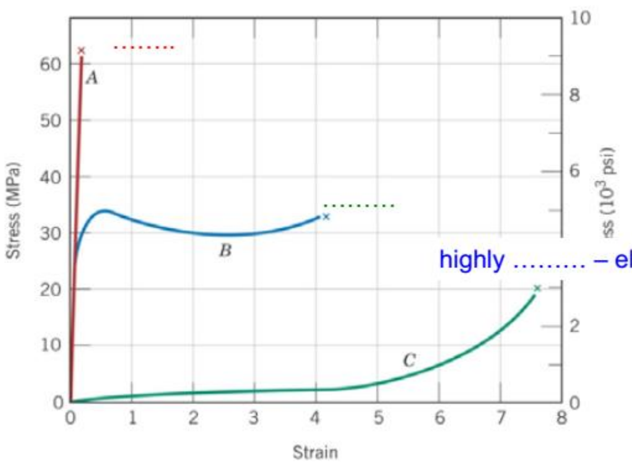
- Resistance to permanently (plastically) indenting the surface of a product.
- Large hardness means:
  - Resistance to plastic deformation or cracking in compression.
  - Better wear properties.





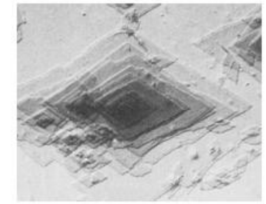
Mechanical Properties of Polymers

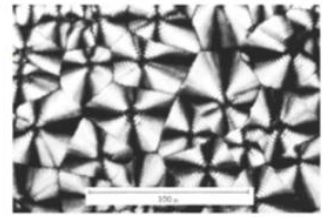
There are three typical classes of polymer stress-strain characteristic

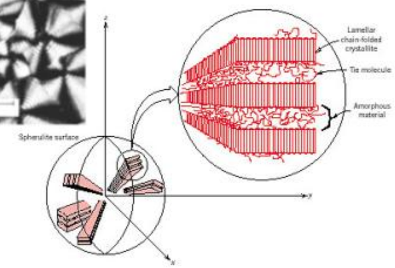


highly ……… – elastomeric

Chain folded model: **crystals are actually small platelets of interwoven polymer chains**







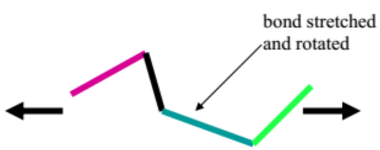
Mechanisms of Elastic Deformation, in Amorphous & Semicrystalline Polymers

- Elastic deformation takes place due to the elongation of chain molecules by **bond stretching** *(all regions)* and bond **rotation** *(amorphous region)*, along the direction of the applied stress.

stable conformation

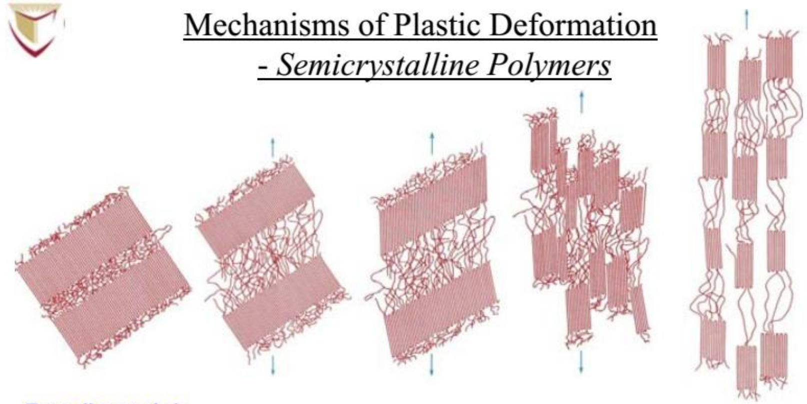
Bonds do not break and chains do not slip past each other.

Inter-molecular bonding (**……………..**) is much weaker than other types, hence **yield strength** of polymers is low compared to metals or ceramics.



"stressed" conformation

Mechanisms of Plastic Deformation - *Semicrystalline Polymers*



Two adjacent chain folded lamellae and interlamellar amorphous material before deformation

Elongation of amorphous tie chains

Tilting of lamellar chain folds

Separation of crystalline block segments

Orientation of block segments and tie chains with tensile axis

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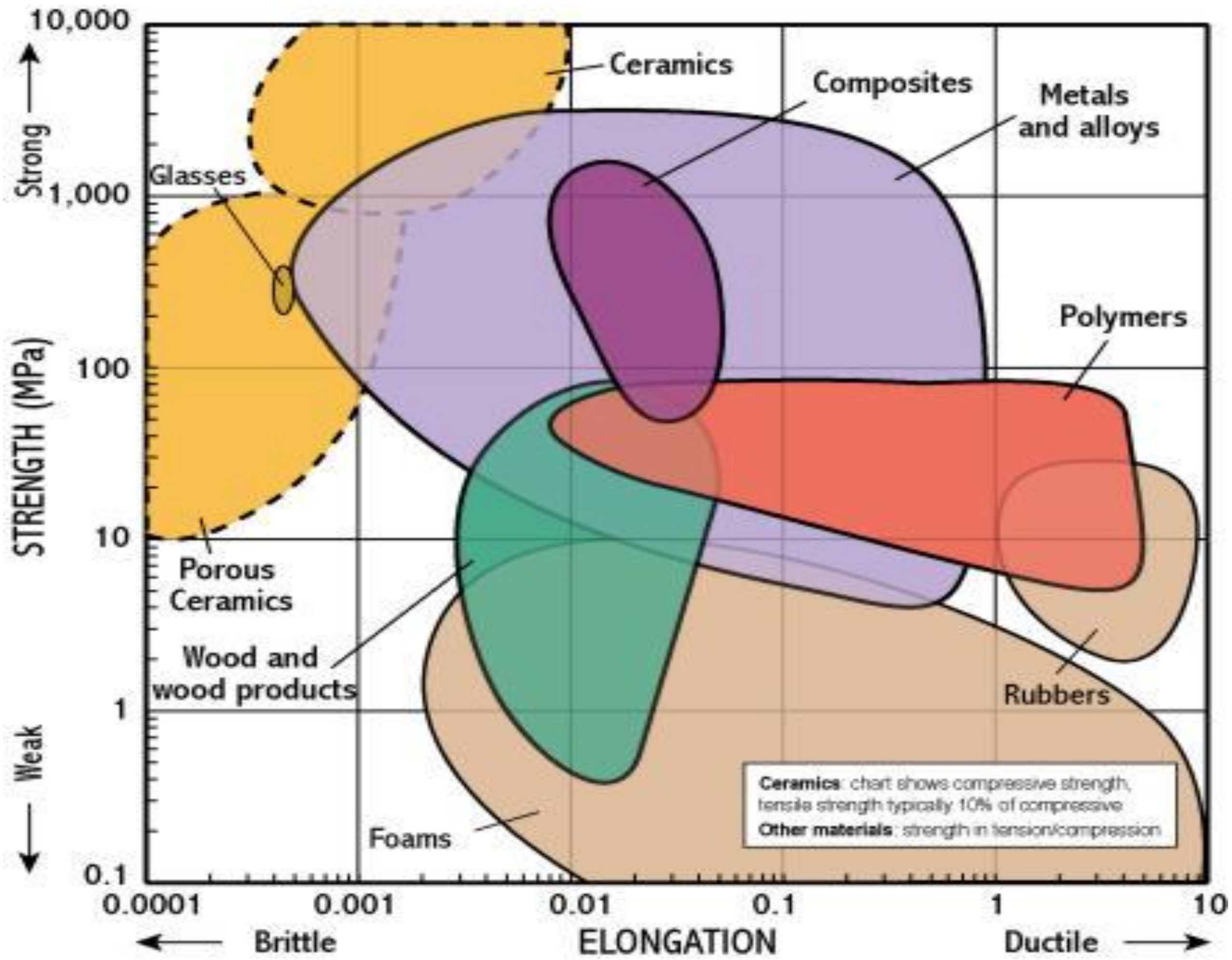
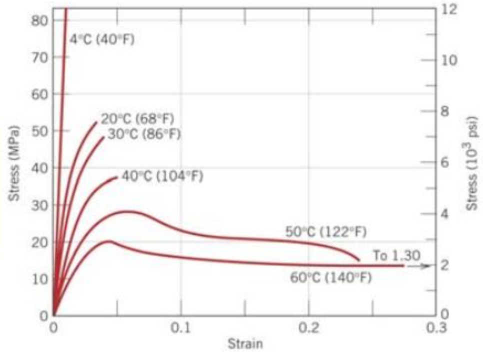
General Classes of Materials



- Decreasing Temp.
  - .... E
  - .... TS
  - .... %EL



Effect of temperature on stress-strain behavior of PMMA (left).

