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**05/20/03**

Program - Project - Job: Rapid Prototyping – Materials – UC3924

Title: Rapid Prototyping Materials Exposed to Ionizing Radiation

## Introduction

Rapid prototyping refers to the fabrication of a physical, three-dimensional part of arbitrary shape directly from 3D computer-aided design (CAD) data. RP technology is an additive process that can generate free-form fabricated parts using powdered metals, polymers, paper, and other materials. RP machines fabricate 3-dimensional objects by depositing these materials layer by layer based on thin horizontal cross sections taken from a computer model.

## Scope

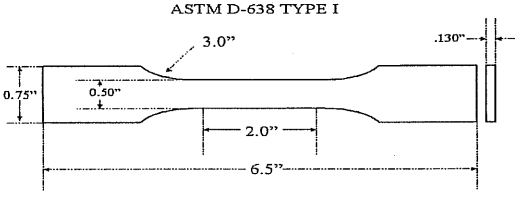
Fabricate tensile test samples on Fused Deposition Modeler (FDM) and Stereolithography (SLA) rapid prototyping machines. Tensile test samples that have been exposed to ionizing radiation and compare the results with control samples that have not been exposed to radiation.

## Description

Make 10 samples of each desired material. Irradiate 5 samples from each material. Tensile test all samples to failure per ASTM Designation: D-638-97 "Standard Test Method for Tensile Properties of Plastics" and report the following:

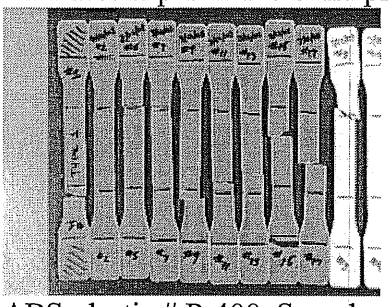
Stress at Failure,MPa
Yield Strength,MPa
Elastic Modulus,MPa
Ultimate Strength,Mpa

**Sample geometry** Compliant with ASTM D-638:

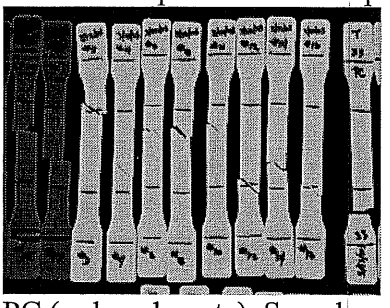


## Materials

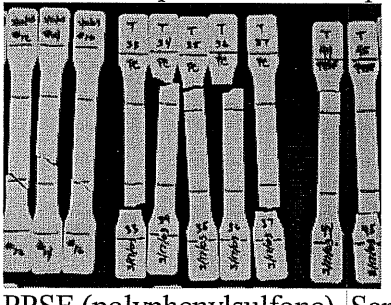
1.) **SLA -** Photo Epoxy Resin # 5170. Samples run in flat orientation where sample thickness is parallel to build platform. Built at LBNL RP lab.



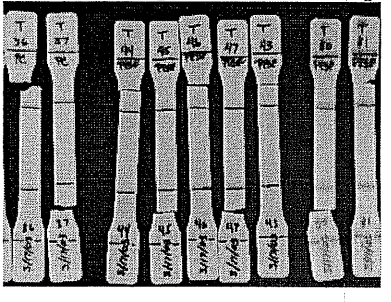
2.) **FDM –** ABS plastic # P-400. Samples run in flat orientation where sample thickness is parallel to build platform. Built at LBNL RP lab.



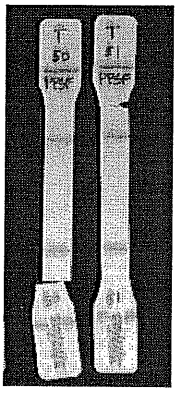
3.) **FDM –** PC (polycarbonate). Samples run in flat orientation where sample thickness is parallel to build platform. Built at Stratasys Inc. RP lab.



4.) **FDM –** PPSF (polyphenylsulfone). Samples run in flat orientation where sample thickness is parallel to build platform. Built at Stratasys Inc. RP lab.



5.) **FDM –** PPSF (polyphenylsulfone). Samples run on "edge orientation" where sample thickness is normal to build platform. Built at Stratasys Inc. RP lab.



## Radiation

Ionizing radiation from a Cesium source. Sample exposure rate is 4.9 kRad/minute to a total of 50MRad.

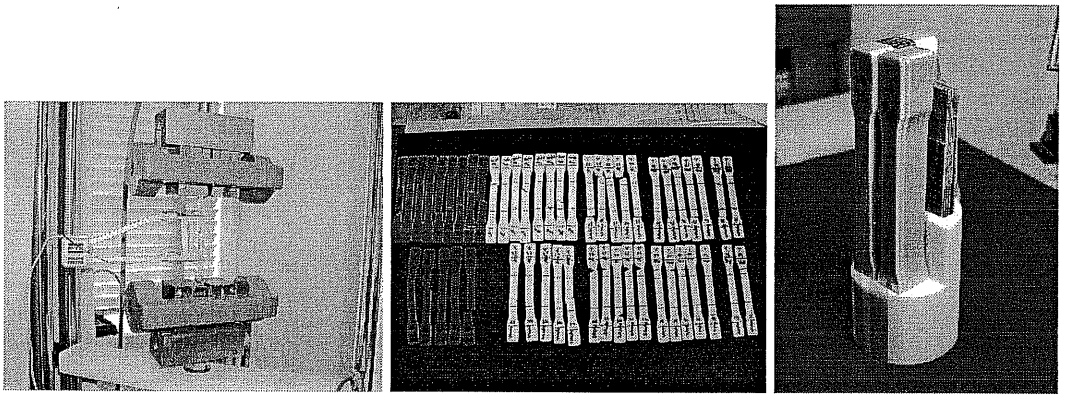

**Tensile test facility and parameters**

Tensile test apparatus: Dillon Model: DTM serial #97028 with floating grips.

Load cell: Dillon "Weight-Tronix Inc." Model #0155, serial #98121, capacity - 5000lbs.

Extensometer: MTS Model #634.25E-24, serial #0388516 – 2.0" extension.

Control Software: Labview – Custom V.I. "Dillon DAQ two-axis 7.vi"
Scan rate: 100Hz
Pull Velocity: 0.204 in./min.



## Tensile test results

See summary charts:

**"elongation.xls", "failure.xls", "modulus.xls", "ultimate.xls", "yield.xls"**

Stress-strain curves are calculated from displacements (measured by the extensometer) and force load (measured by the force transducer on the Dillon). Strain is calculated as engineering strain from the equation

$$strain = \frac{displacement}{griplength}$$

where *griplength* is the extensometer grip length (2 inches).

Stress is calculated from the equation

$$stress = \frac{load}{area}$$

where *area* is the measured cross sectional area of the test sample (generally about 0.0664 square inches).

Material elastic modulus is calculated using a least-squares fit between the straight portion of the data and a straight line. This "straight portion" of the stress strain curve varies slightly from sample to sample, and varies significantly between samples of different materials. For example, FDM ABS samples typically have straight sections of about 0.3% strain and SLA 5170 typically have straight sections of about 1.0%.

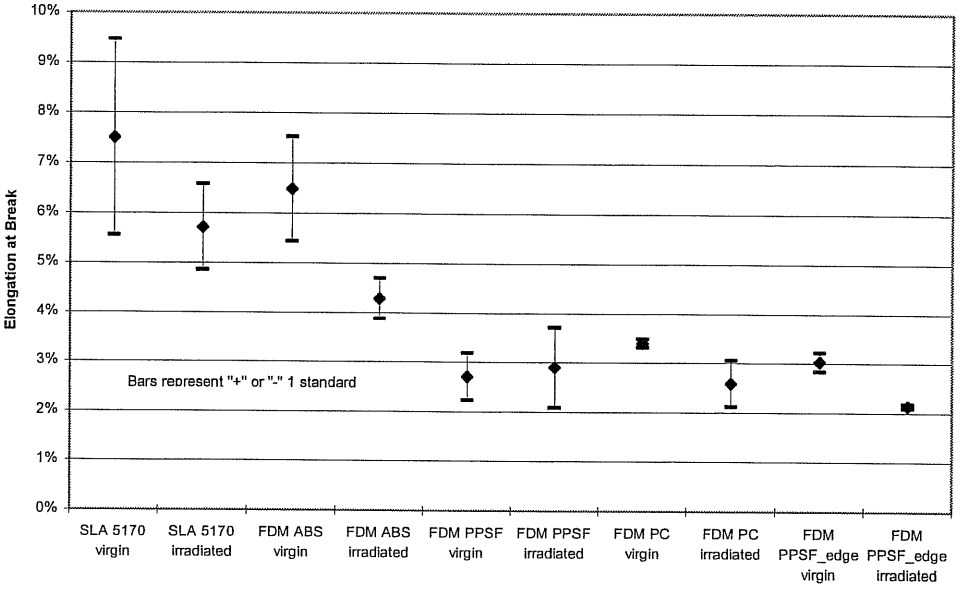
Yield strength is calculated as 0.2% offset to the elastic modulus. Ultimate strength is calculated as the peak stress. Failure strength is calculated as the stress at the final break point of the test sample. Elongation at break is calculated as the percentage increase in sample length (between the extensometer grips) at the time of sample break.

## Observations / Comments

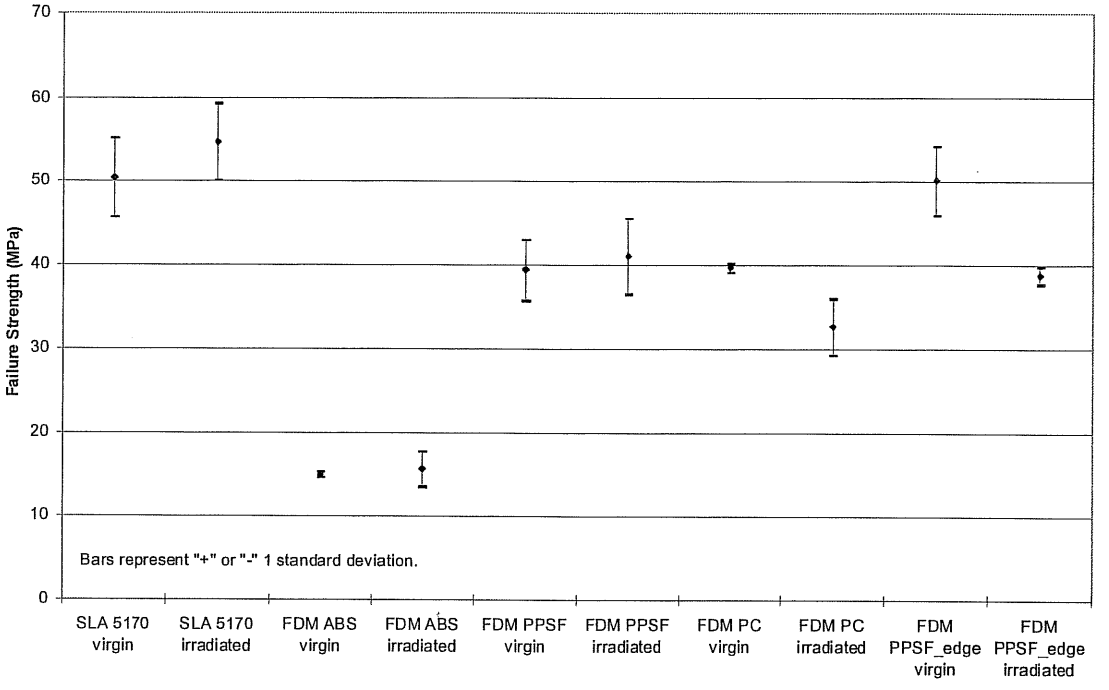
None of the samples show a significant change in material mechanical properties or physical dimensions at this level of radiation exposure. There was a significant change in material color on all samples except the PPSF material. It should be noted that the SLA epoxy and FDM ABS materials broke at or within the sample gauge length. The FDM PC, PPSF, and PPSF "edge" all broke outside of the sample gauge length near the "gauge / radius" transition.