Increasing strain rate causes the SAME effects as ***decreasing T.***

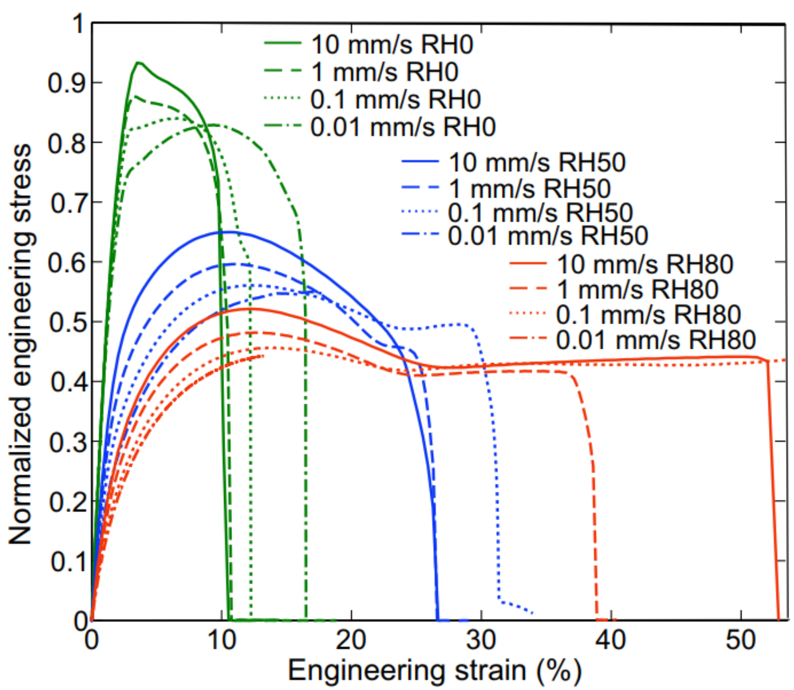


Fig. 2. Normalized engineering stress versus engineering strain curves showing the effect of relative humidity on the tensile properties of PA6.6 matrix subjected to different displacement rates.

mechanical and thermal aspects. Polymer Testing, Elsevier, 2014, 34, pp.290-298.

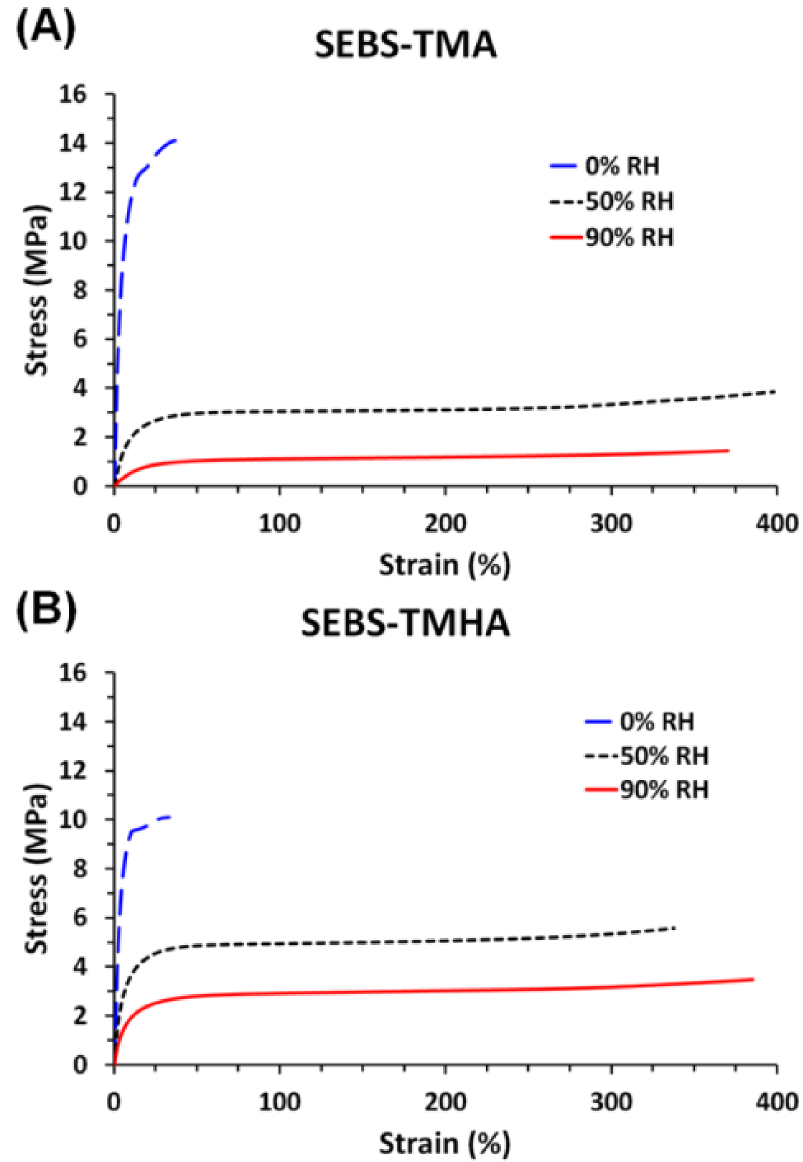


Figure 3. Stress−strain curves of (A) SEBS-TMA and (B) SEBS-TMHA measured at 50 °C with 0%, 50%, and 90% relative humidity (RH).

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Approaches to get better Mechanical Properties

Longer chains make stronger polymers.

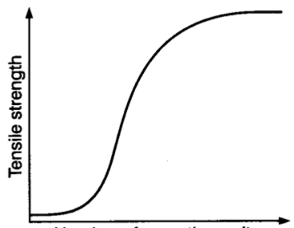
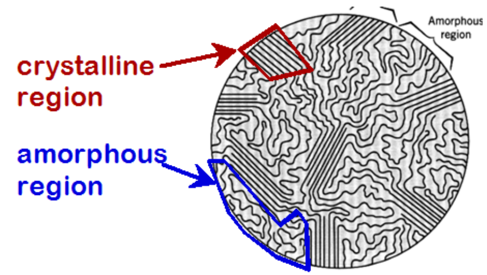


Figure 31 The relationship between tensile strength and chain length for a polymer.

- There is a critical length needed before strength increases.
- An average No. of 100 repeating units is necessary for HC polymers but only 40 for nylons.

- **Molecular weight** M_w: Mass of a mole of chains.

- Tensile strength (TS):
  --often increases with M_w.
  --Why? Longer chains are entangled (anchored) better.
- % Crystallinity: % of material that is crystalline.
  --TS and E often increase with % crystallinity.
  --Annealing causes crystalline regions to grow. % crystallinity increases.



Crystalline polymers

- Crystallinty is areas in polymer where chains packed in a regular way.
- Both amorphous and crystalline areas can exist in the same polymer.
- More crystalline polymer causes stronger and less flexible polymer.

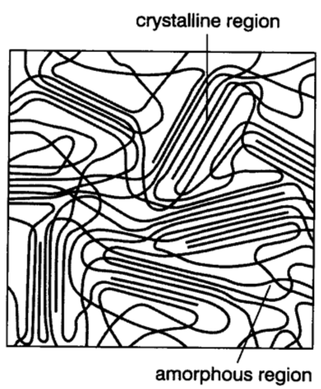
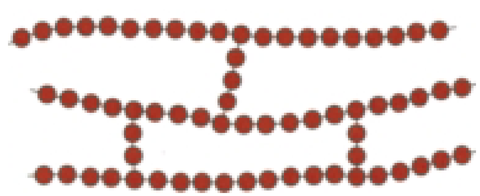


Figure 32 Crystalline and amorphous regions of a polymer.