**Summary charts – next page**

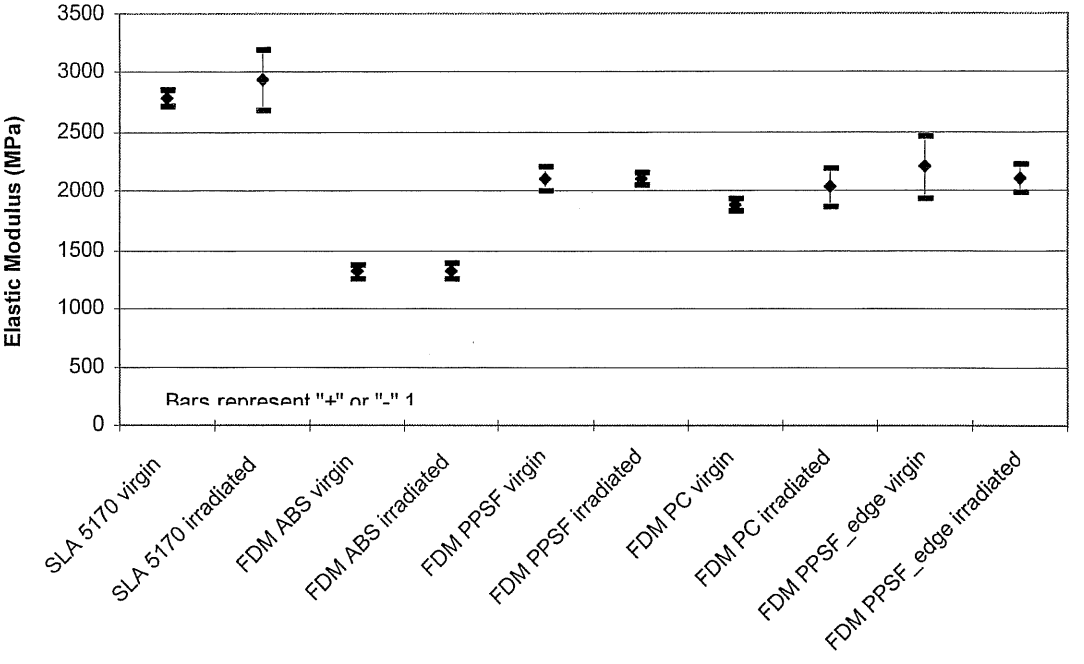
**Summary Chart: Elongation at Break**



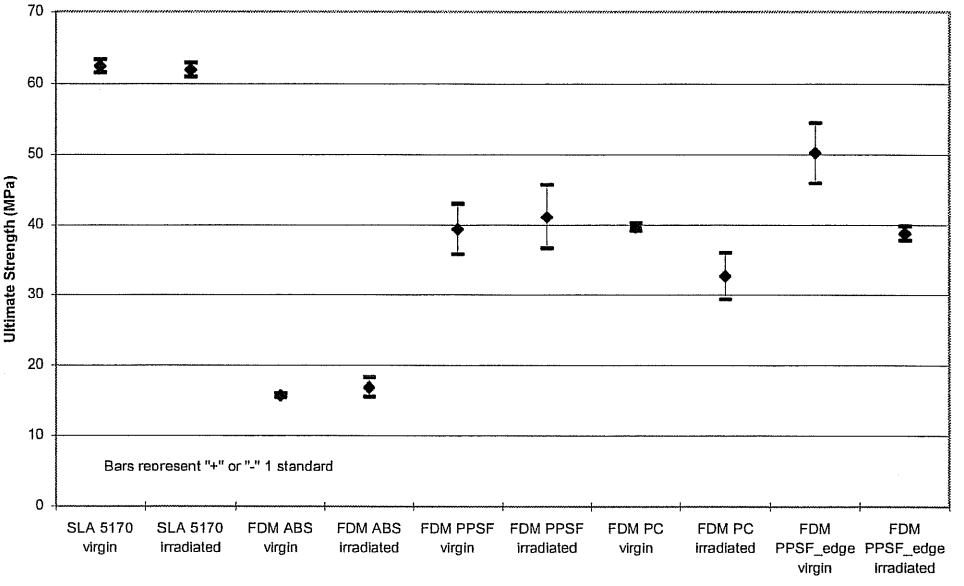
**Summary Chart: Stress at Failure**

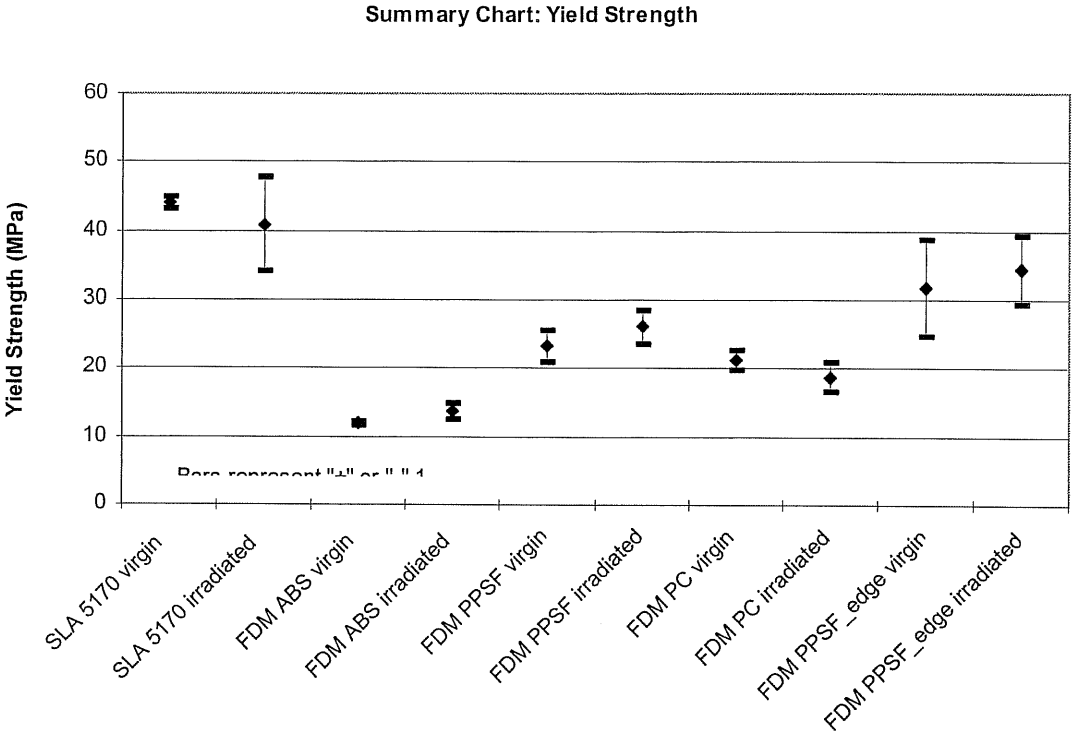


**Summary Chart: Elastic Modulus**

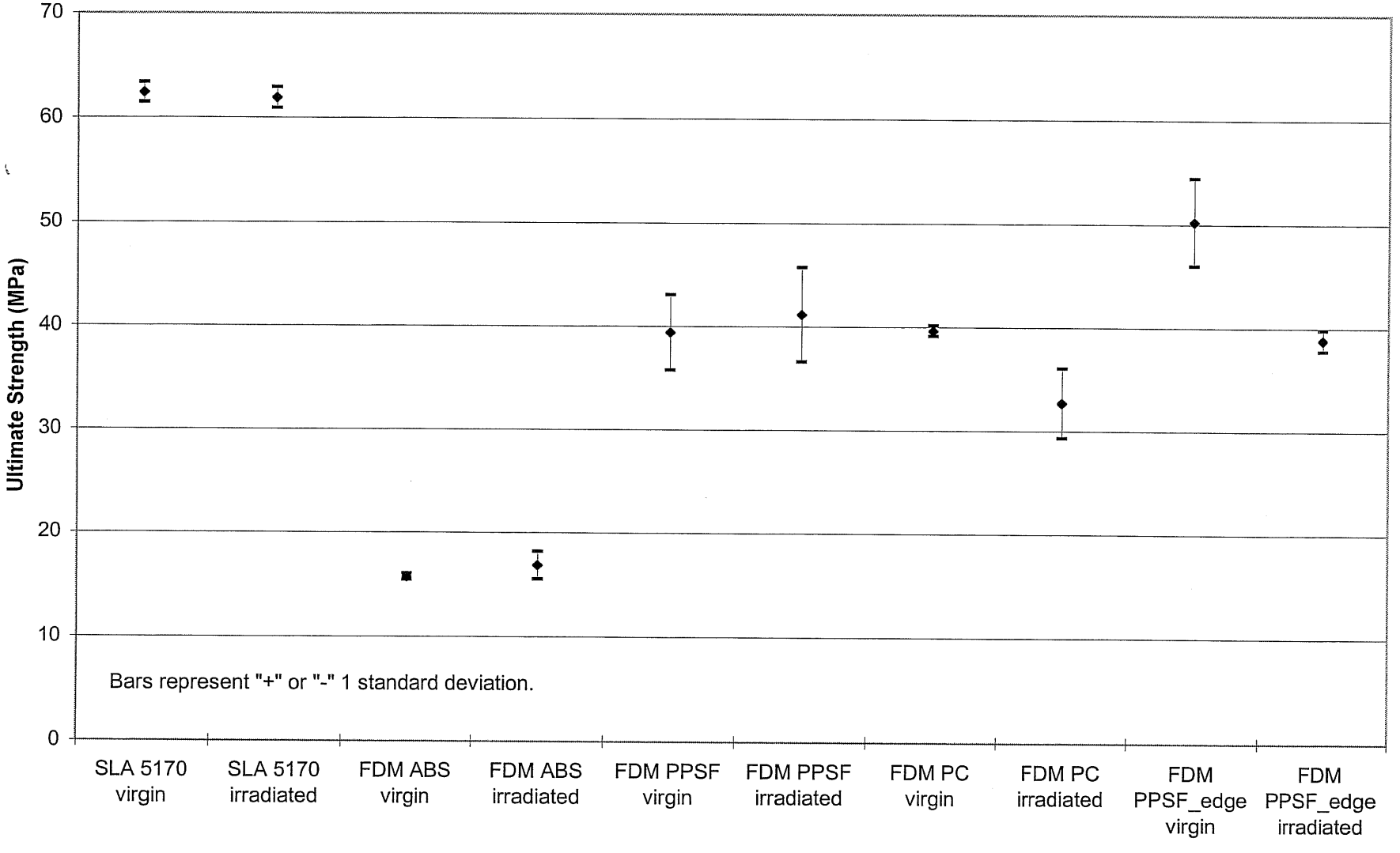



**Summary Chart: Ultimate Strength**

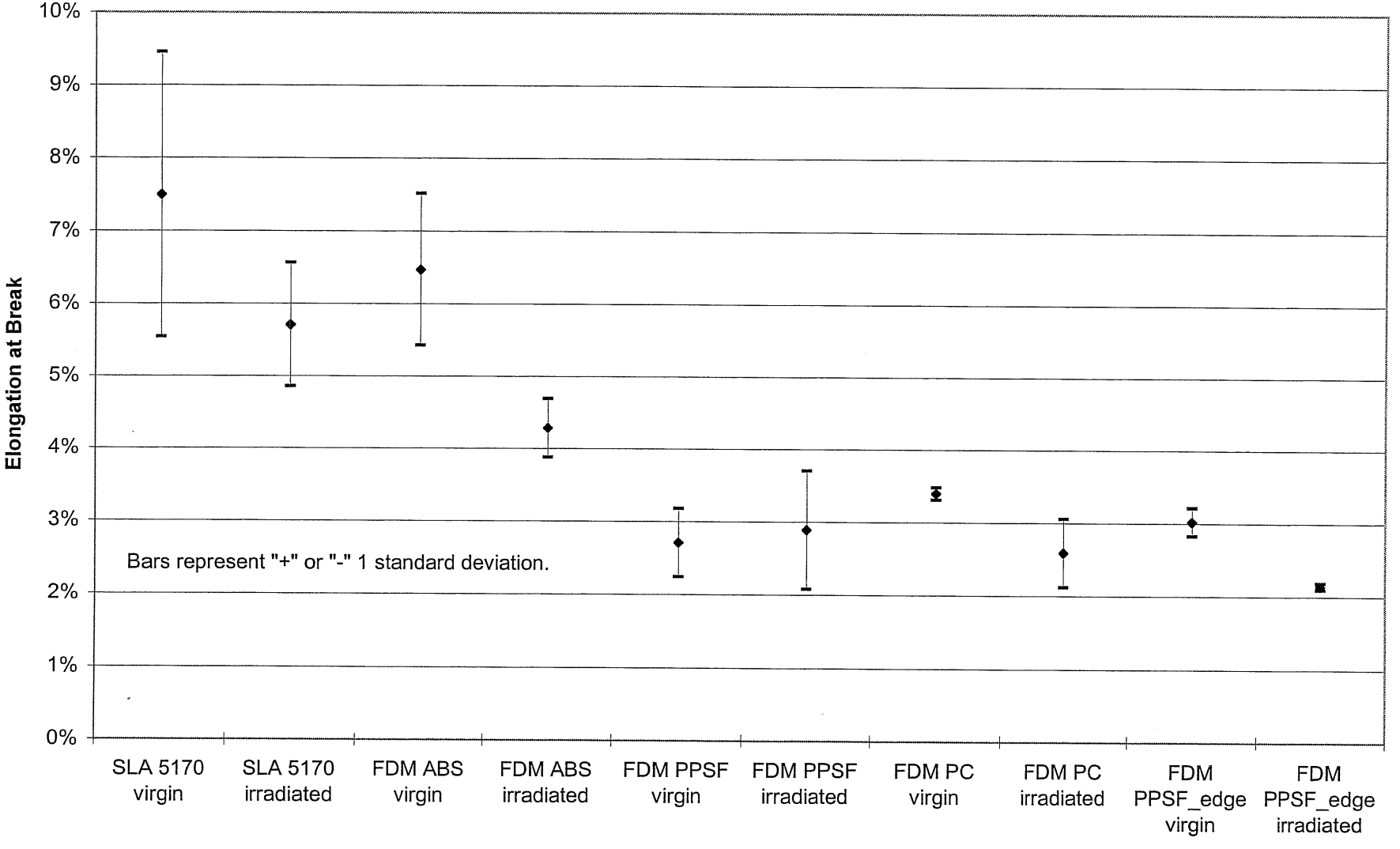




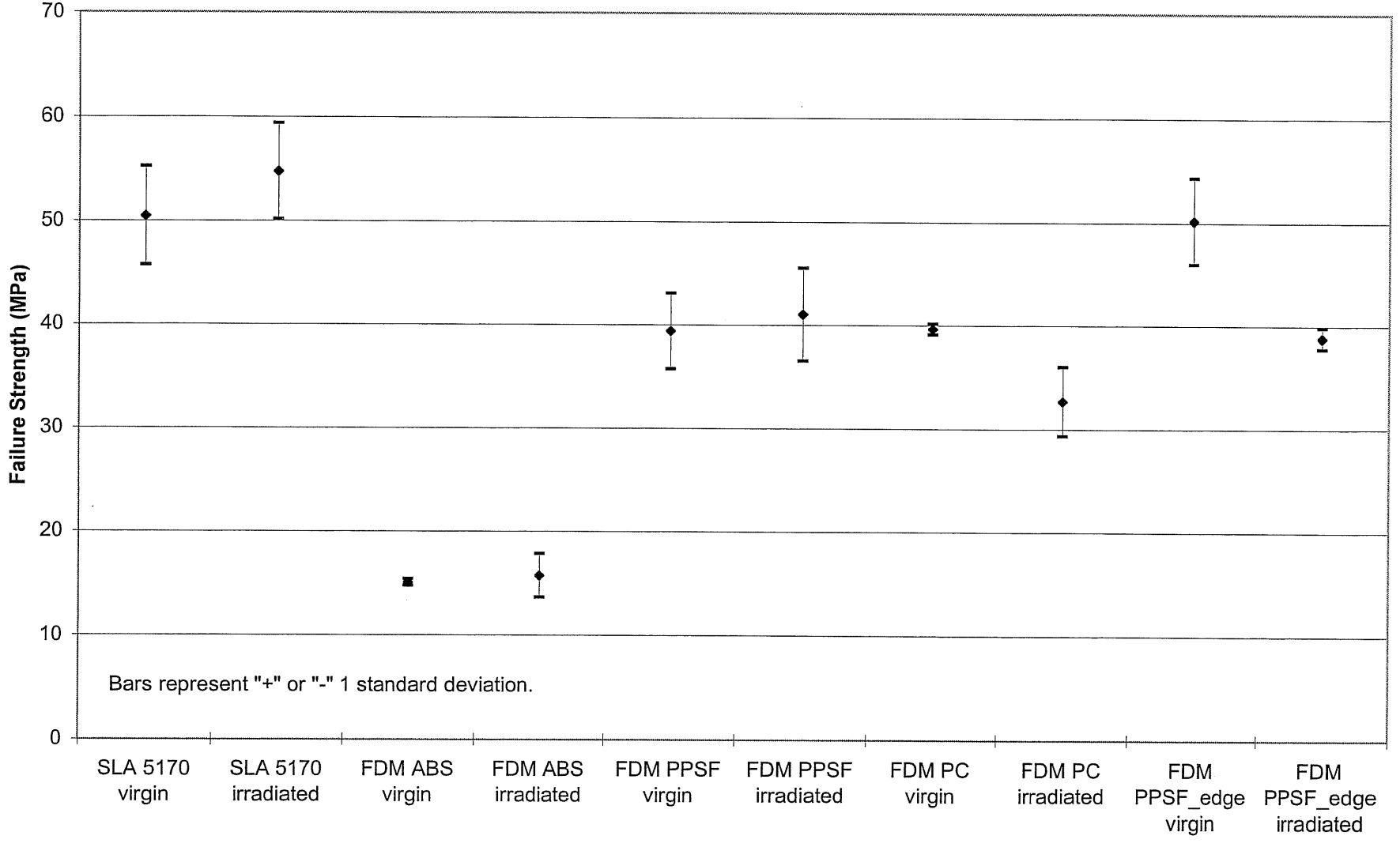
## Summary Chart: Ultimate Strength



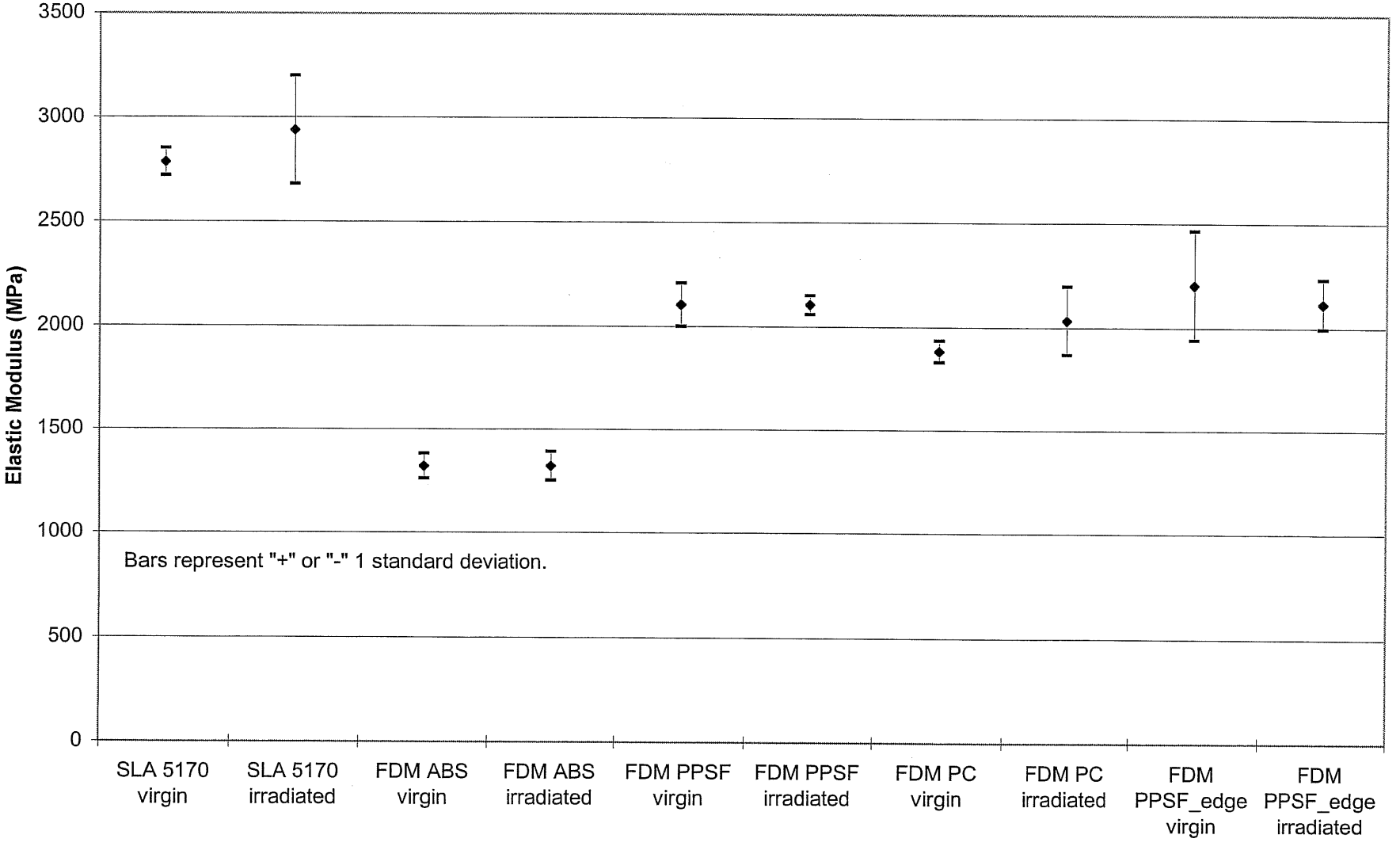
## Summary Chart: Elongation at Break

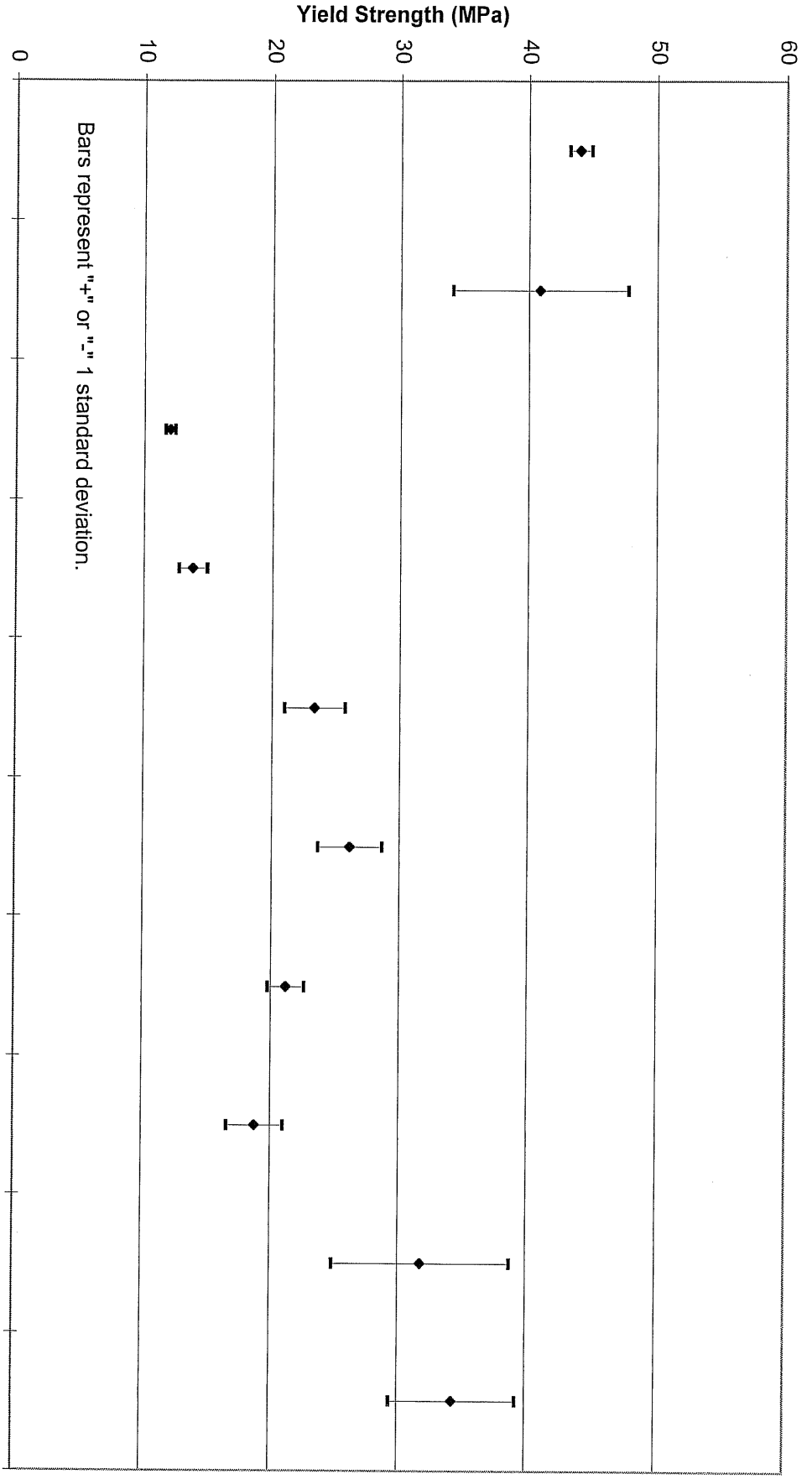