Plasticizers

Are small molecules which occupy position between polymer chains (like adding water to mud to make it easy in molding)

1. To increase flexibility, elongation and to reduce hardness and stiffness.
2. To lower the processing temperature (energy saving, decomposition preventing)



By cross-linking tensile stress could be increase

Essentials of Materials Science & Engineering

Second Edition

Authors: Donald R. Askeland & Pradeep P. Fulay

Materials Science and Engineering: An Introduction

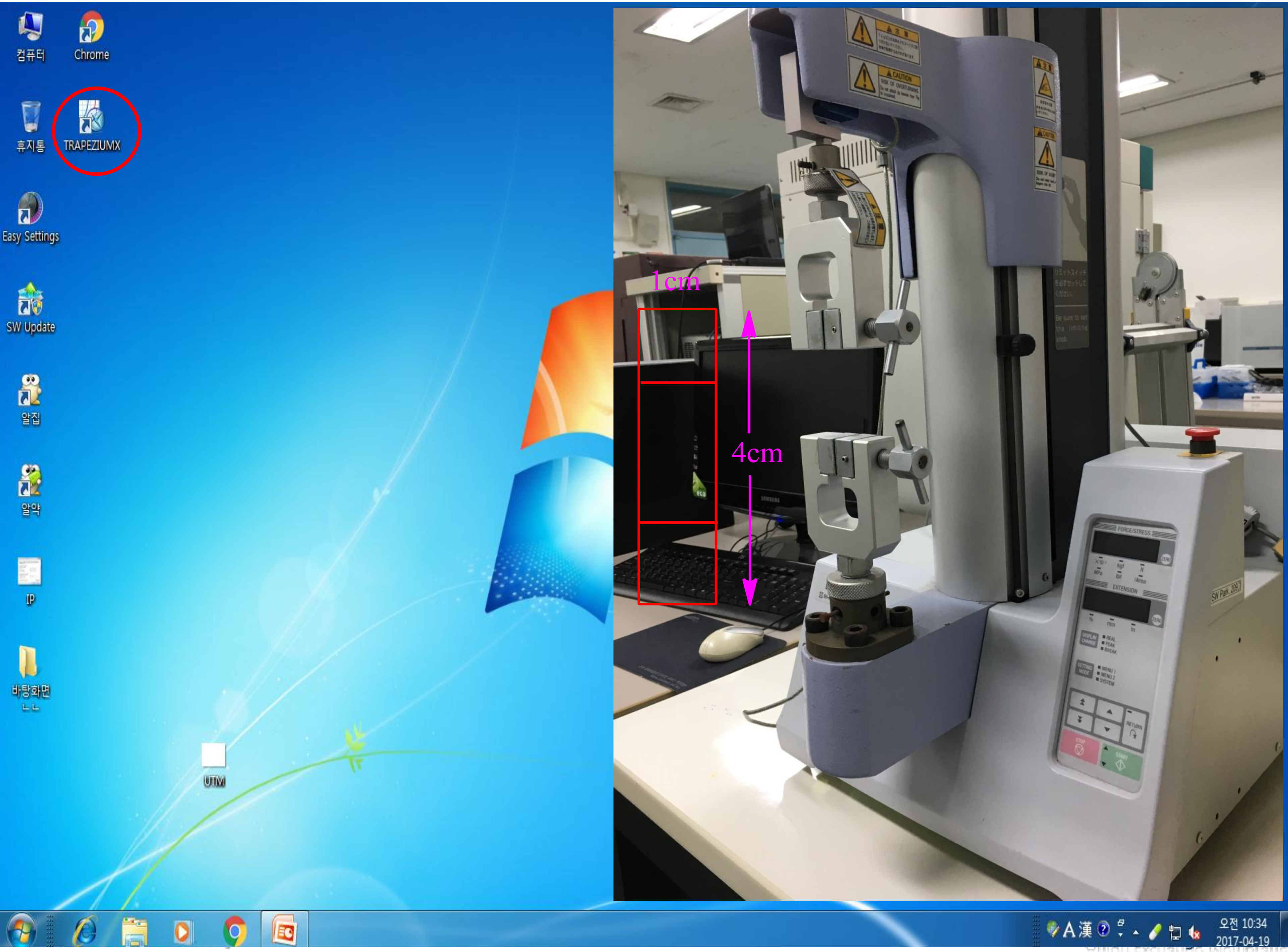
Sixth Edition, **Author: William D. Callister, Jr.**