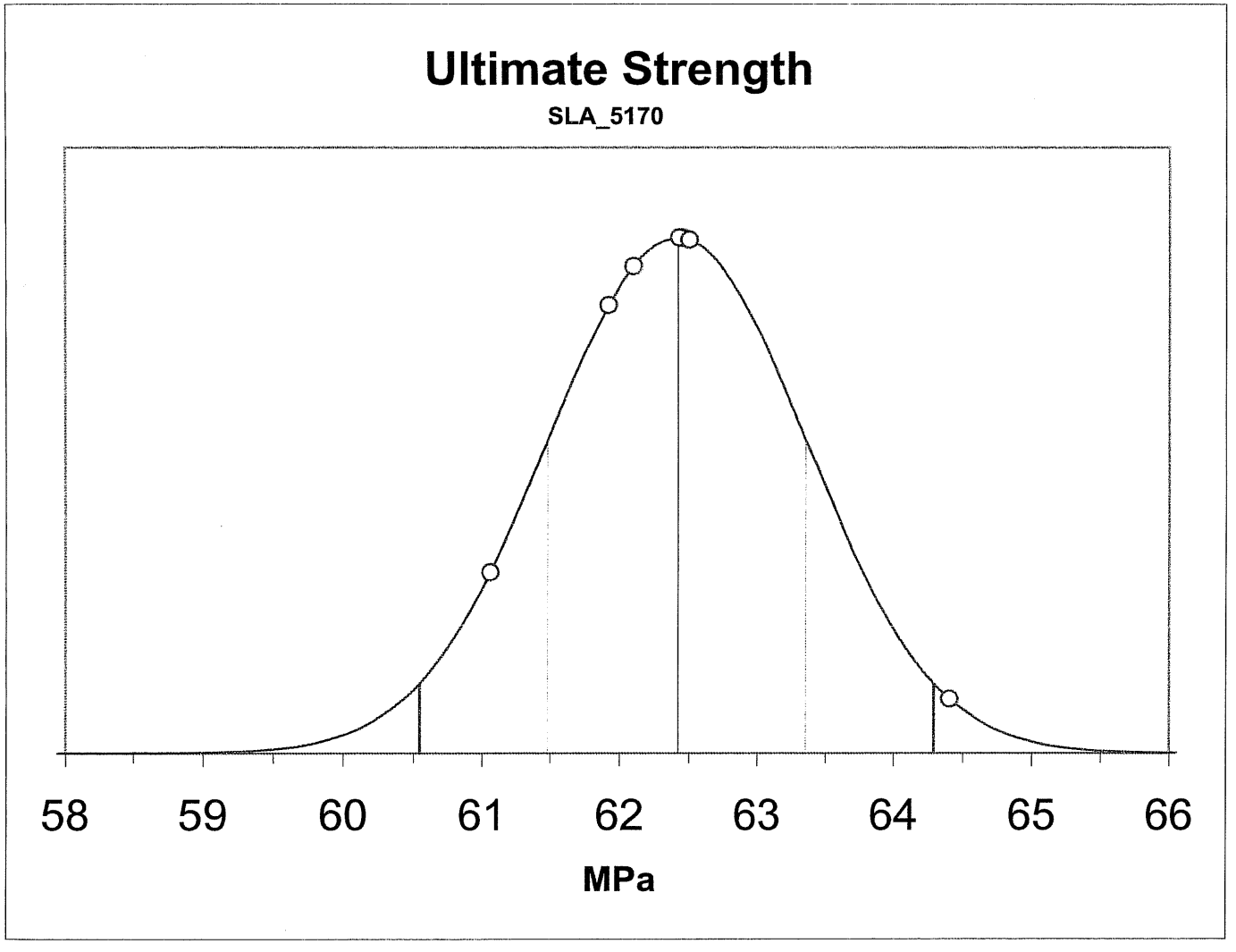
## Summary Chart: Stress at Failure



## Summary Chart: Elastic Modulus





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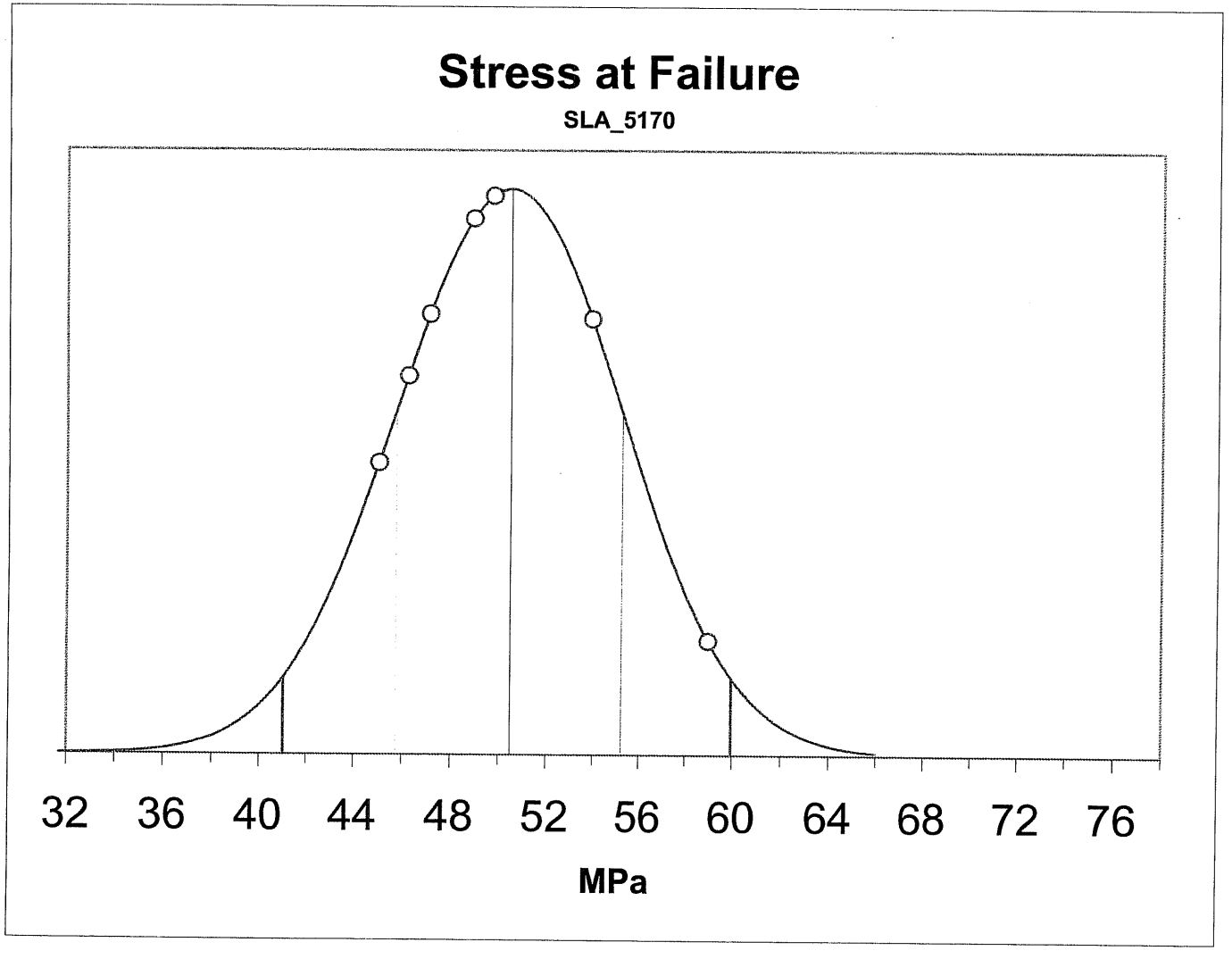


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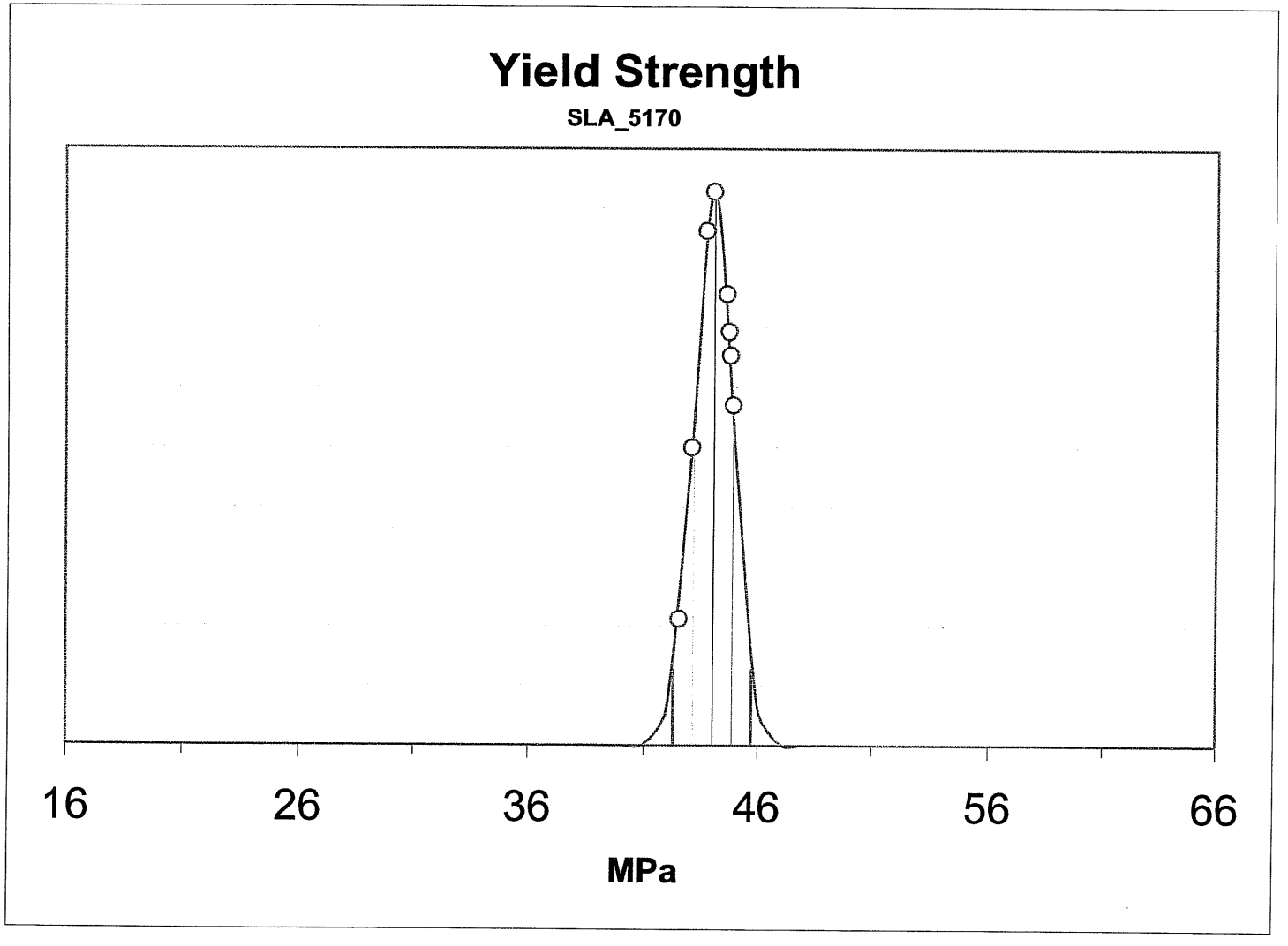


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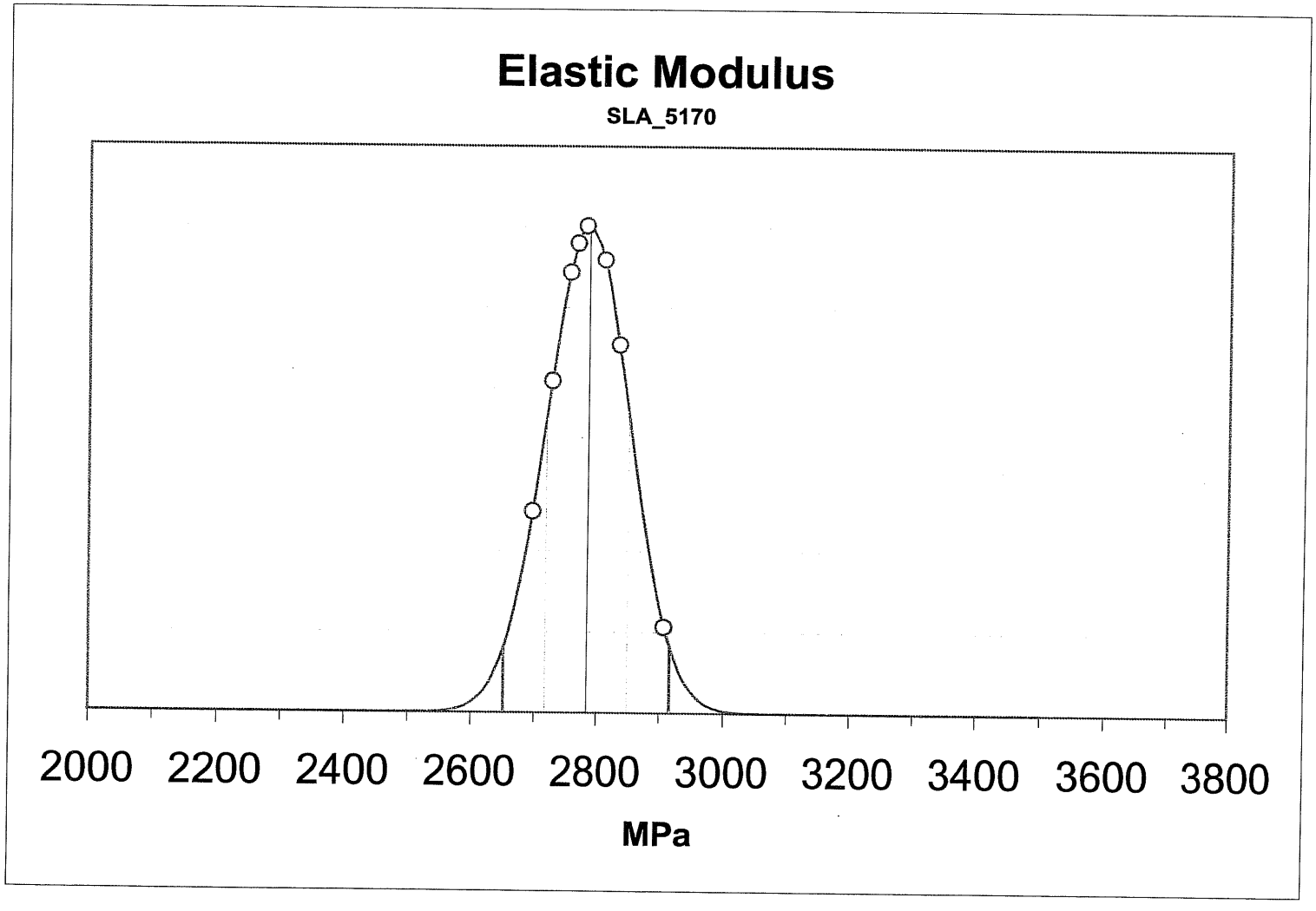


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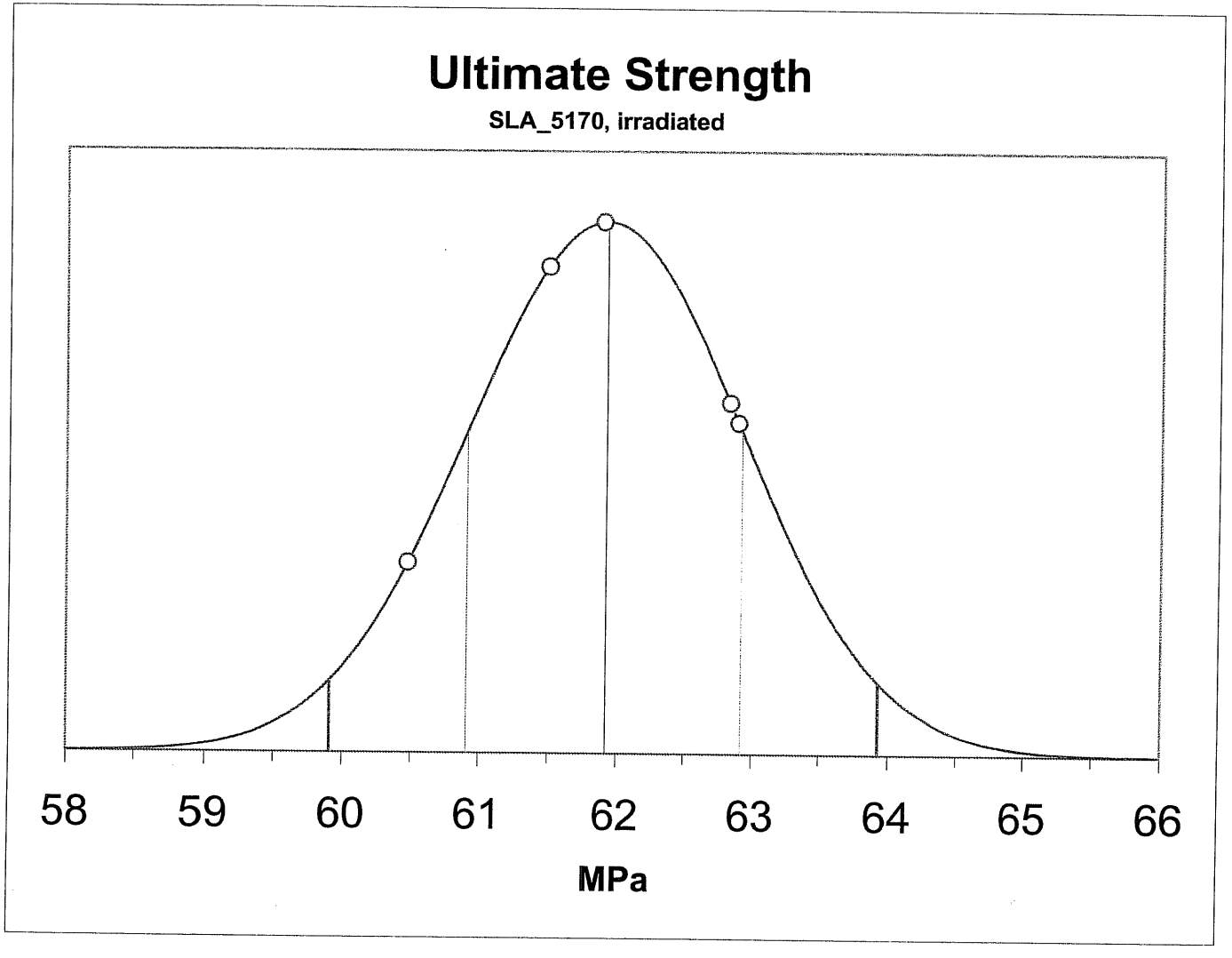


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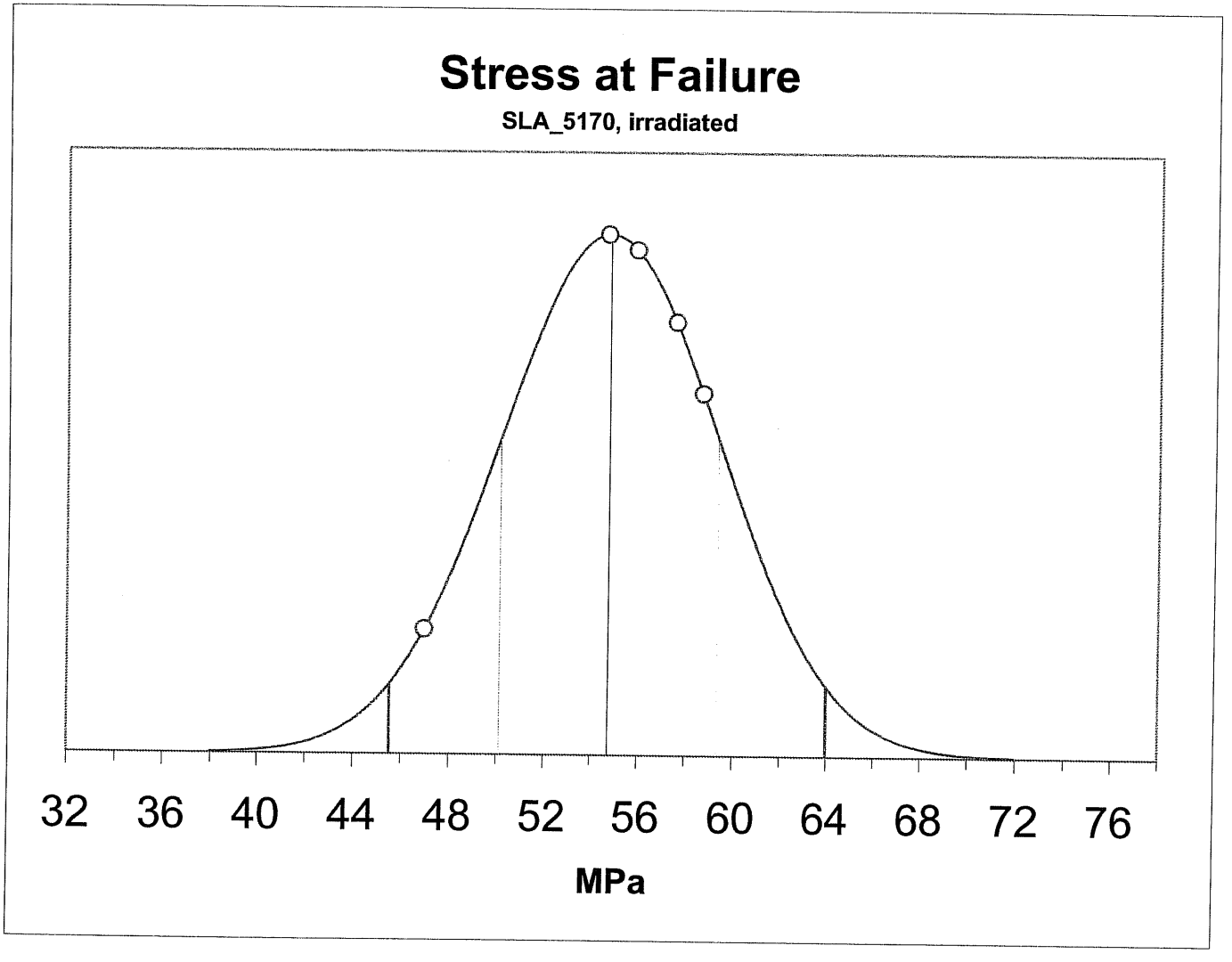


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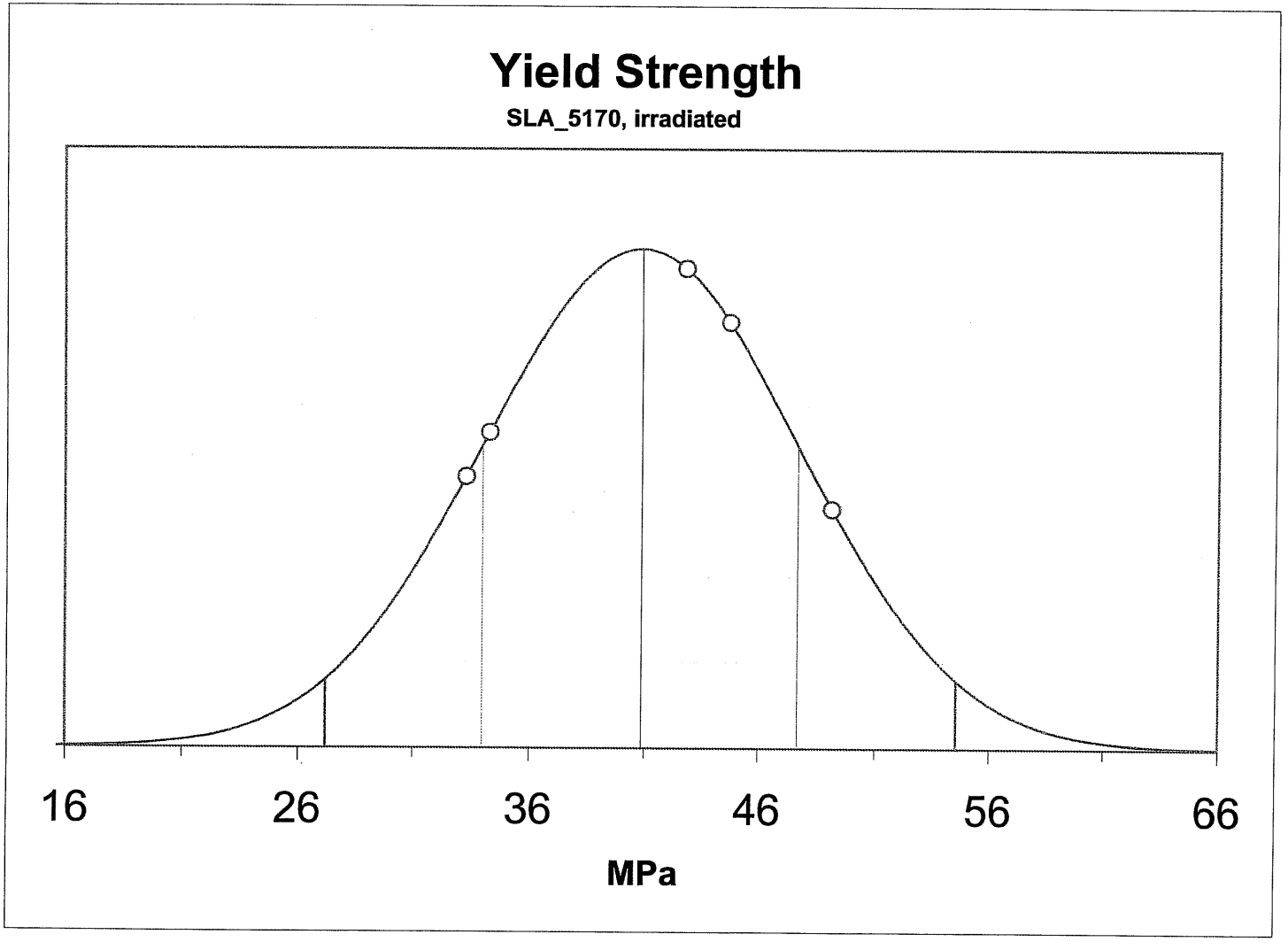


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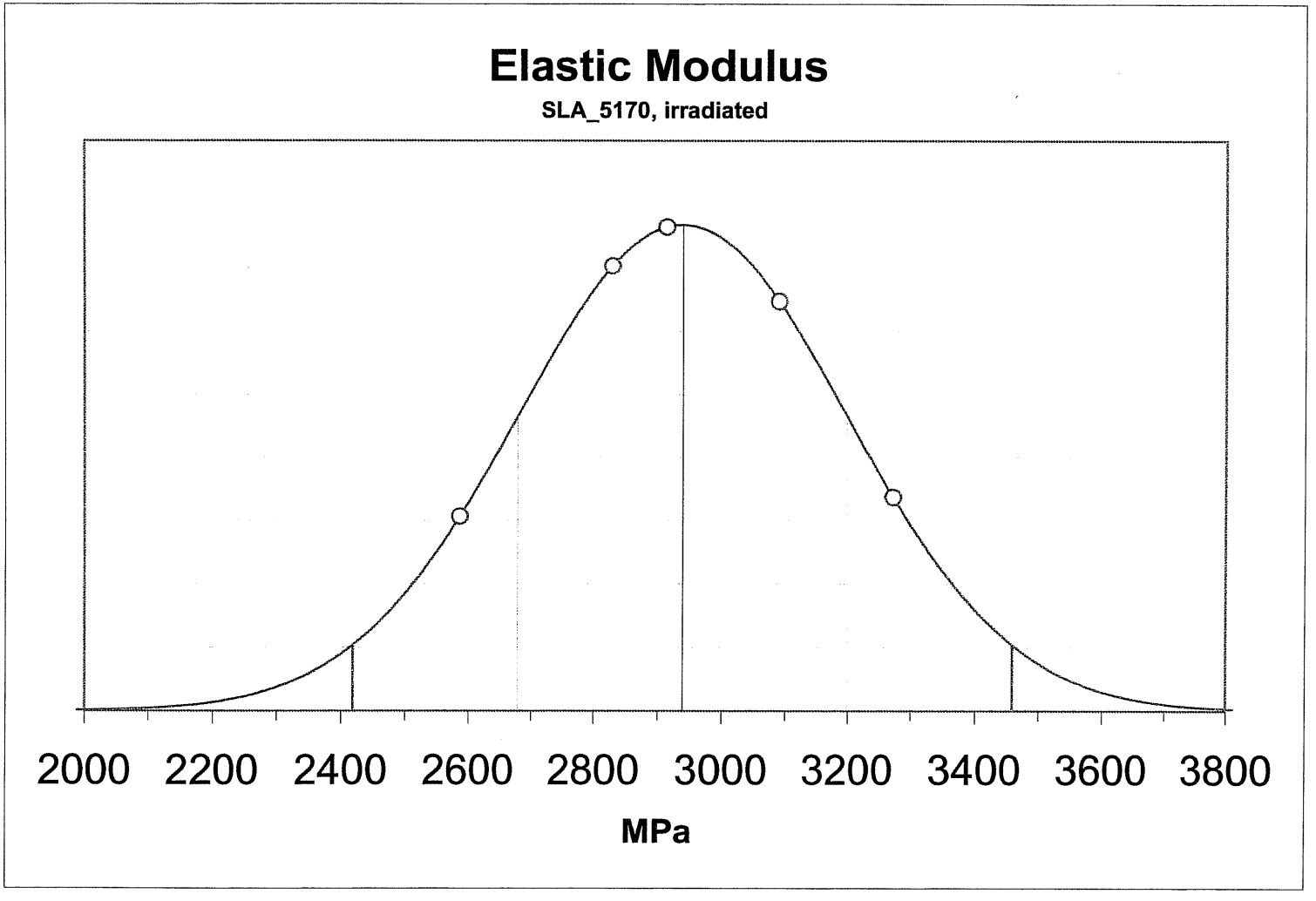


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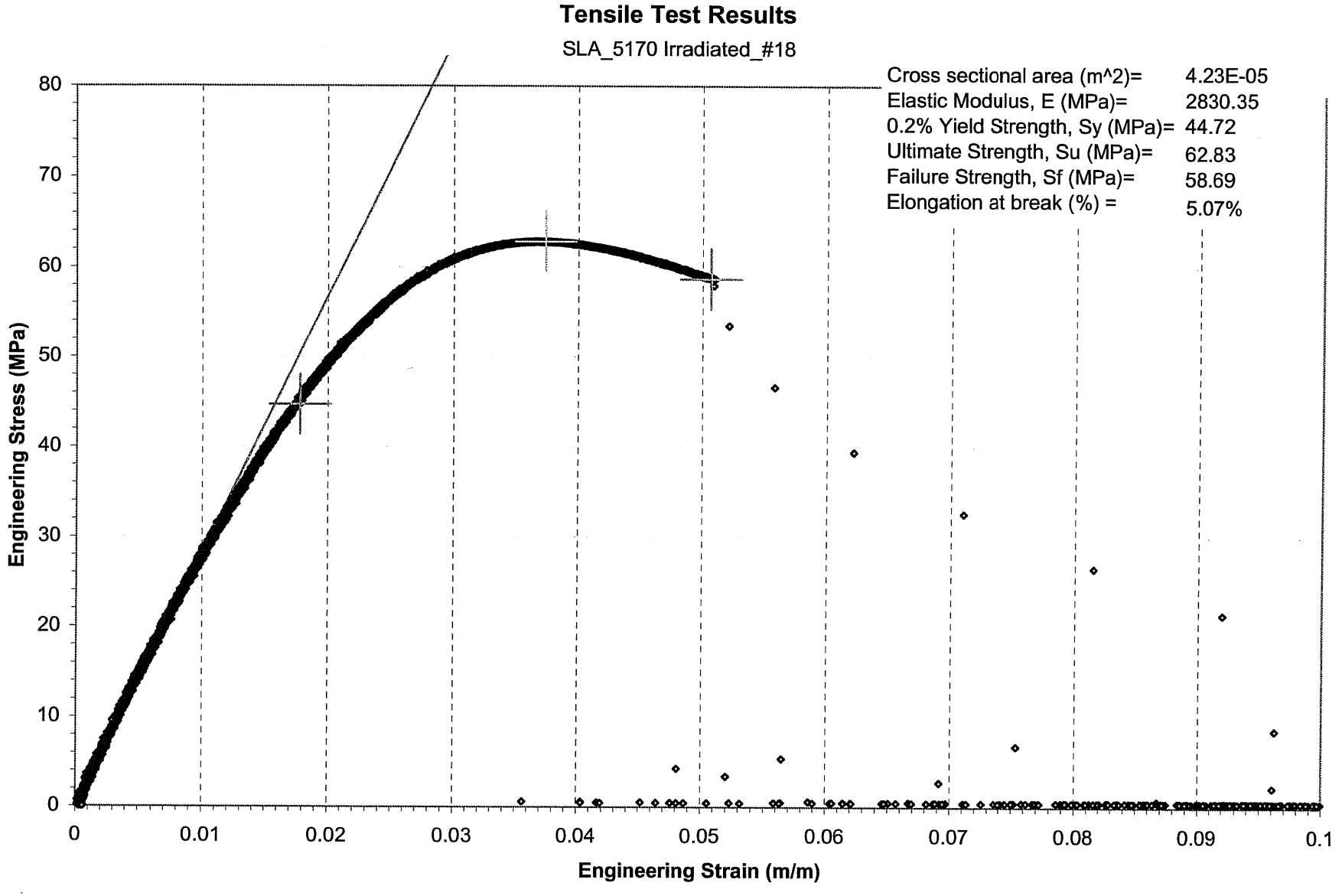
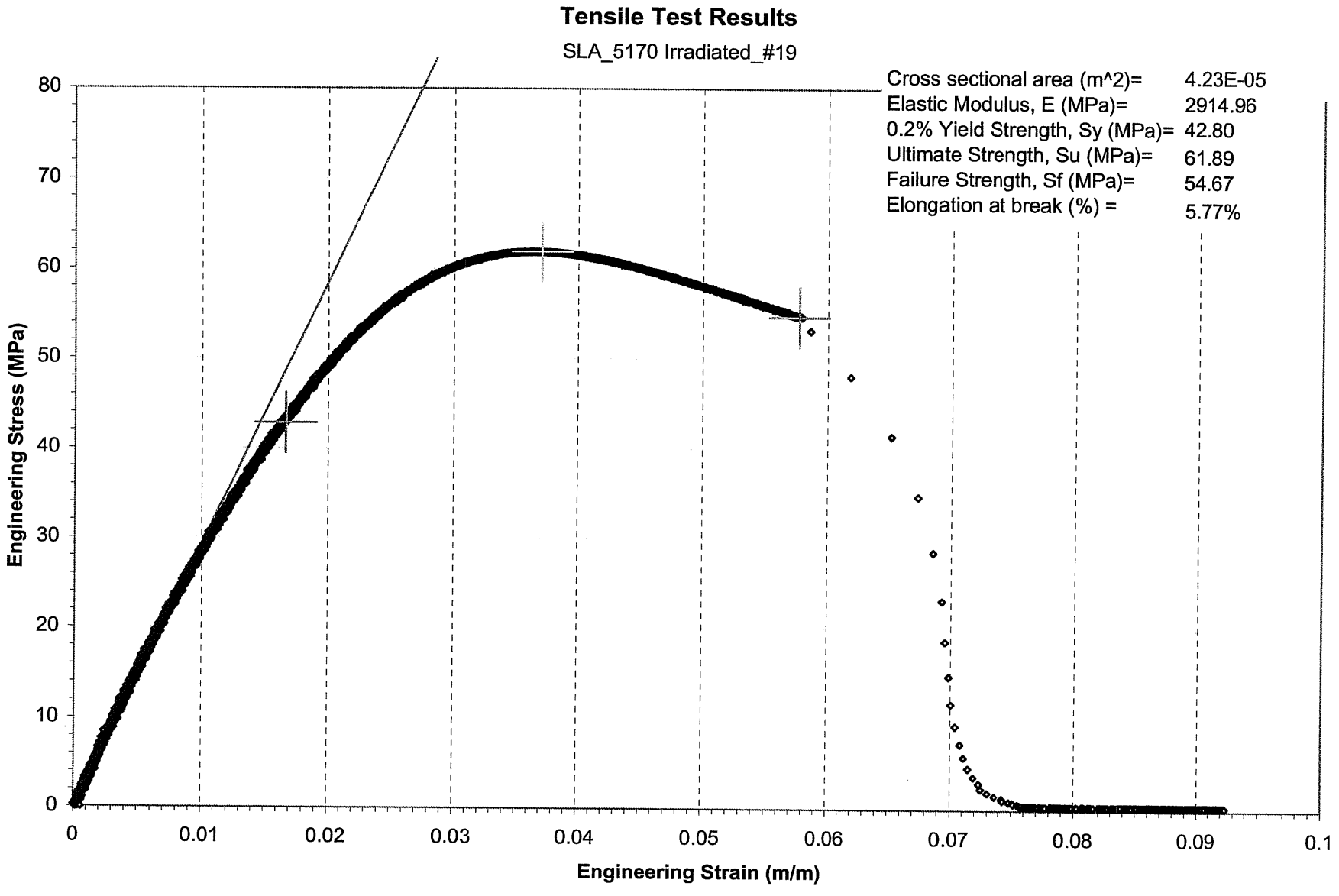
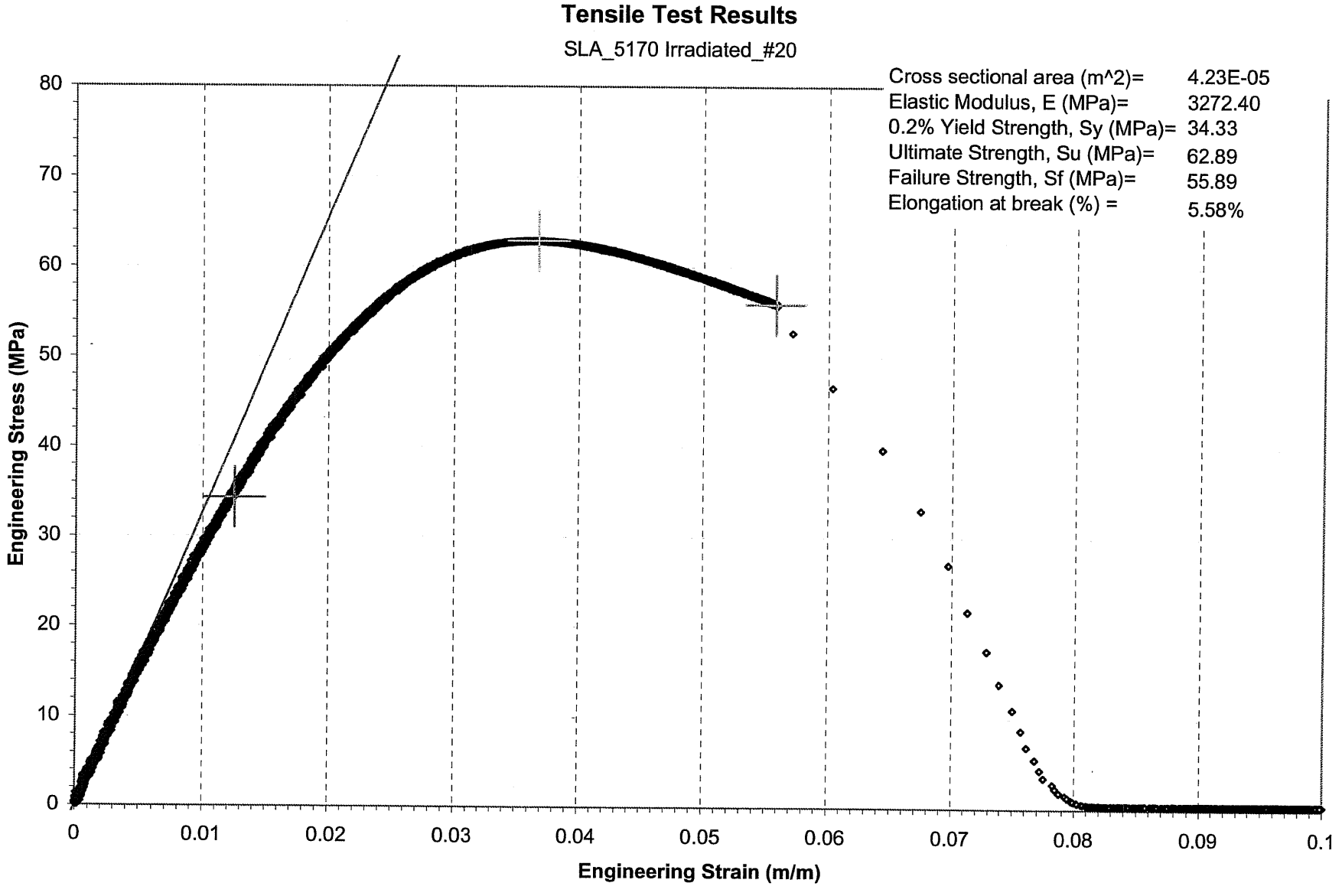
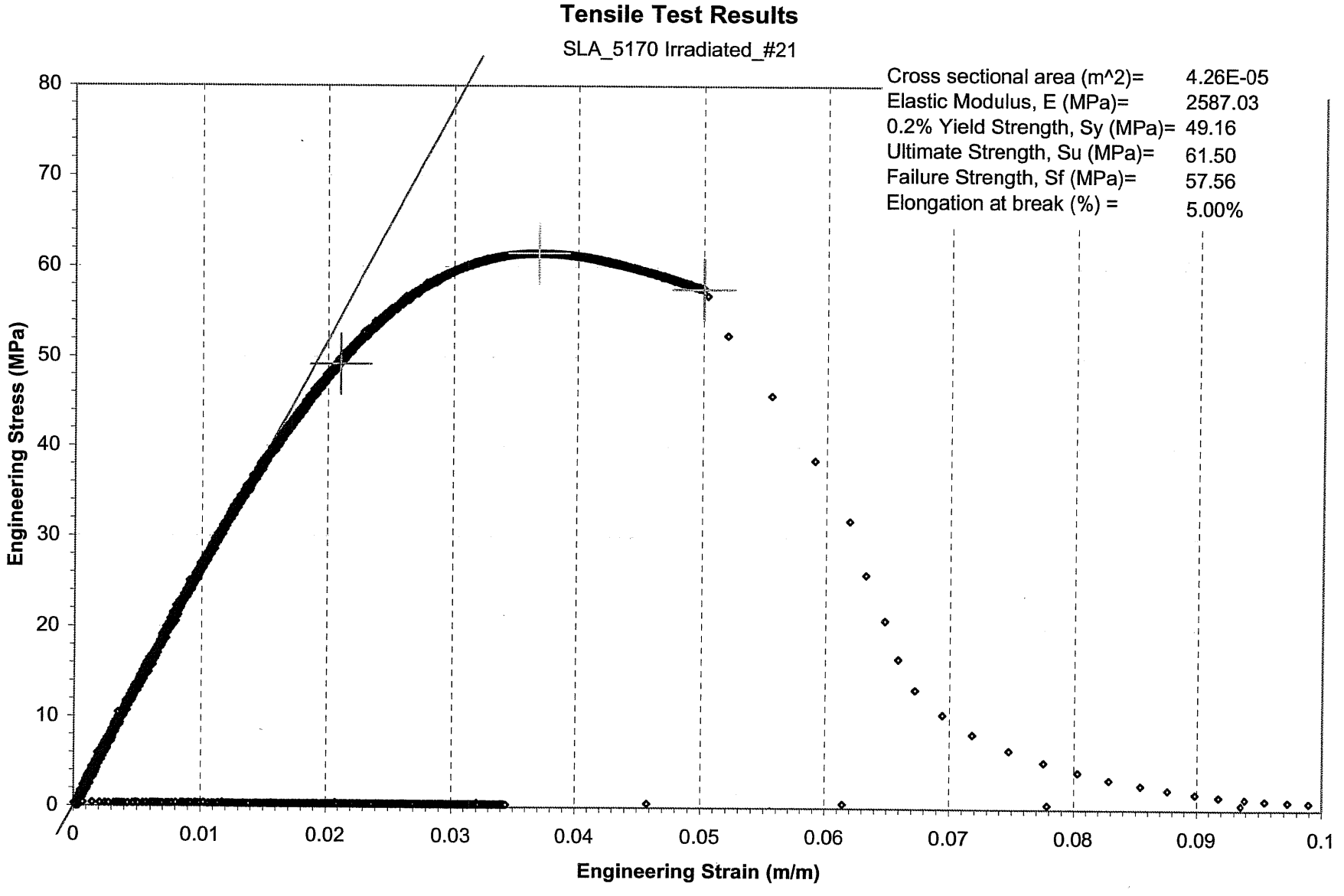
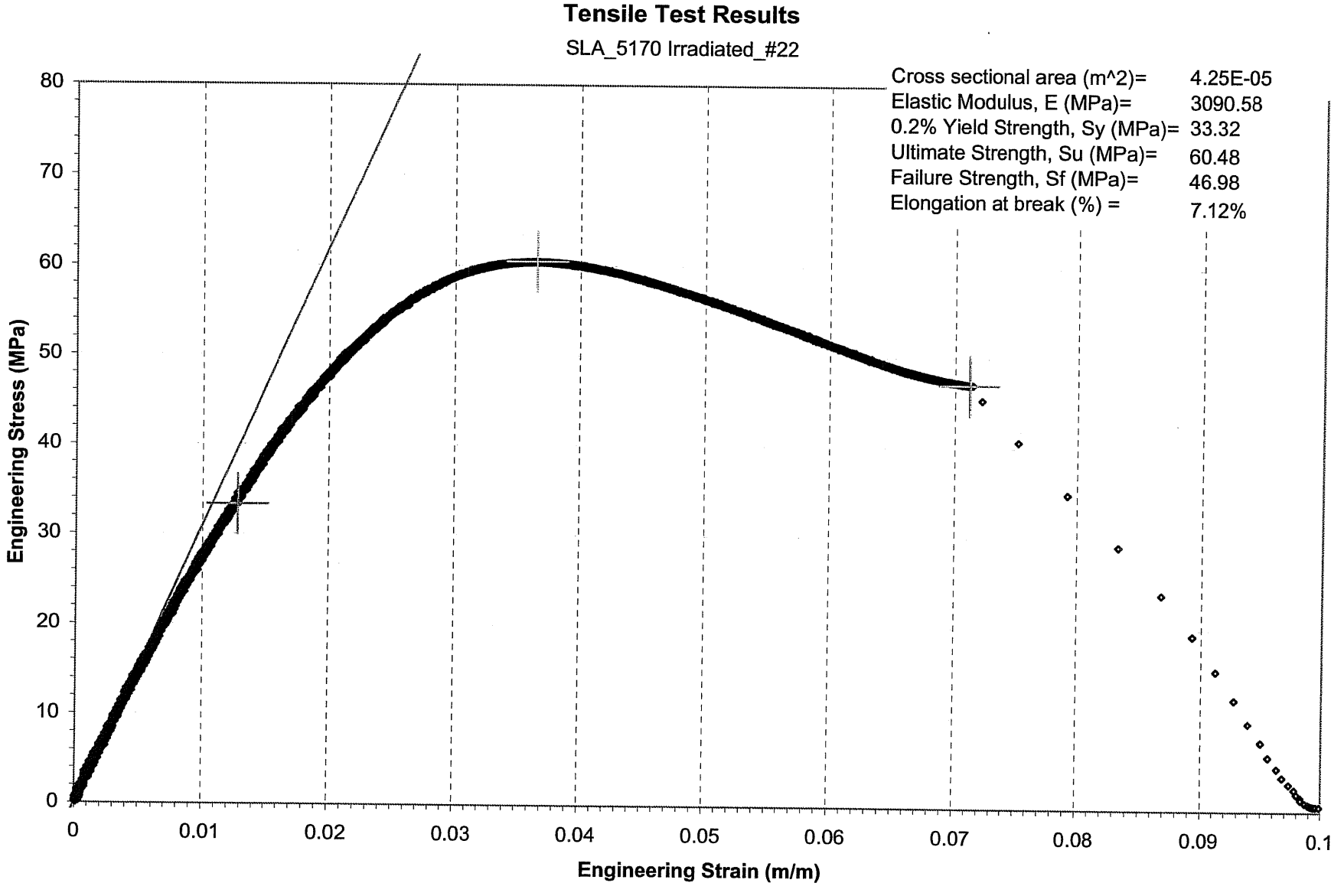
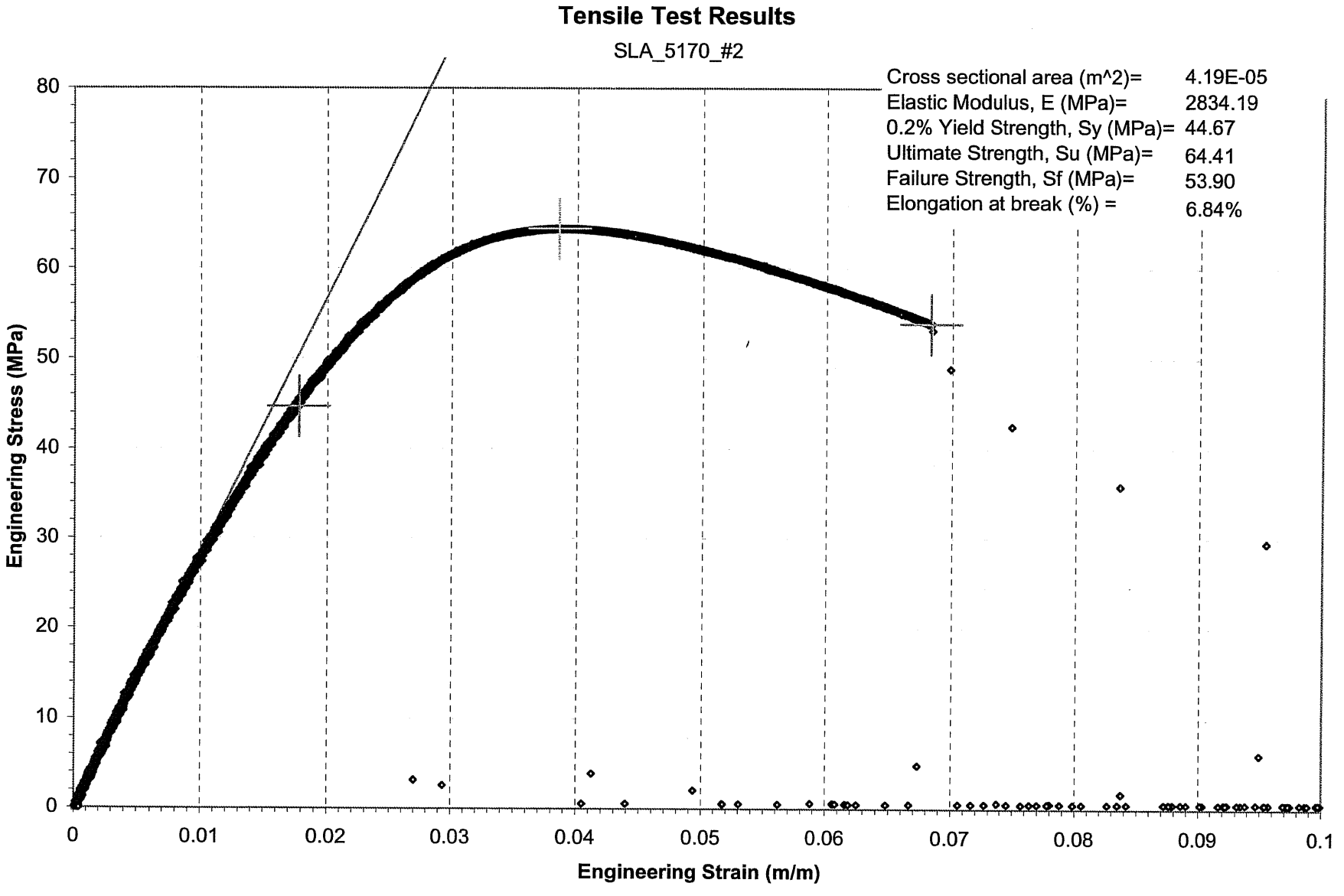