The Science and Engineering of Materials

Fourth Edition, **Authors: Askeland and Phule (Fulay ?)**

Introduction to Materials Science for Engineers

Sixth Edition, **Author: James F. Shackelford**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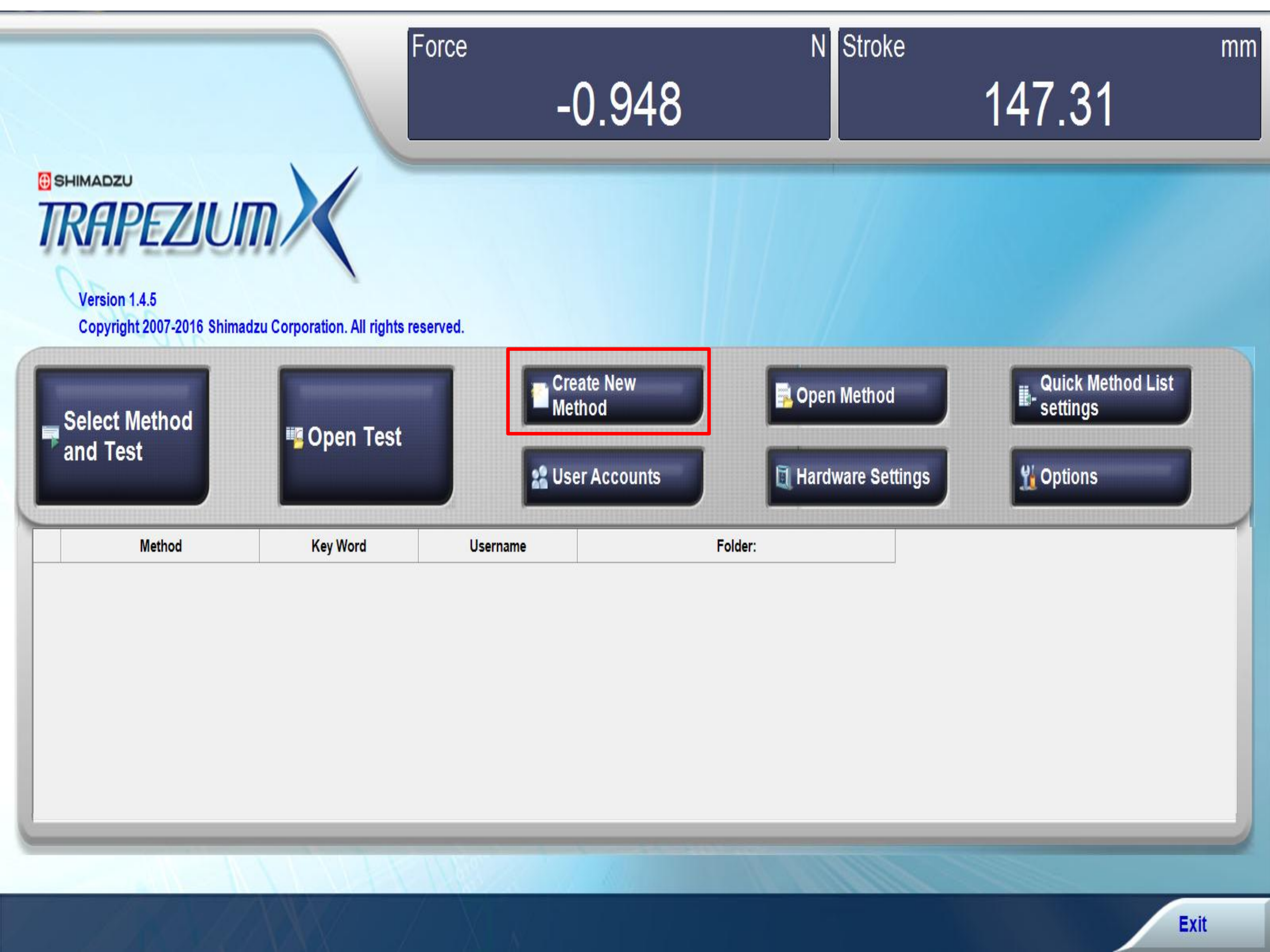
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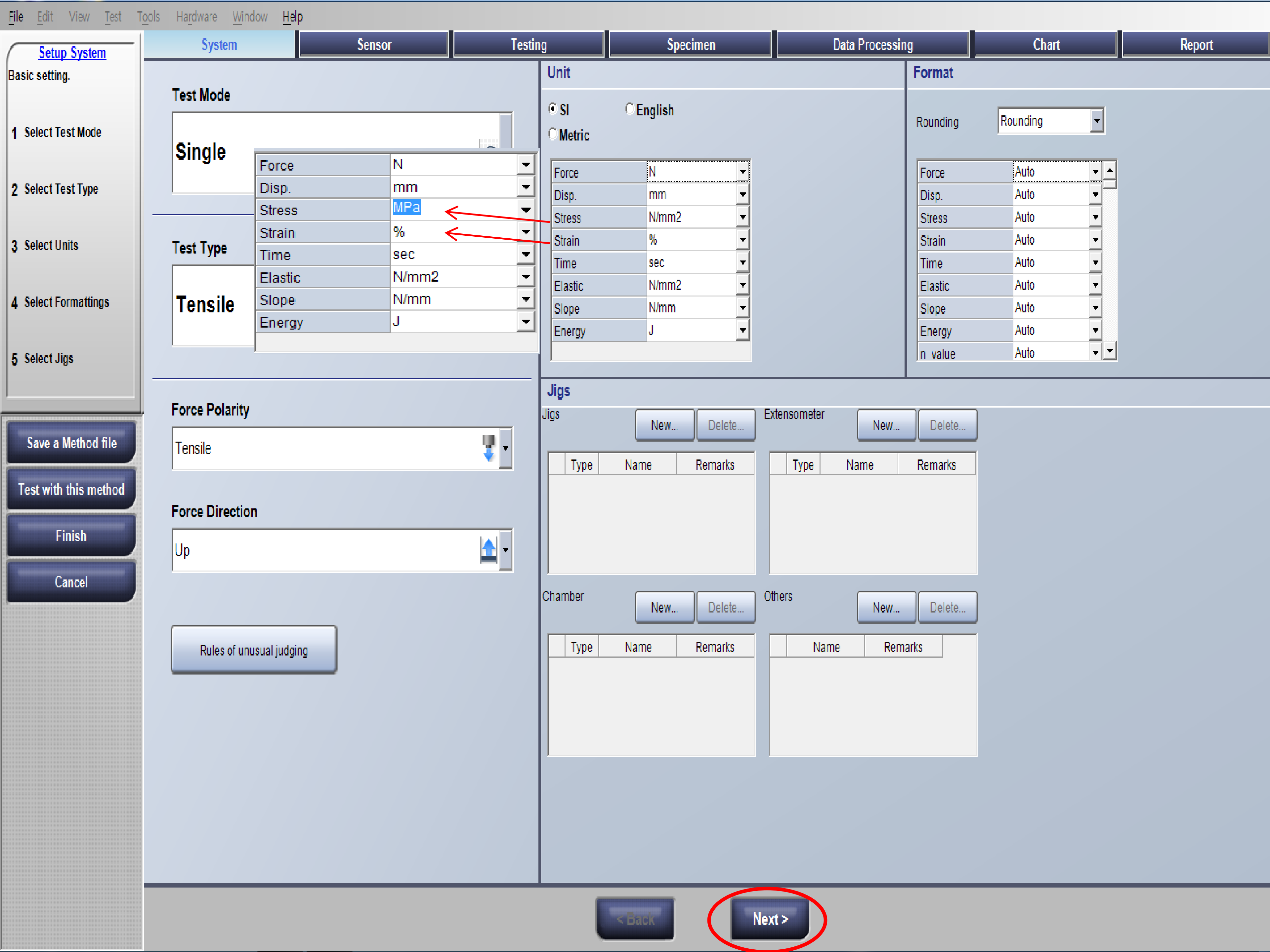
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2 Select Test Type
3 Select Units
4 Select Formattings
5 Select Jigs
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Stress MPa
Strain %
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Slope N/mm
Energy J
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Tensile
Force Direction
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Stress N/mm2
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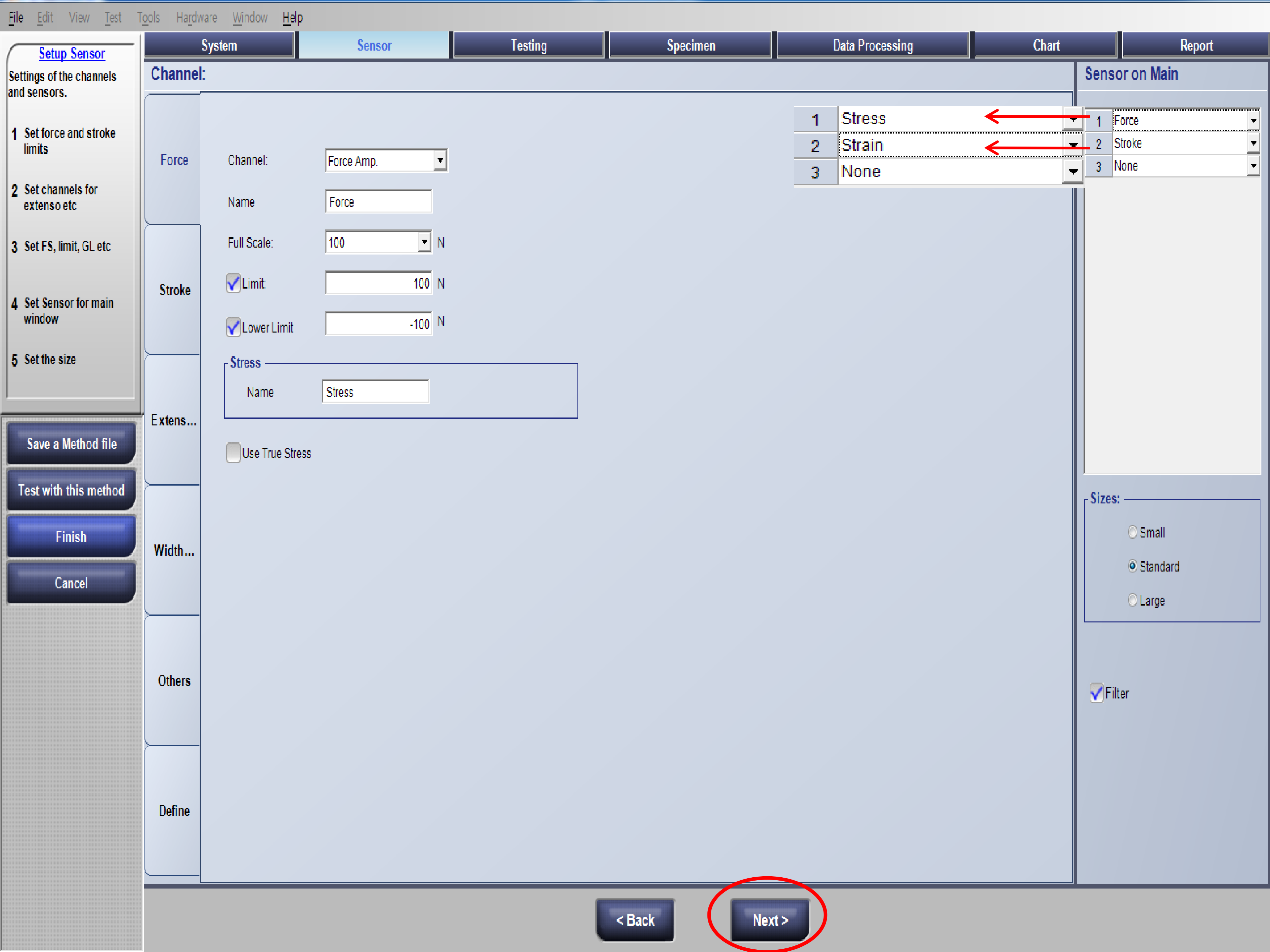
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2 Set channels for extenso etc
3 Set FS, limit, GL etc
4 Set Sensor for main window
5 Set the size
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Cancel
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Force
Stroke
Extens...
Width...
Others
Define
Channel:
Force Amp.
Name
Force
Full Scale:
100
N
Limit:
100
N
Lower Limit
-100
N
Stress
Name
Stress
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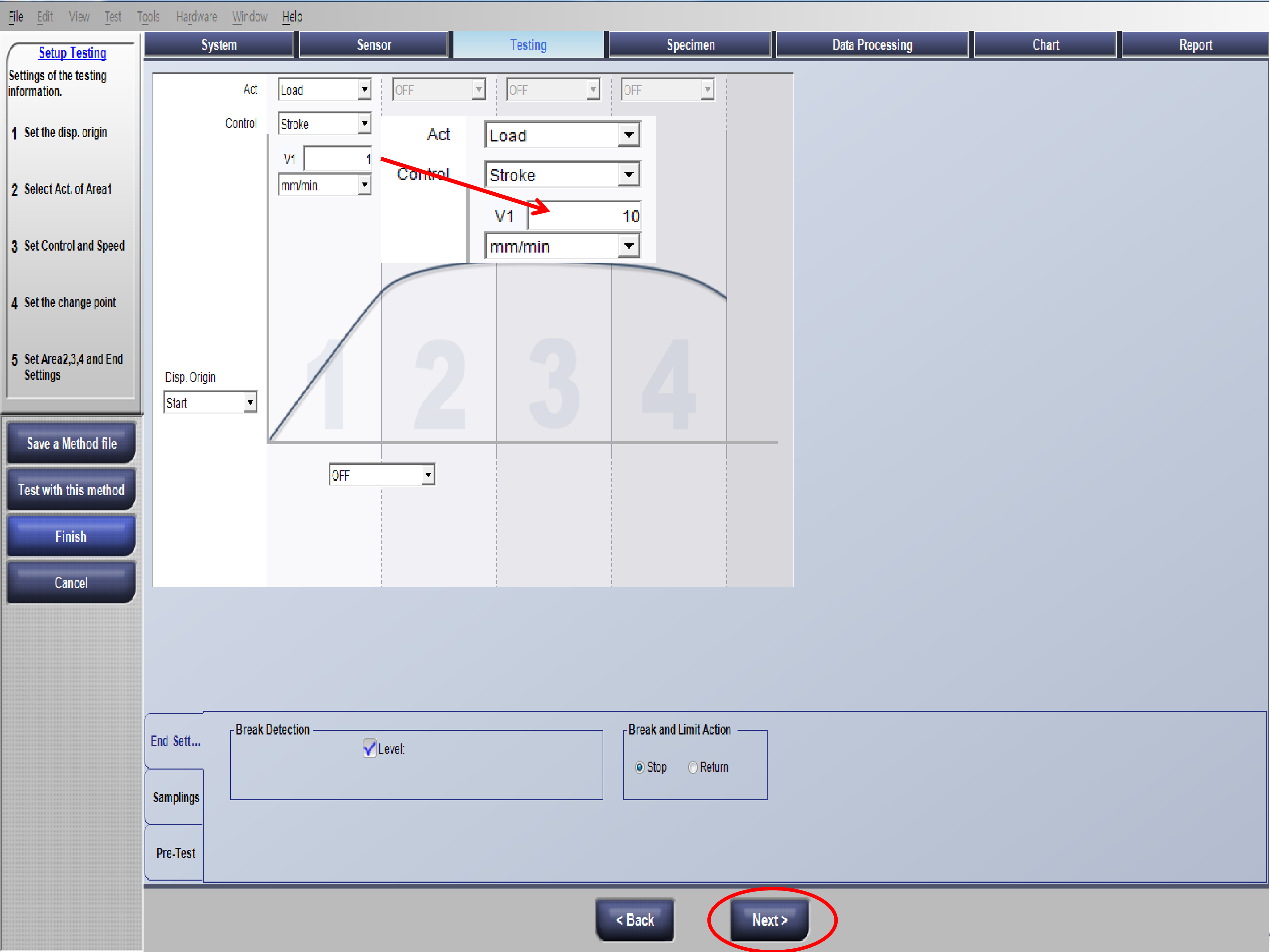
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2 Select Act. of Area1
3 Set Control and Speed
4 Set the change point
5 Set Area2,3,4 and End Settings
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Cancel
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Control
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Control
Stroke
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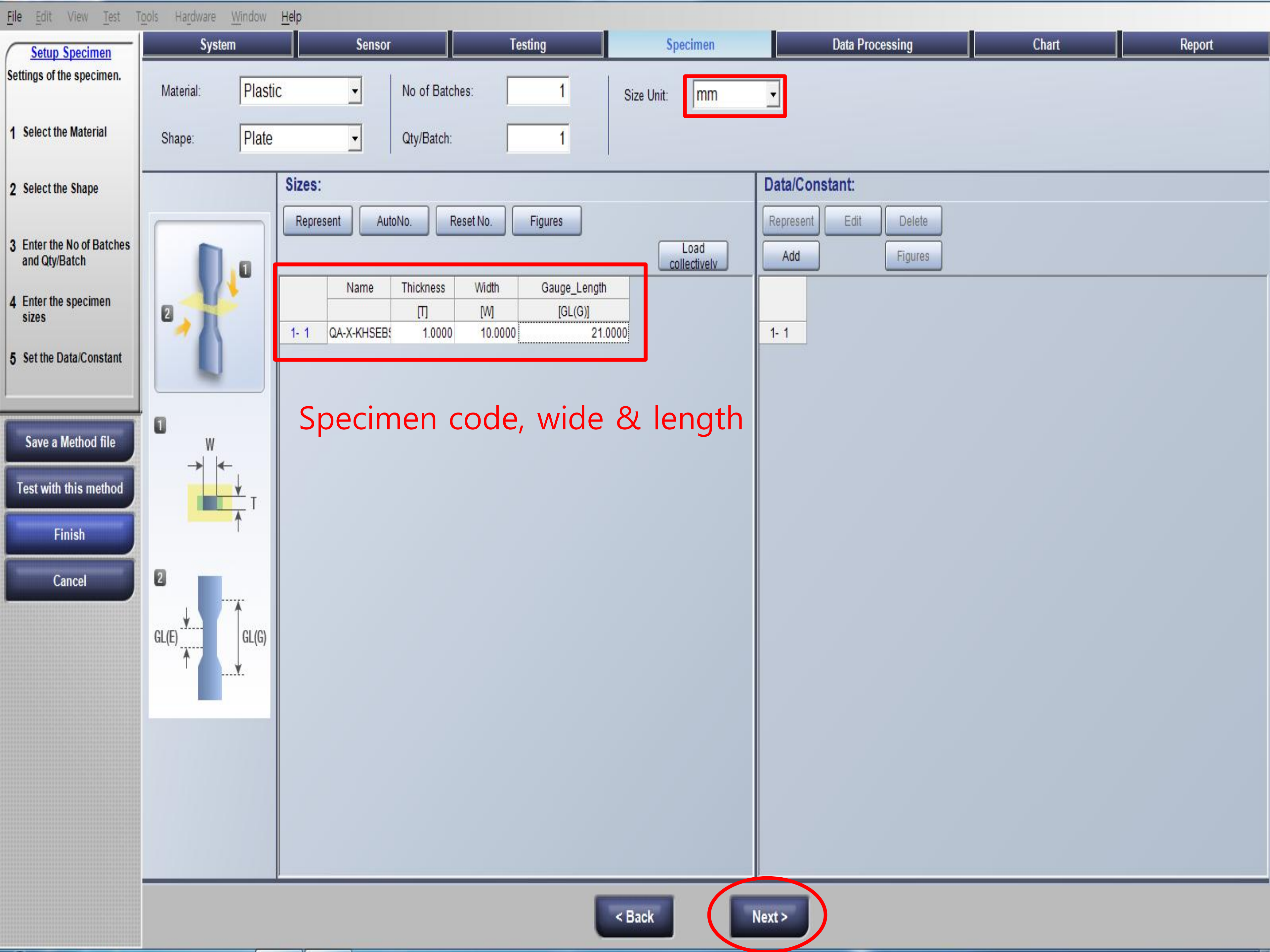