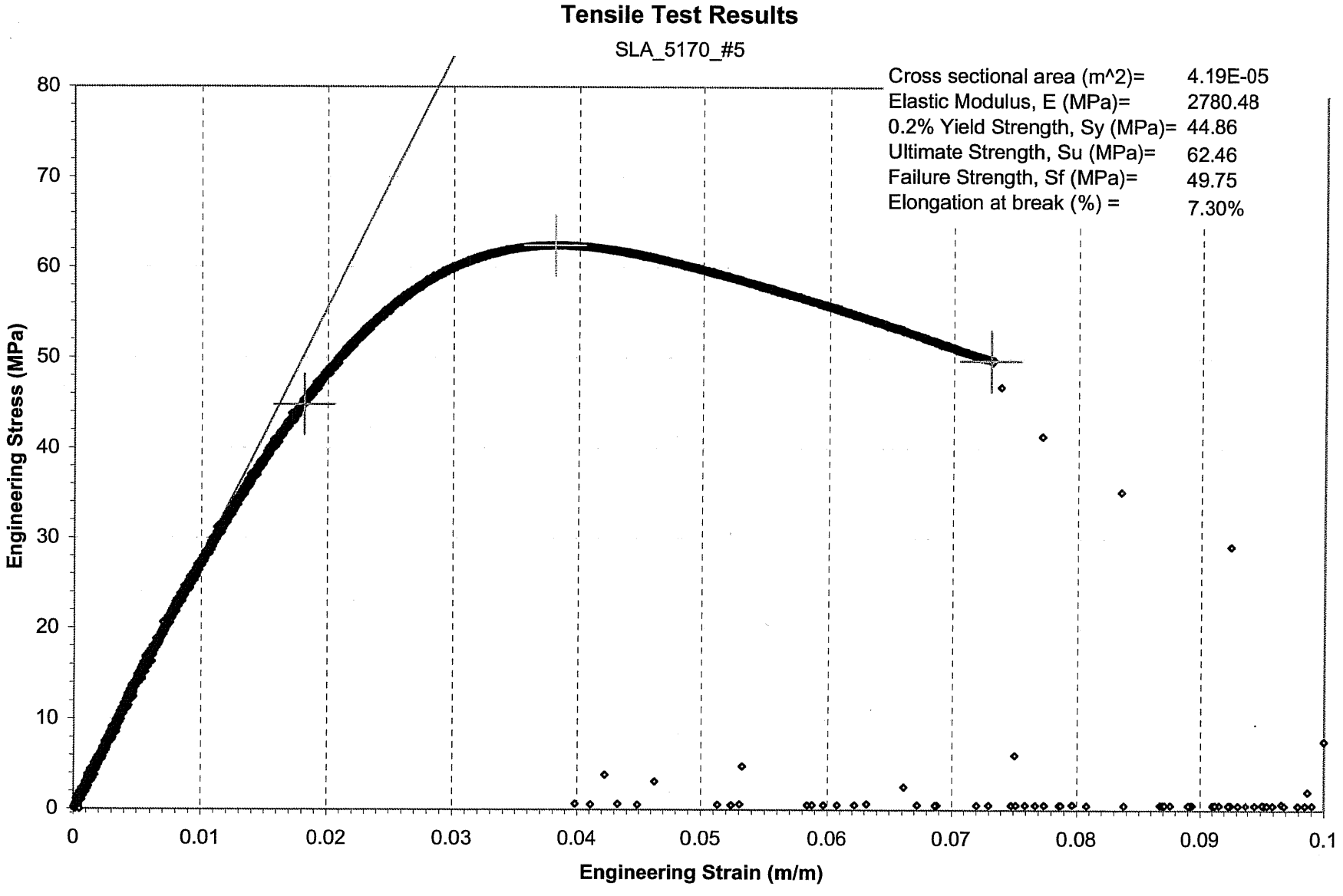






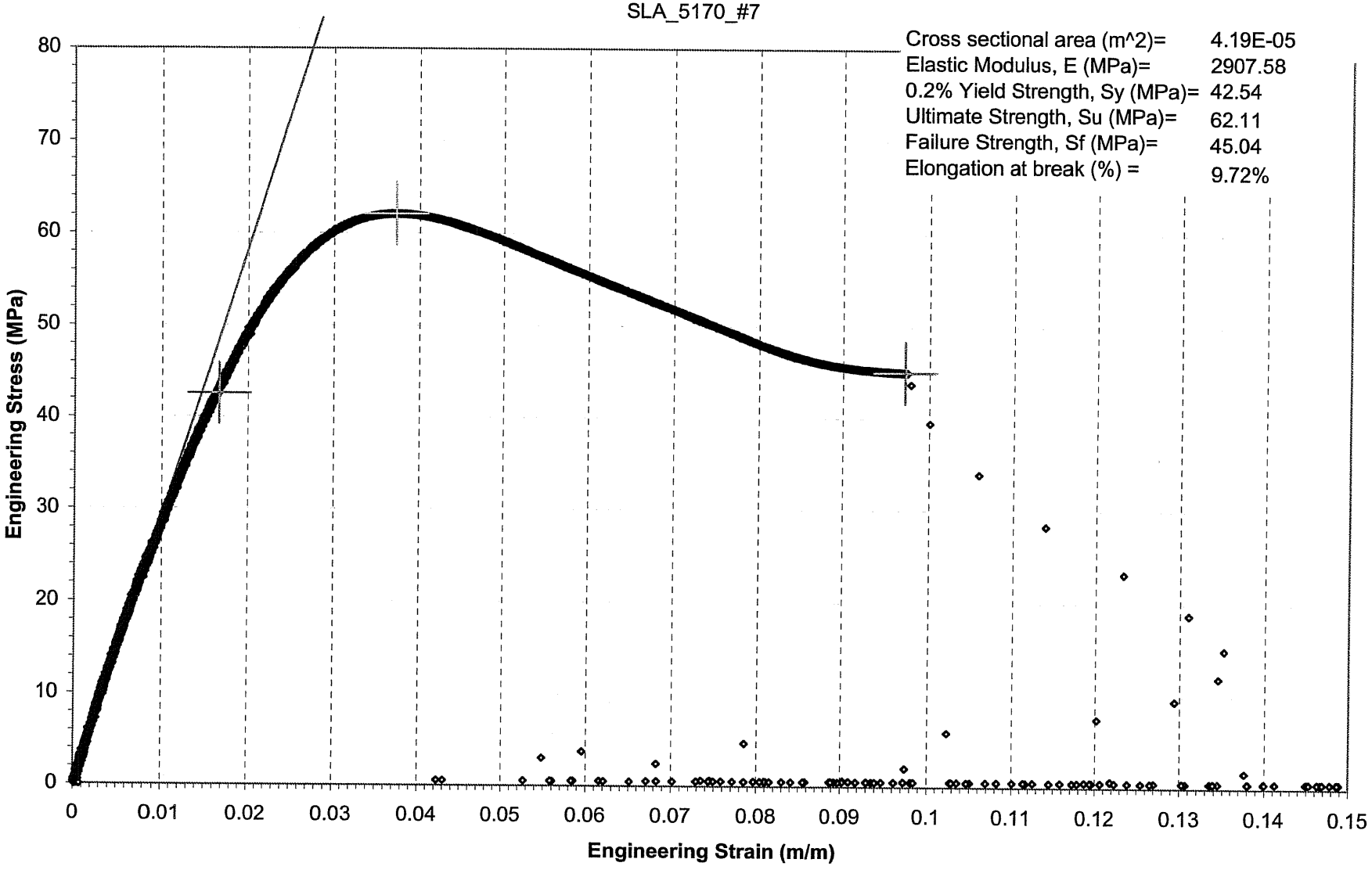


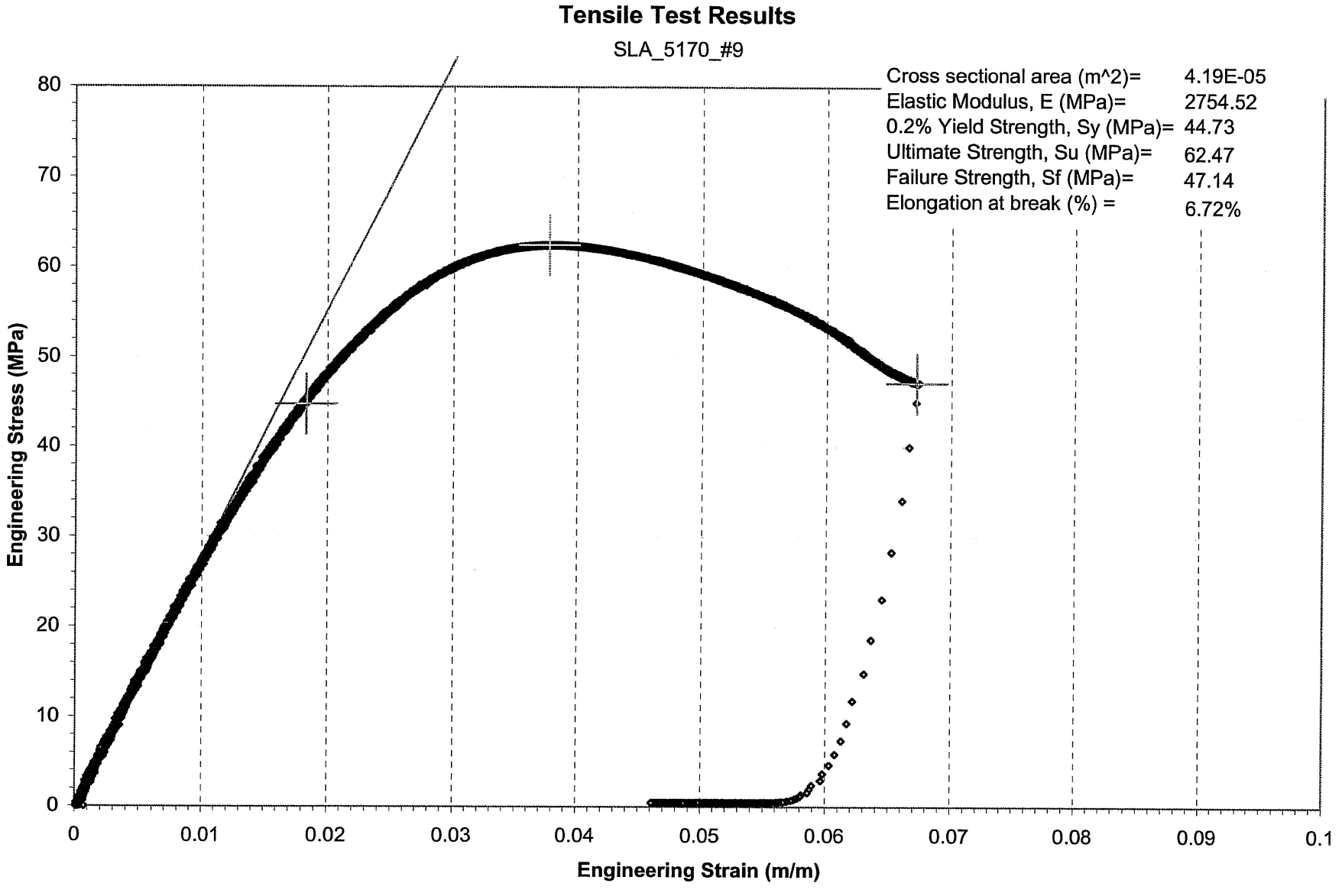


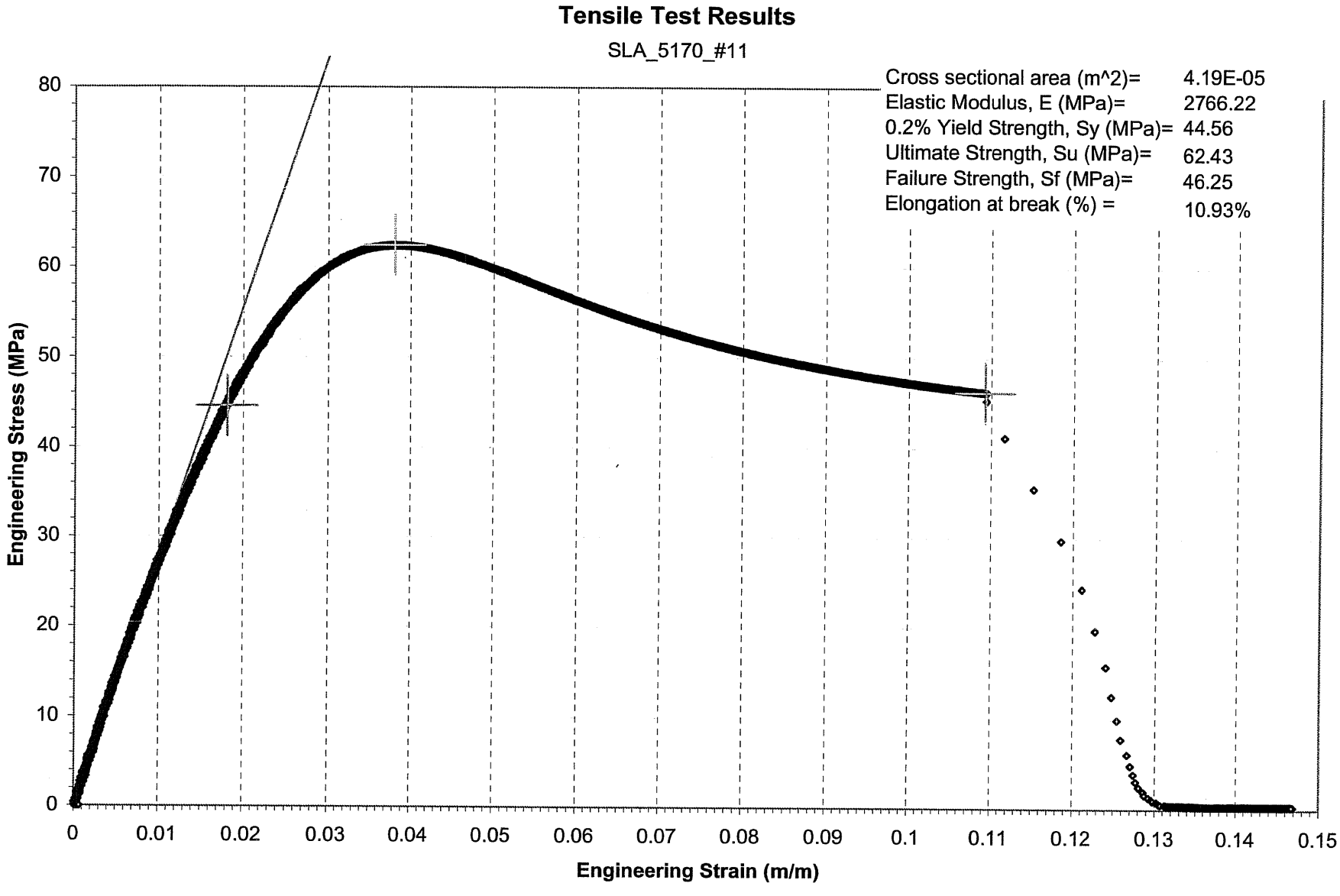


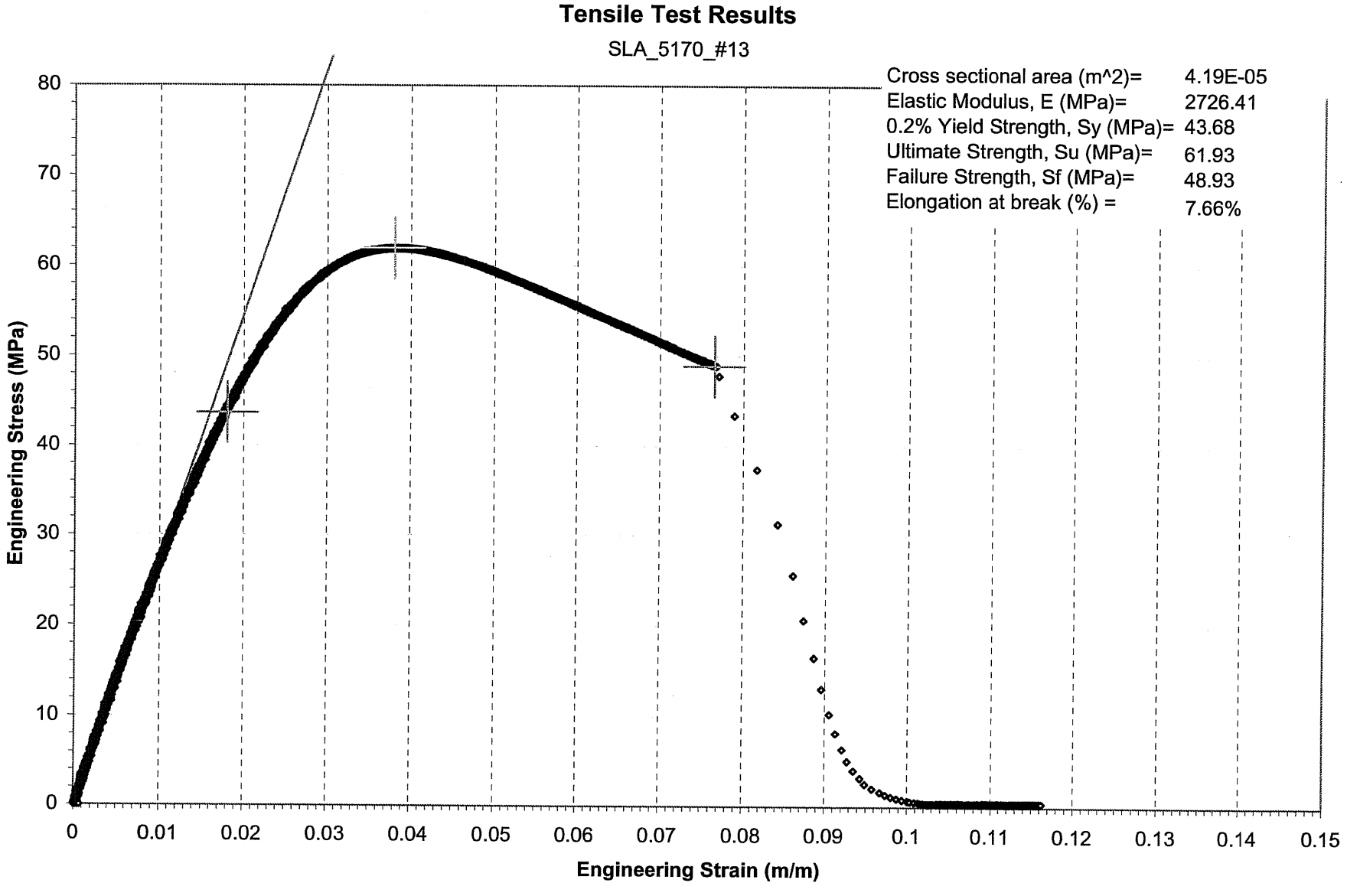