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Settings of the specimen.
1 Select the Material
2 Select the Shape
3 Enter the No of Batches and Qty/Batch
4 Enter the specimen sizes
5 Set the Data/Constant
Save a Method file
Test with this method
Finish
Cancel
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Shape: Plate
No of Batches: 1
Qty/Batch: 1
Size Unit: mm
Sizes:
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AutoNo.
Reset No.
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Width [W]
Gauge_Length [GL(G)]
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10.0000
21.0000
Data/Constant:
Represent
Edit
Delete
Add
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T
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GL(G)
Specimen code, wide & length
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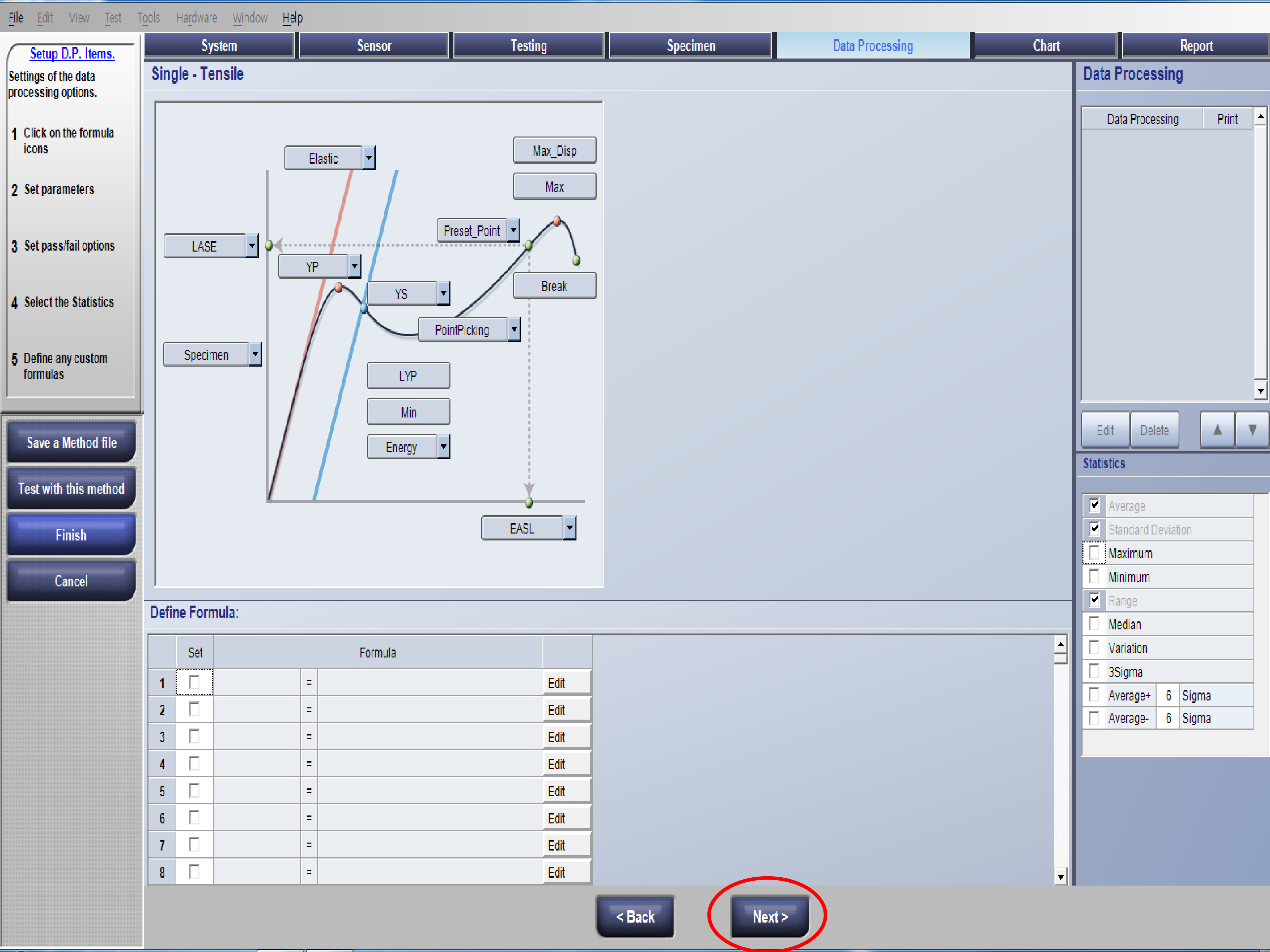
Next >


File Edit View Test Tools Hardware Window Help
System
Sensor
Testing
Specimen
Data Processing
Chart
Report
Setup D.P. Items.
Settings of the data processing options.
1 Click on the formula icons
2 Set parameters
3 Set pass/fail options
4 Select the Statistics
5 Define any custom formulas
Save a Method file
Test with this method
Finish
Cancel
Single - Tensile
Elastic
Max_Disp
Max
Preset_Point
LASE
YP
YS
Break
PointPicking
Specimen
LYP
Min
Energy
EASL
Define Formula:
Set
Formula
1
2
3
4
5
6
7
8
Edit
Data Processing
Print
Edit
Delete
Statistics
Average
Standard Deviation
Maximum
Minimum
Range
Median
Variation
3Sigma
Average+ 6 Sigma
Average- 6 Sigma
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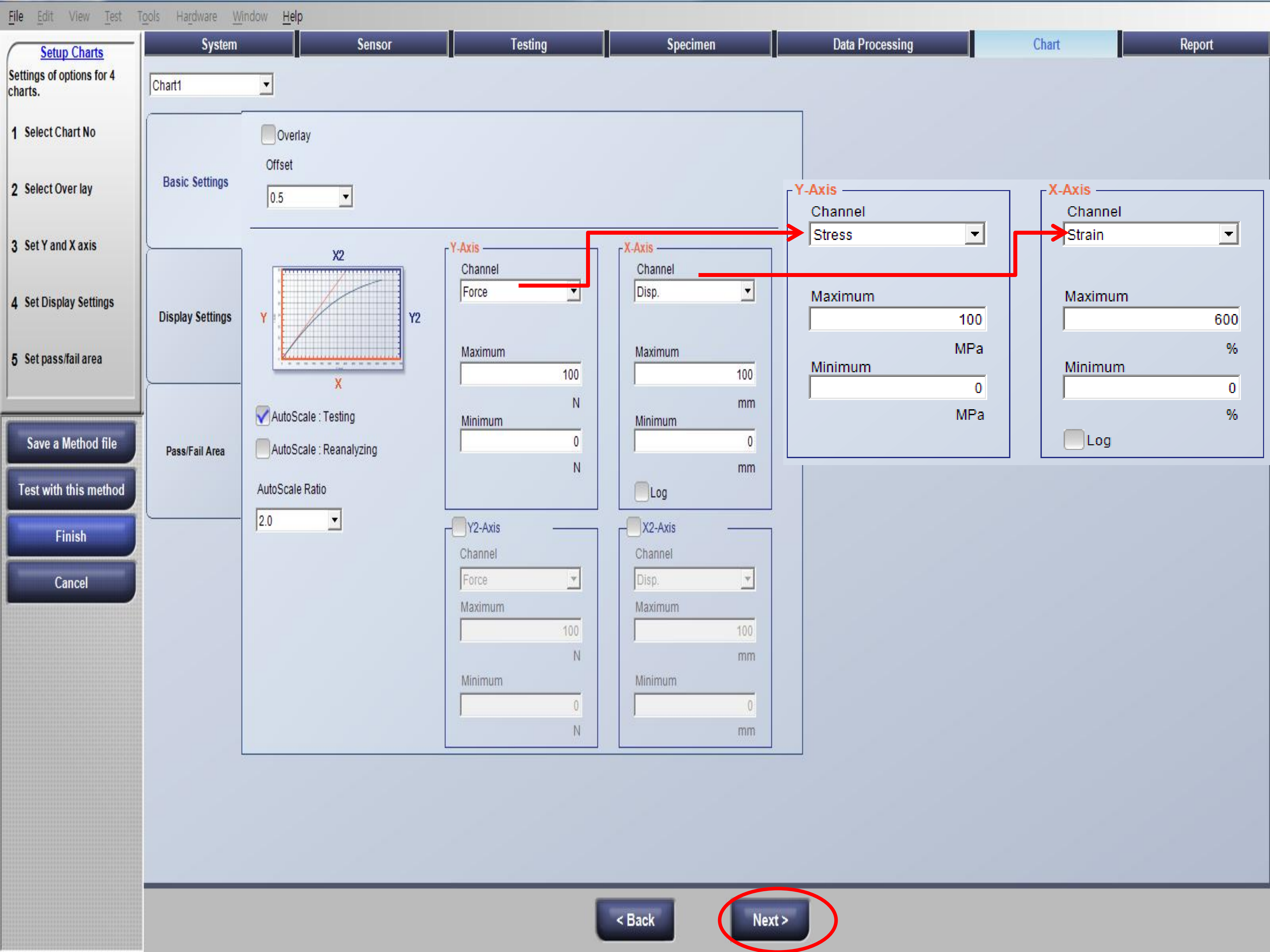
File Edit View Test Tools Hardware Window Help
System
Sensor
Testing
Specimen
Data Processing
Chart
Report
Setup Charts
Settings of options for 4 charts.
1 Select Chart No
2 Select Over lay
3 Set Y and X axis
4 Set Display Settings
5 Set pass/fail area
Save a Method file
Test with this method
Finish
Cancel
Chart1
Basic Settings
Overlay
Offset
0.5
Display Settings
Pass/Fail Area
X2
Y
Y2
X
AutoScale : Testing
AutoScale : Reanalyzing
AutoScale Ratio
2.0
Y-Axis
Channel
Force
Maximum
100
N
Minimum
0
N
X-Axis
Channel
Disp.
Maximum
100
mm