## Tensile Test Results

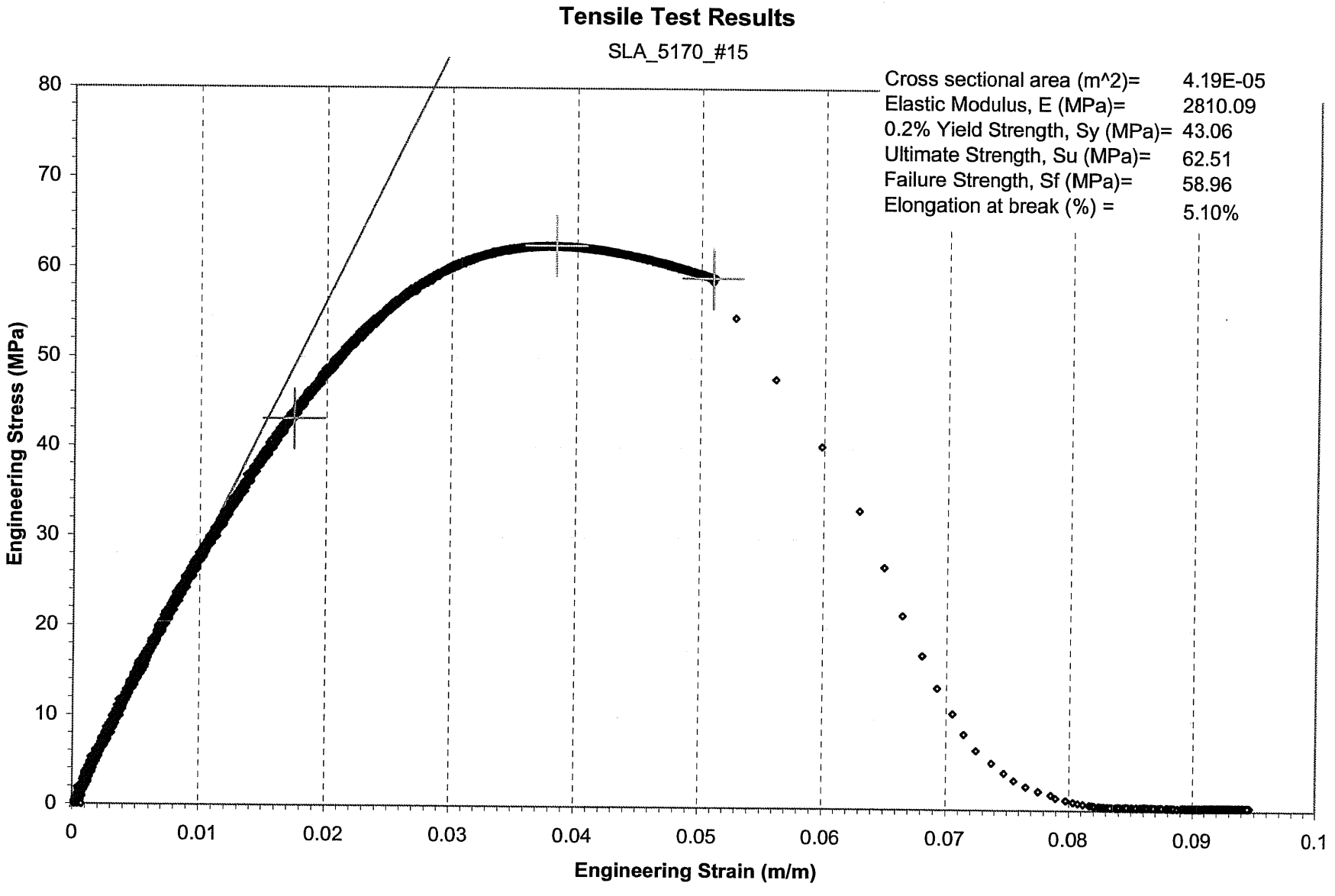
SLA_5170_#7

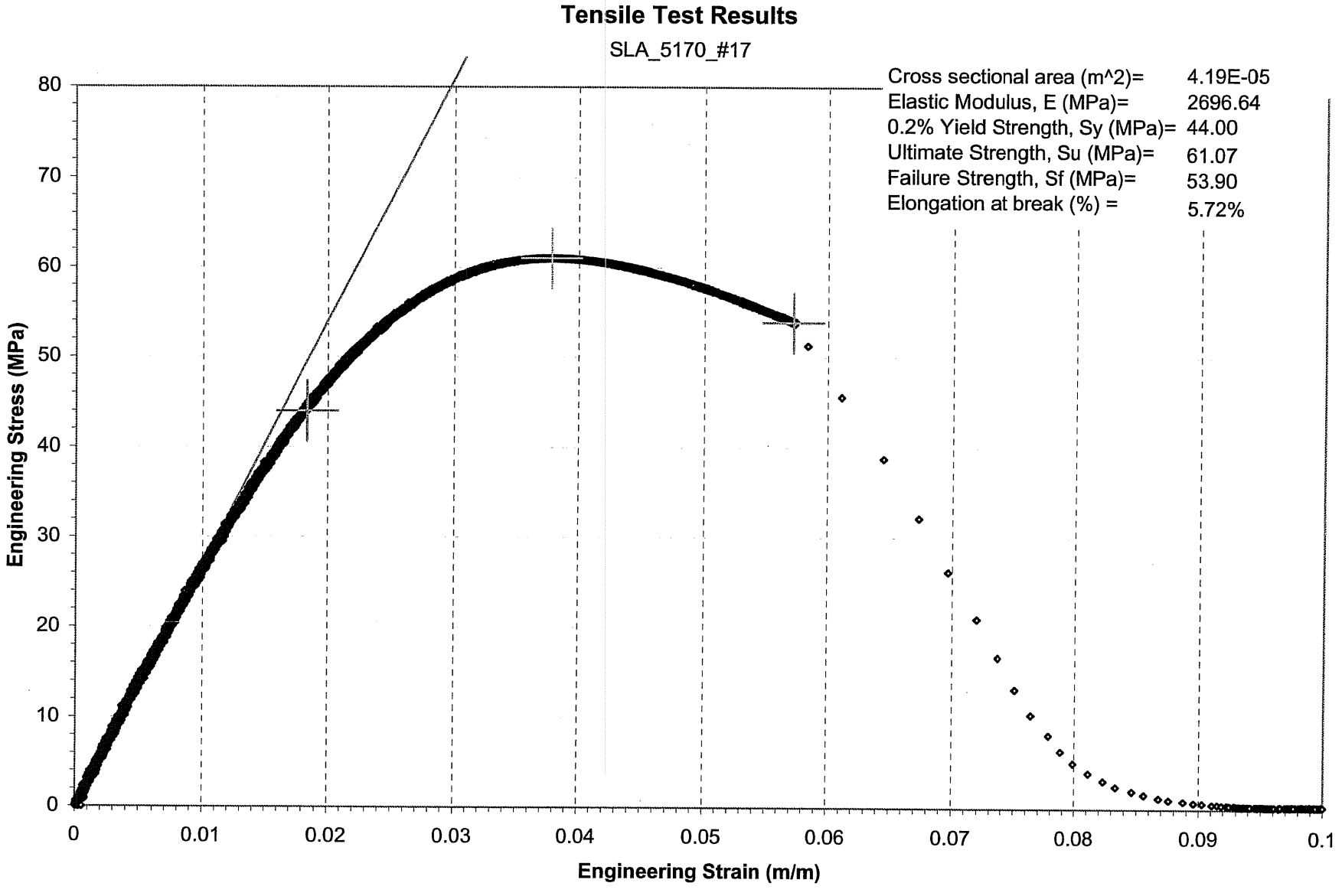


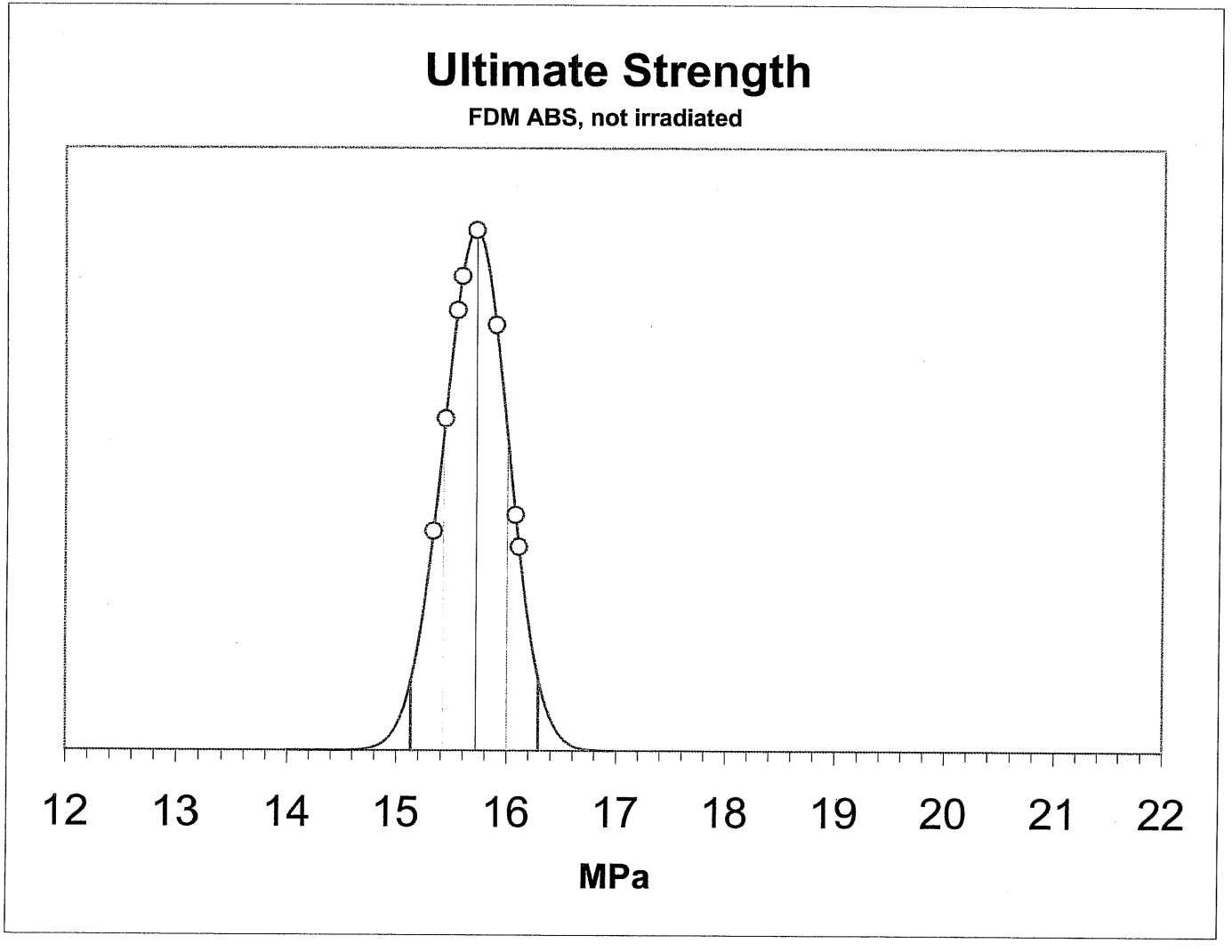













| | |
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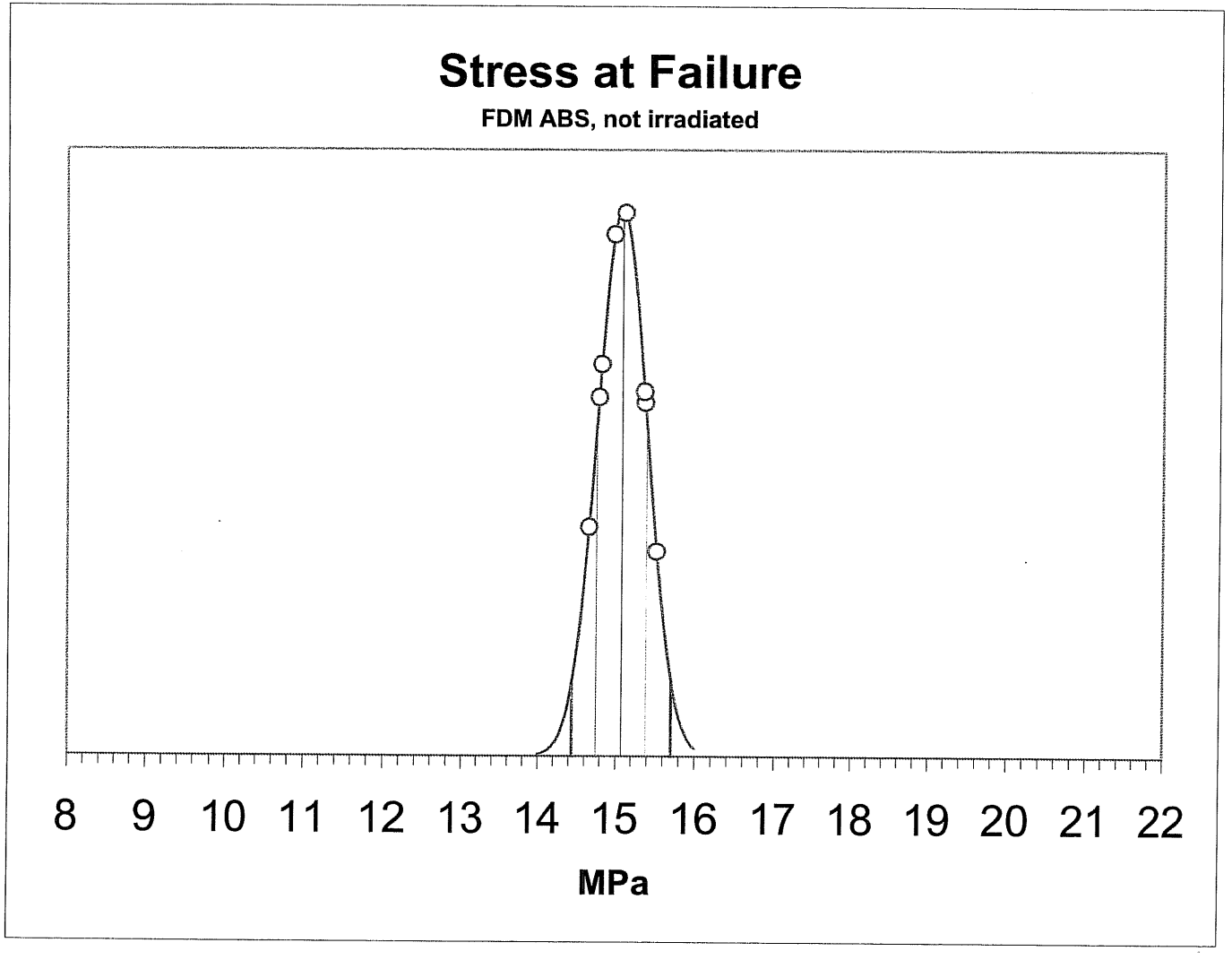