Minimum
0
mm
Log
Y2-Axis
Channel
Force
Maximum
100
N
Minimum
0
N
X2-Axis
Channel
Disp.
Maximum
100
mm
Minimum
0
mm
Y-Axis
Channel
Stress
Maximum
100
MPa
Minimum
0
MPa
X-Axis
Channel
Strain
Maximum
600
%
Minimum
0
%
Log
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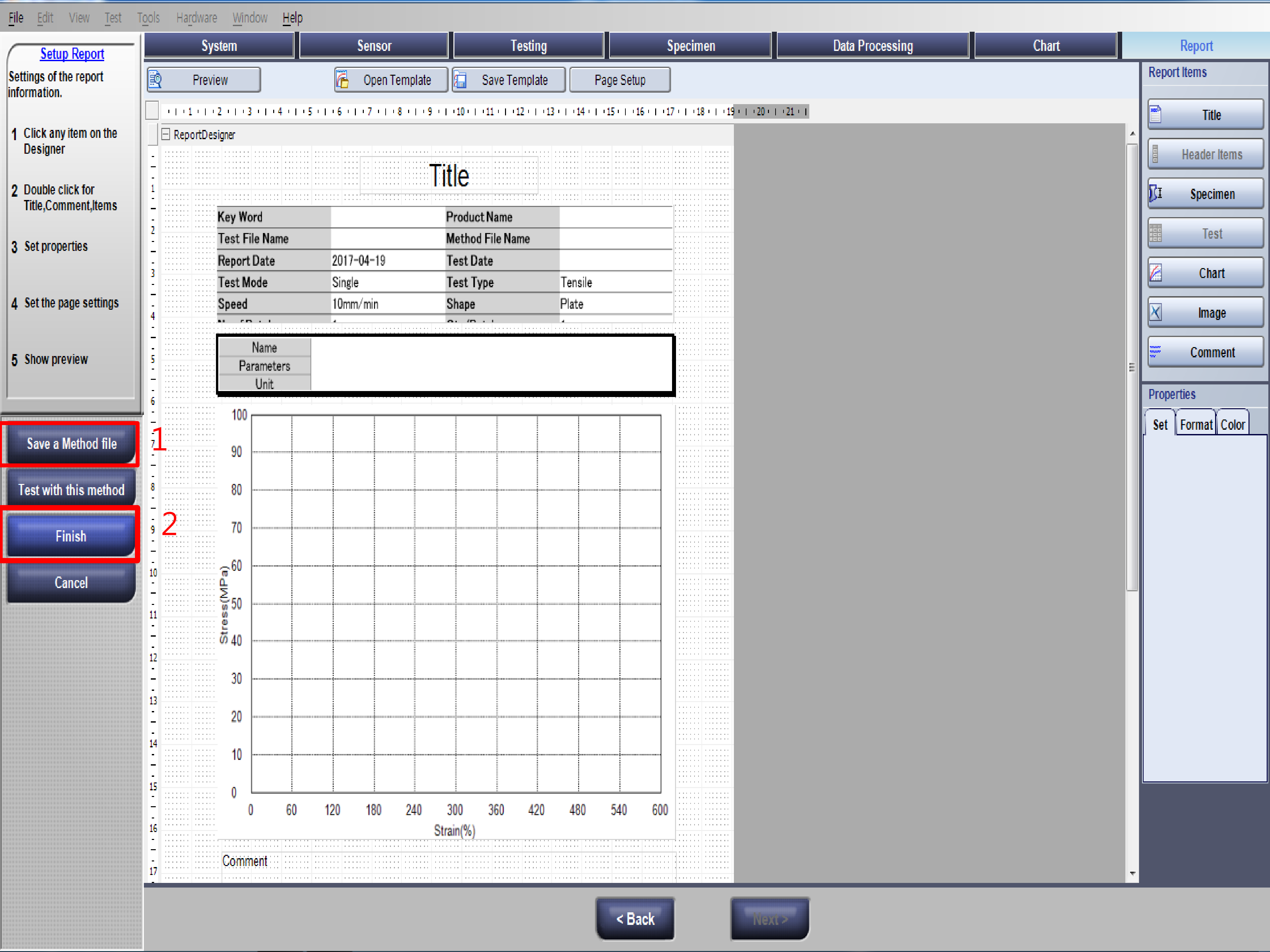
File Edit View Test Tools Hardware Window Help
System
Sensor
Testing
Specimen
Data Processing
Chart
Report
Setup Report
Settings of the report information.
1 Click any item on the Designer
2 Double click for Title,Comment,Items
3 Set properties
4 Set the page settings
5 Show preview
Save a Method file
Test with this method
Finish
Cancel
1
2
Preview
Open Template
Save Template
Page Setup
ReportDesigner
Title
Key Word
Product Name
Test File Name
Method File Name
Report Date
2017-04-19
Test Date
Test Mode
Single
Test Type
Tensile
Speed
10mm/min
Shape
Plate
Name
Parameters
Unit
Stress(MPa)
Strain(%)
Comment
Report Items
Title
Header Items
Specimen
Test
Chart
Image
Comment
Properties
Set
Format
Color
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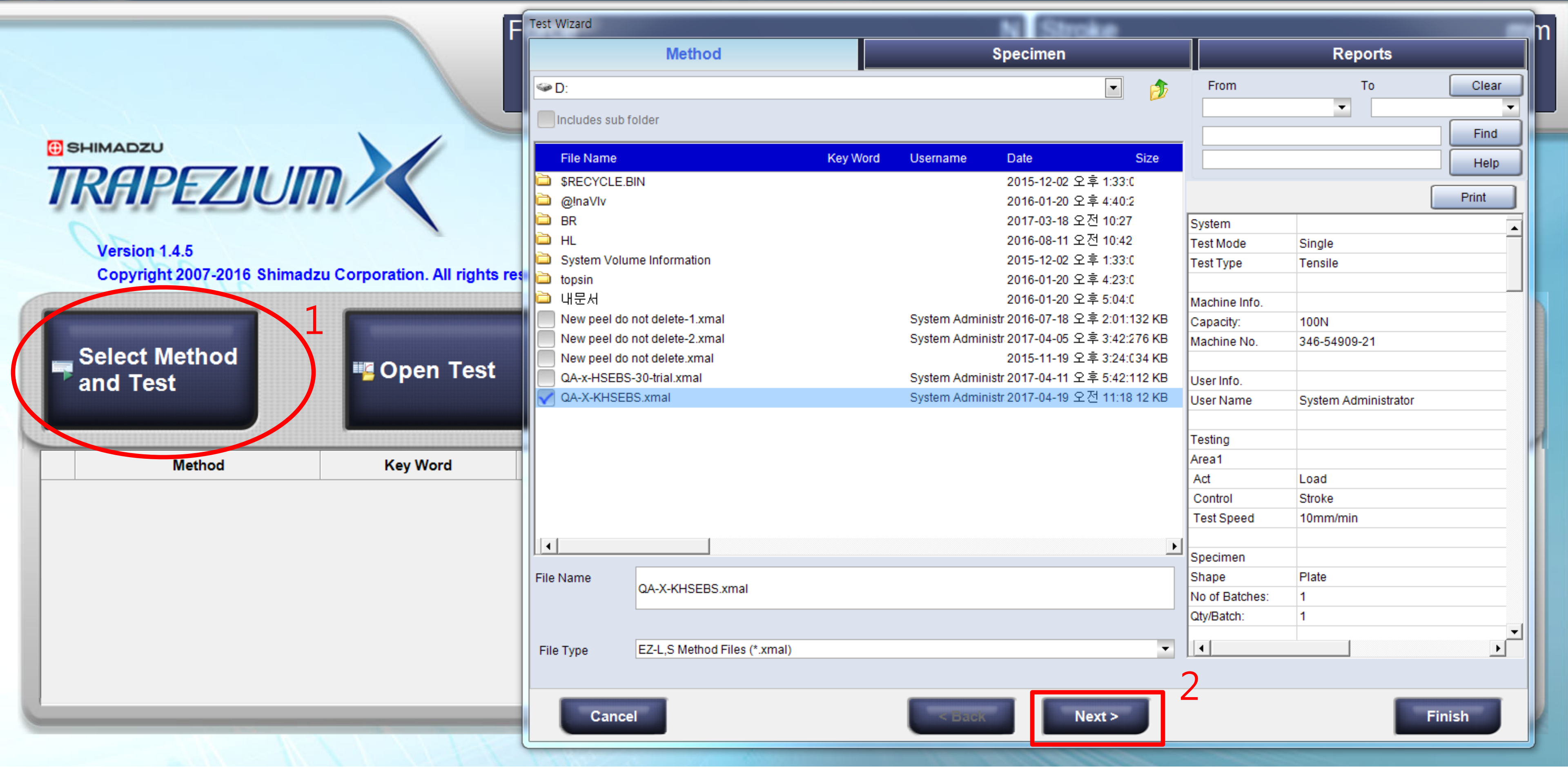
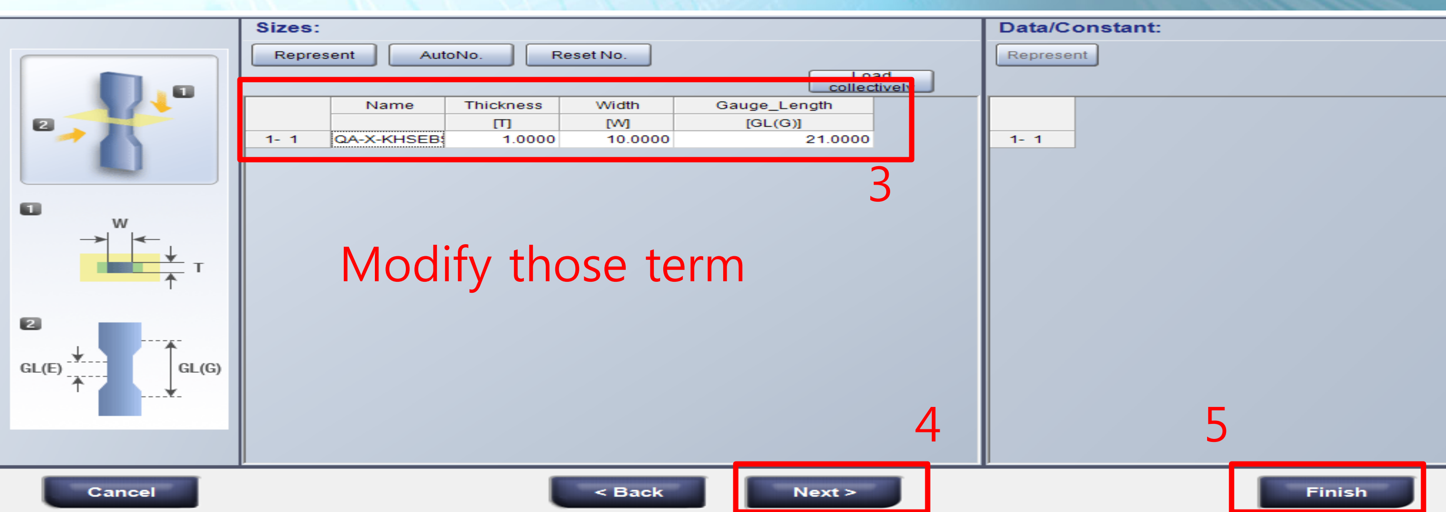
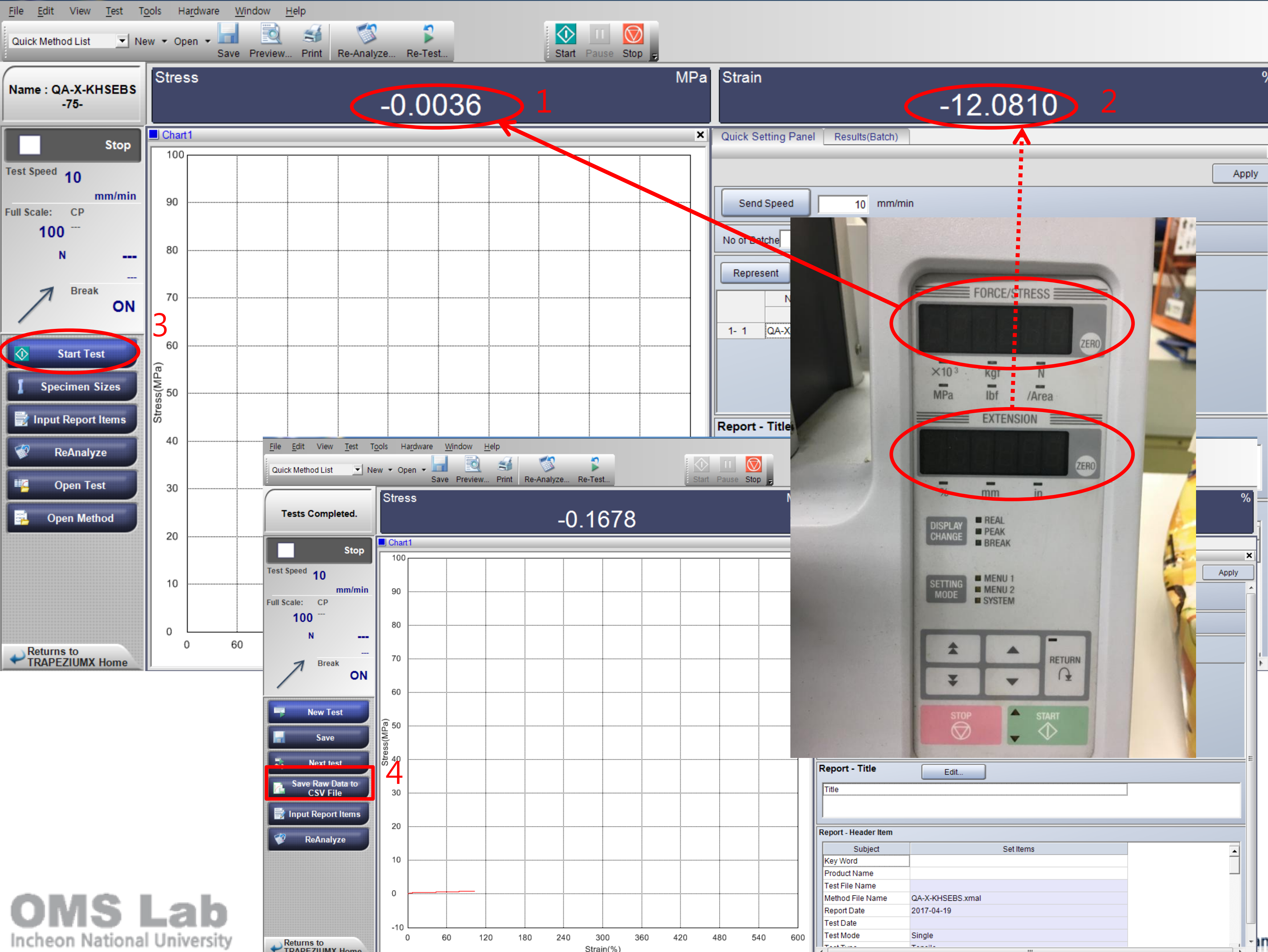




AEM TEAM
Anion Exchange Membrane



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