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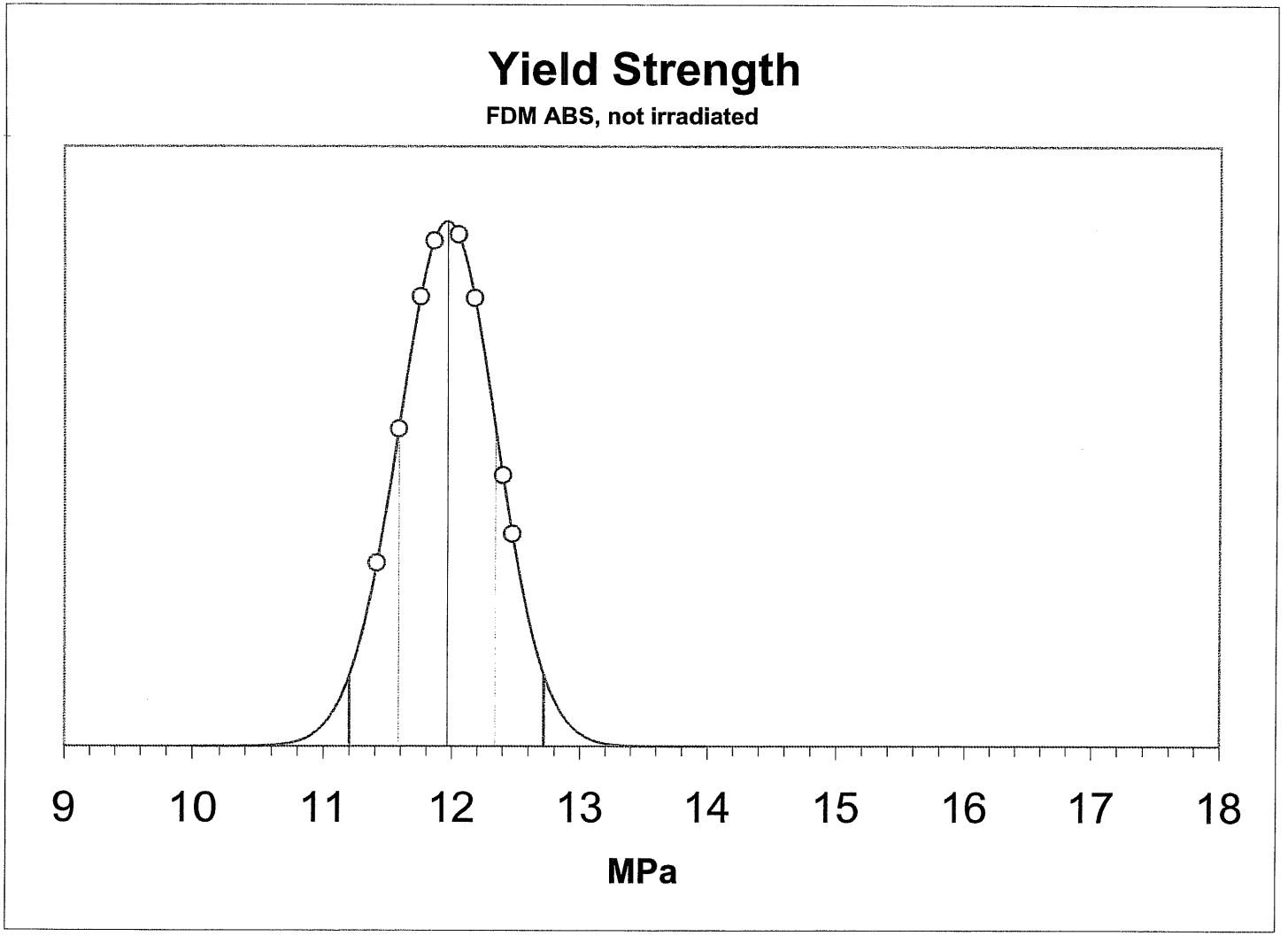


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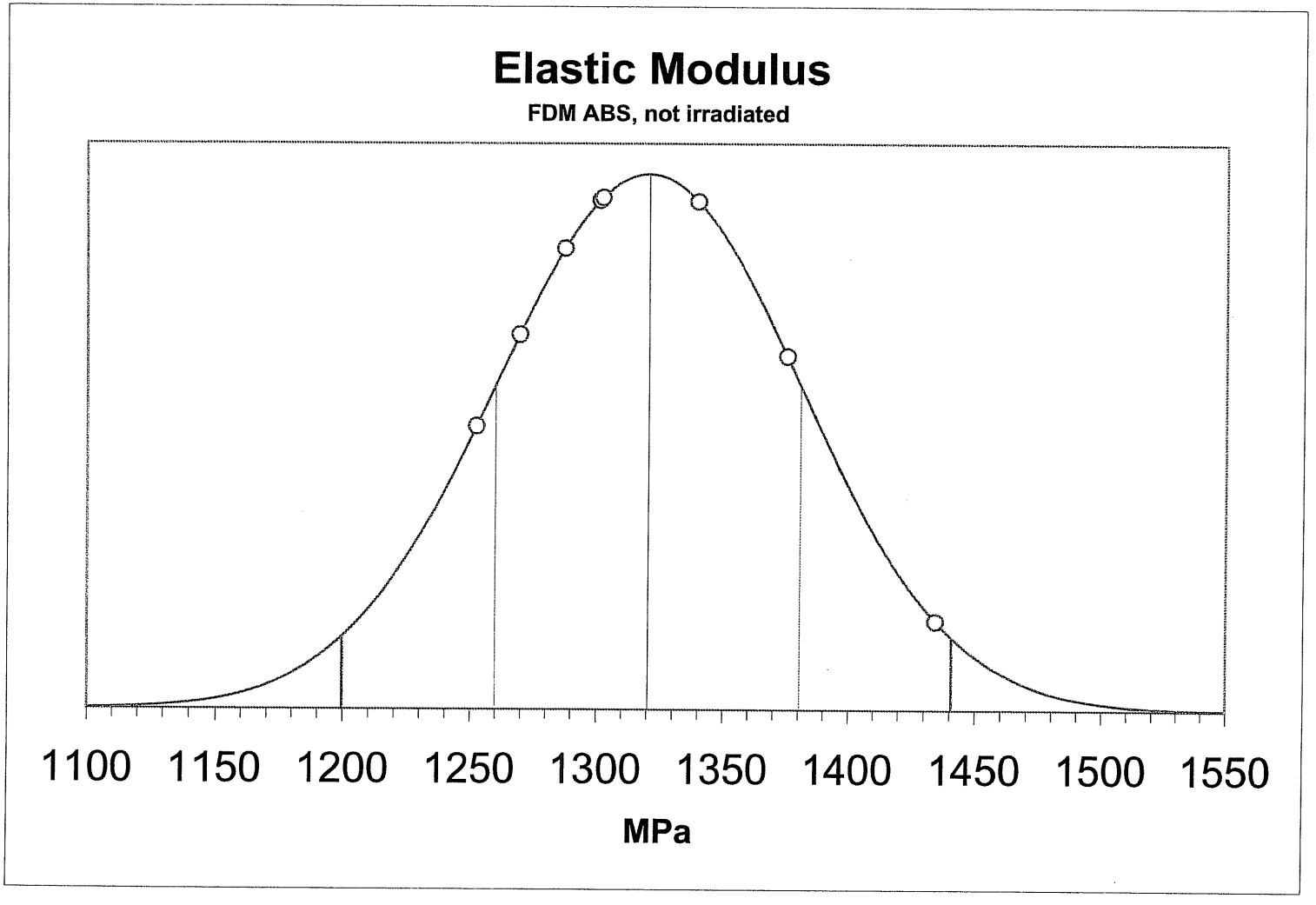


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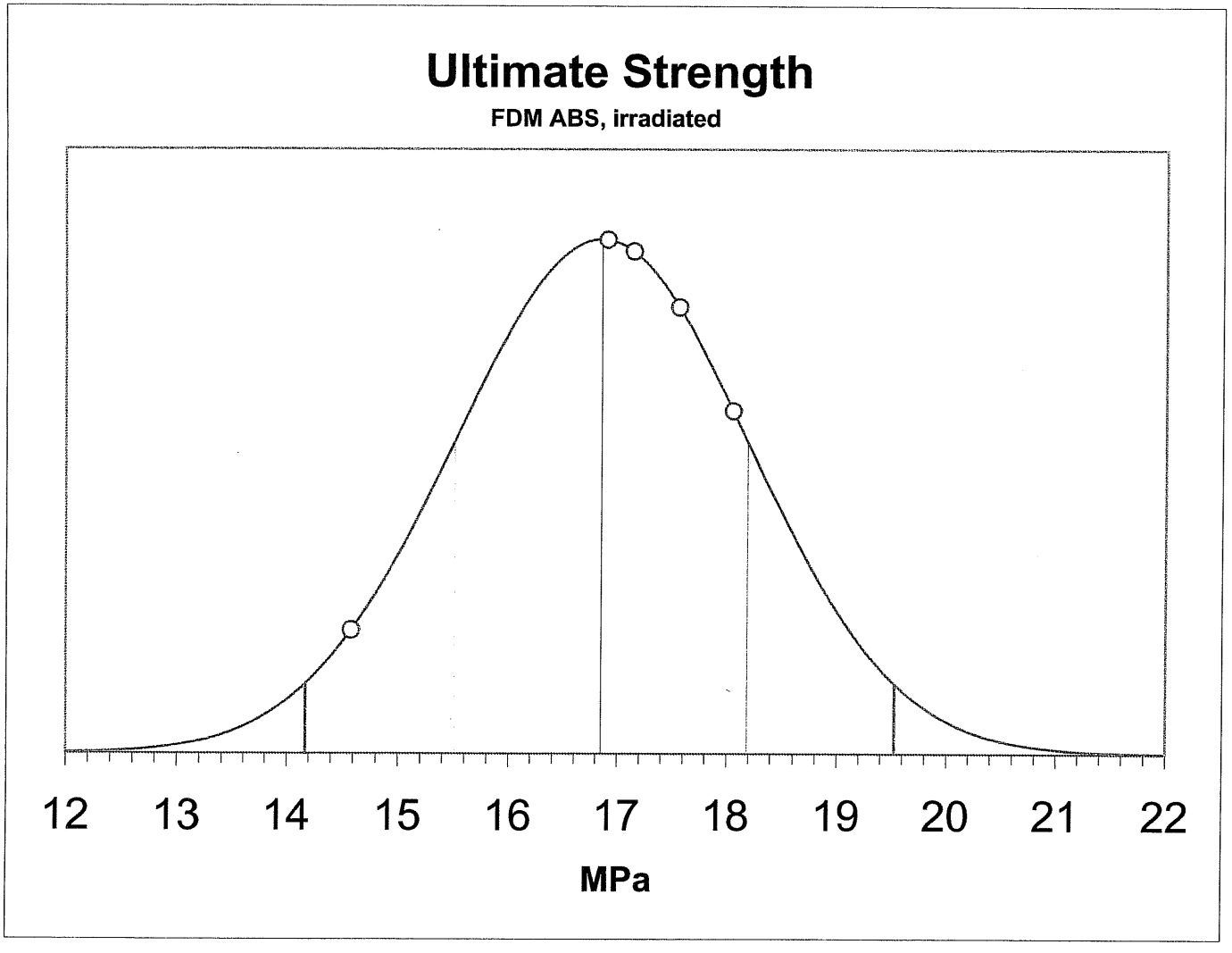


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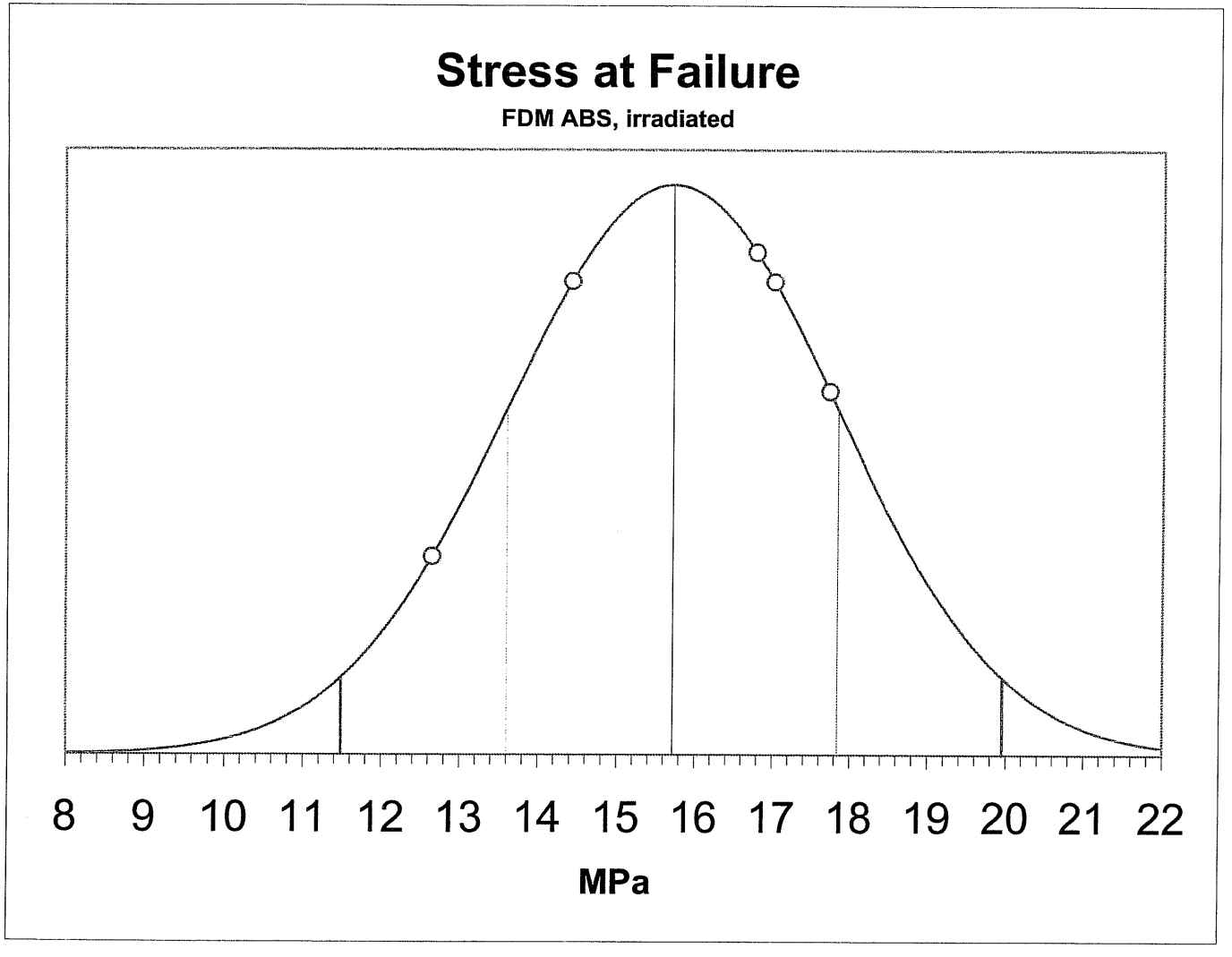


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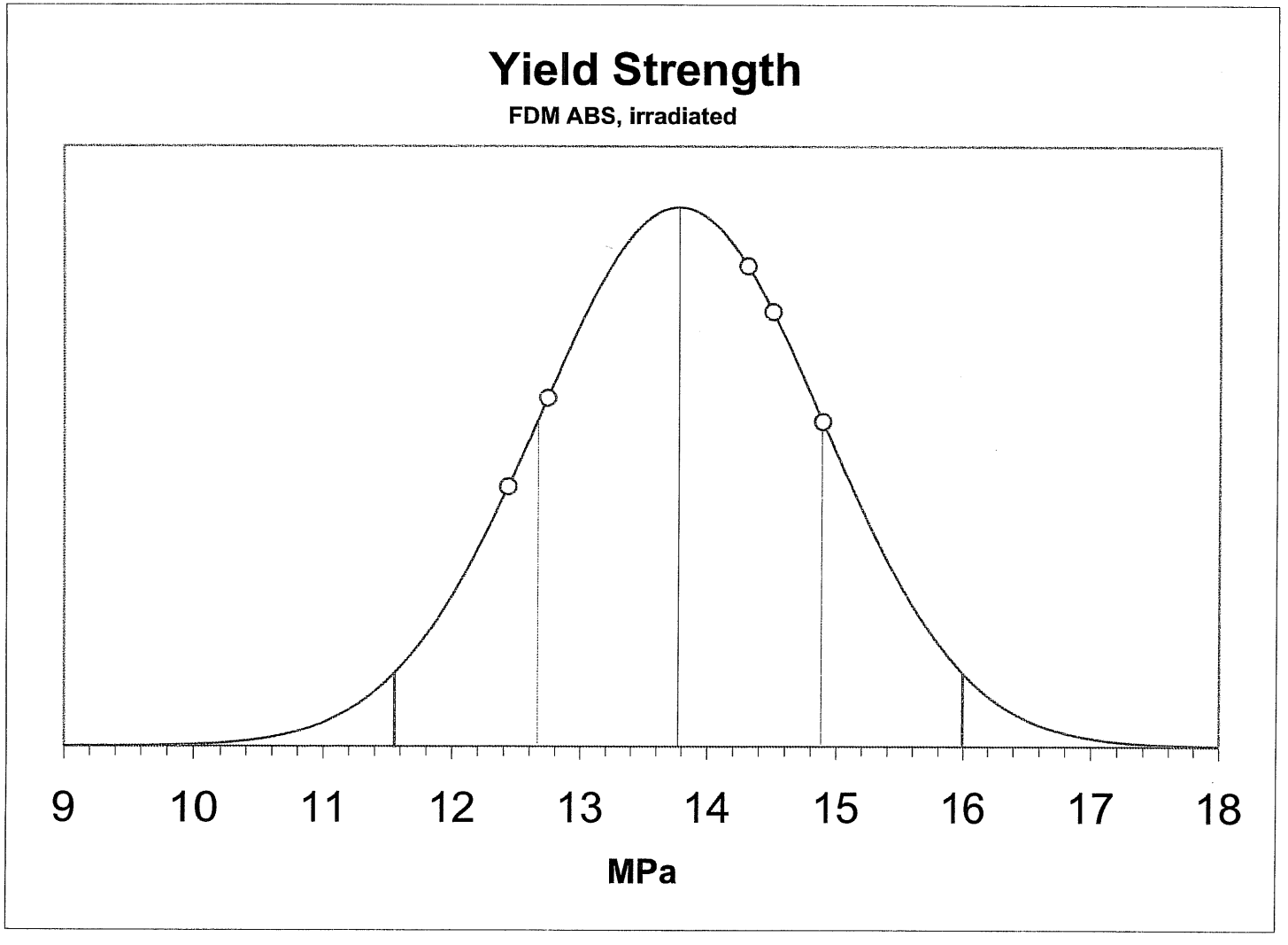


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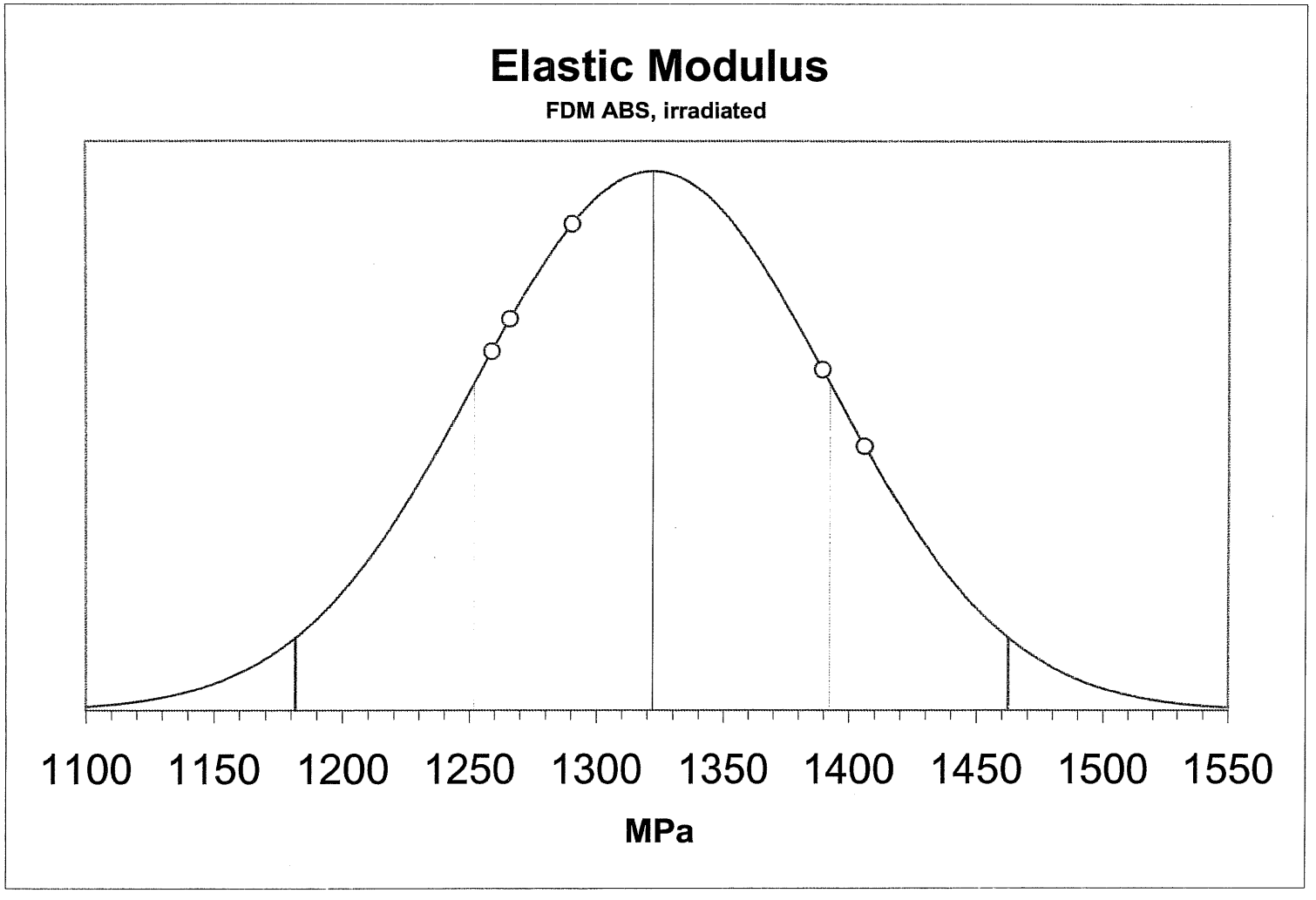


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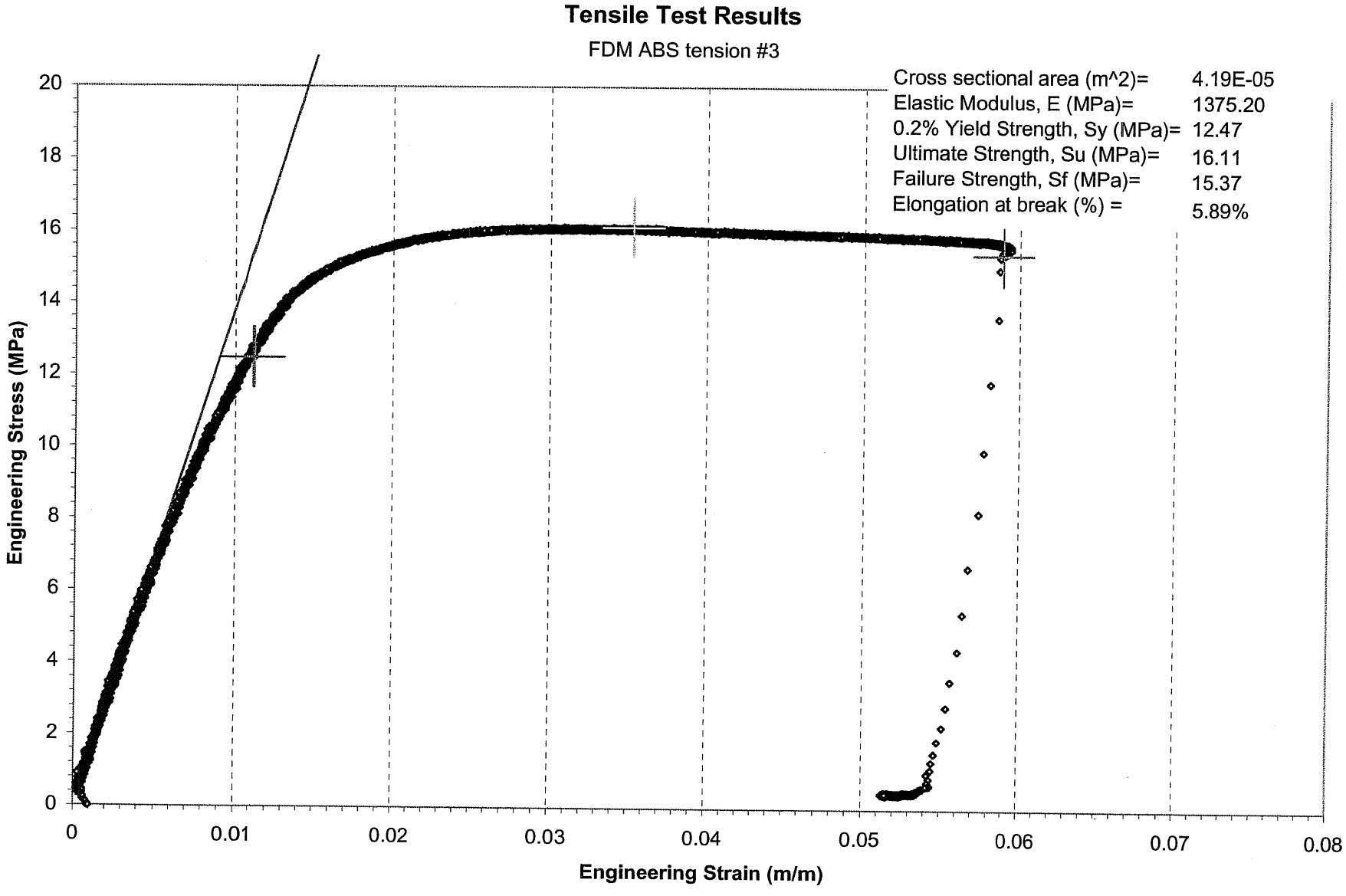
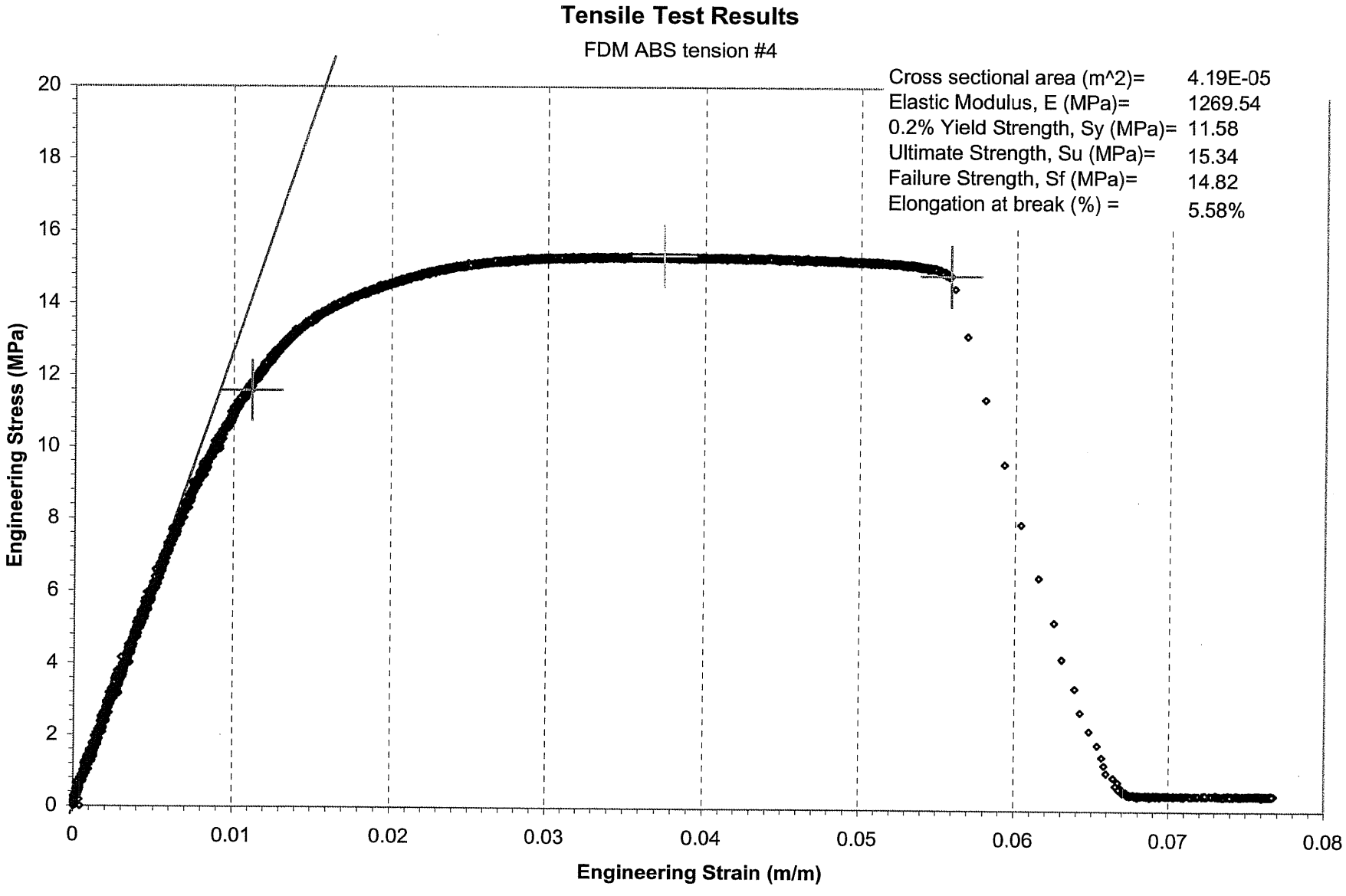
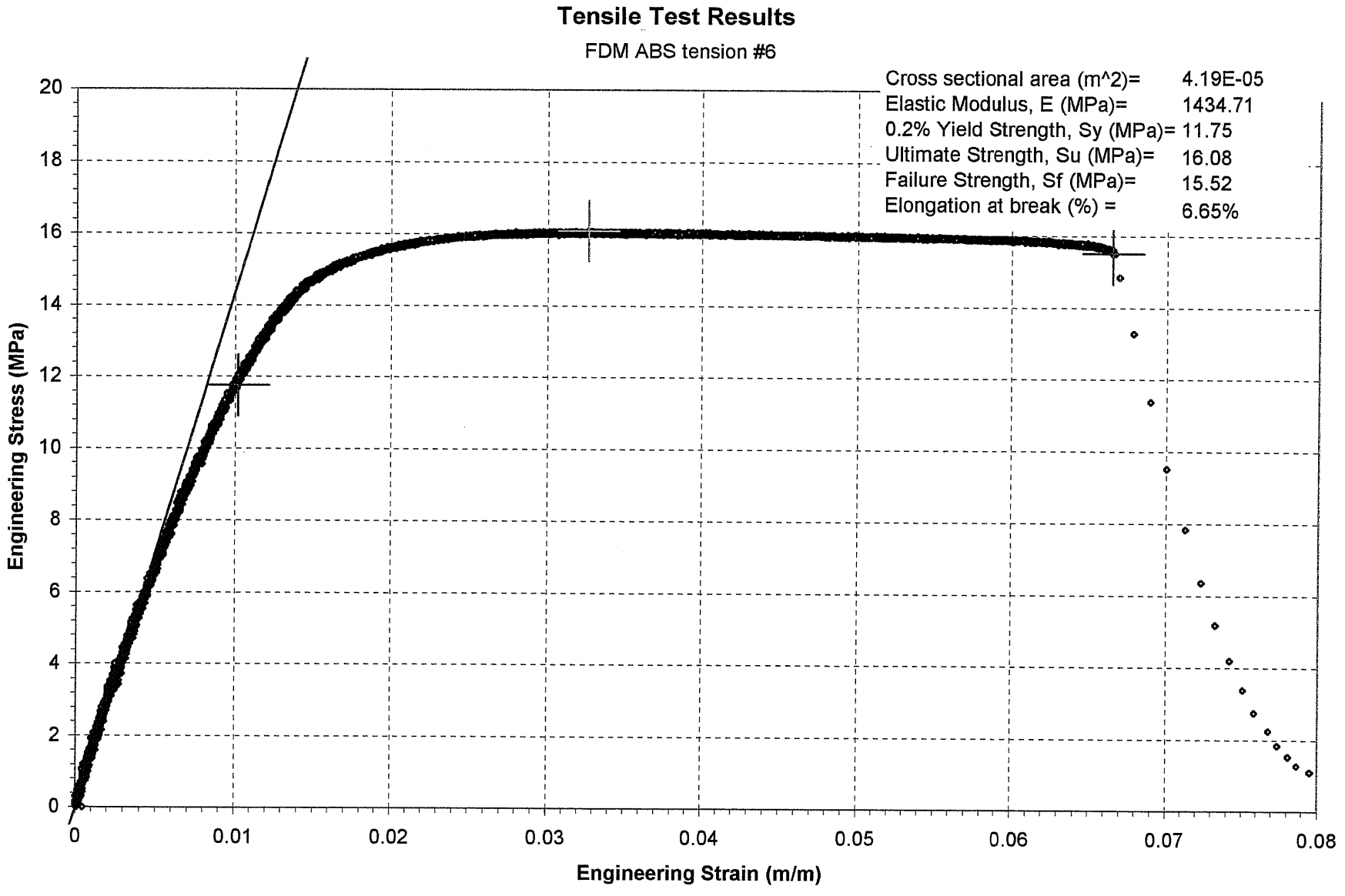
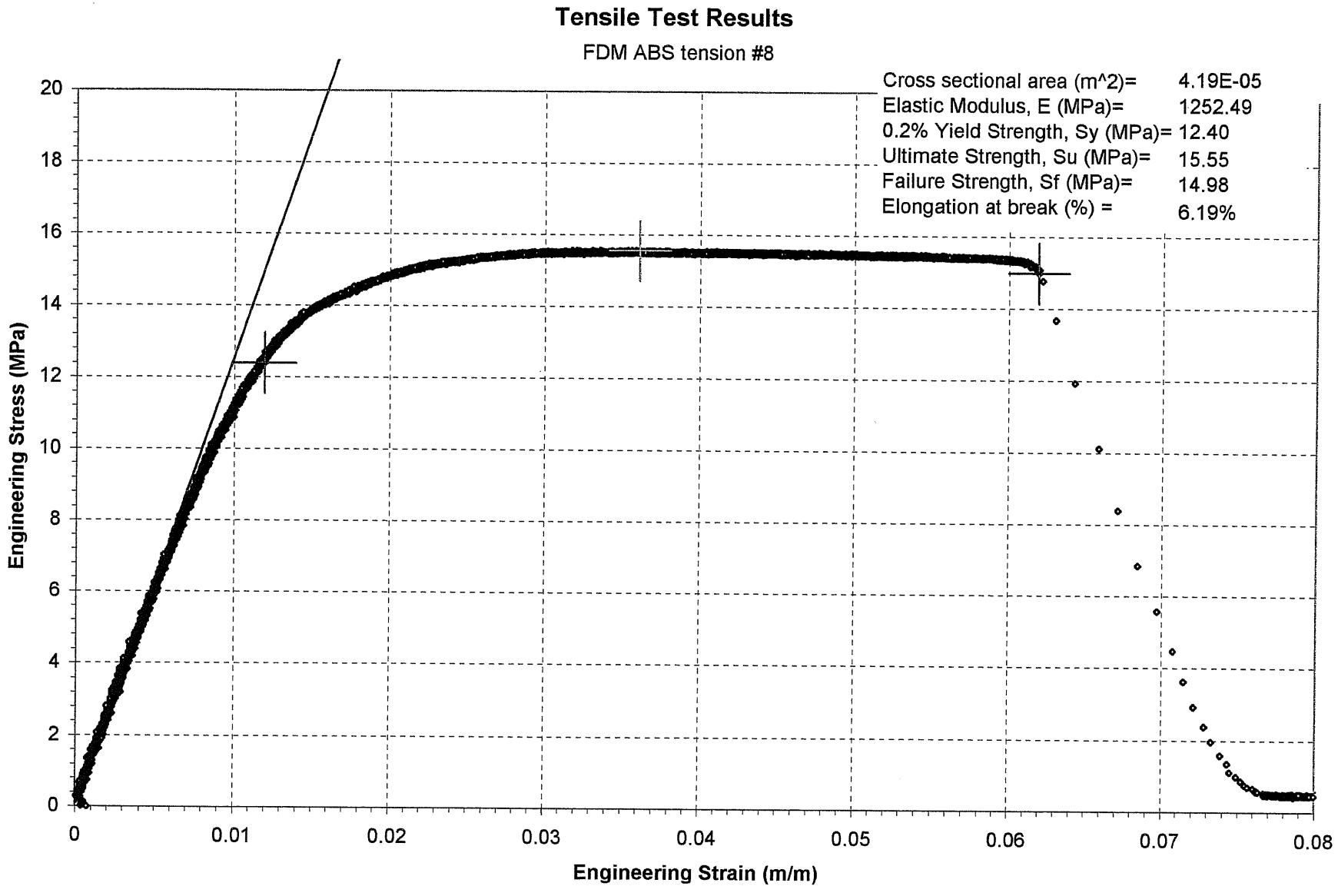
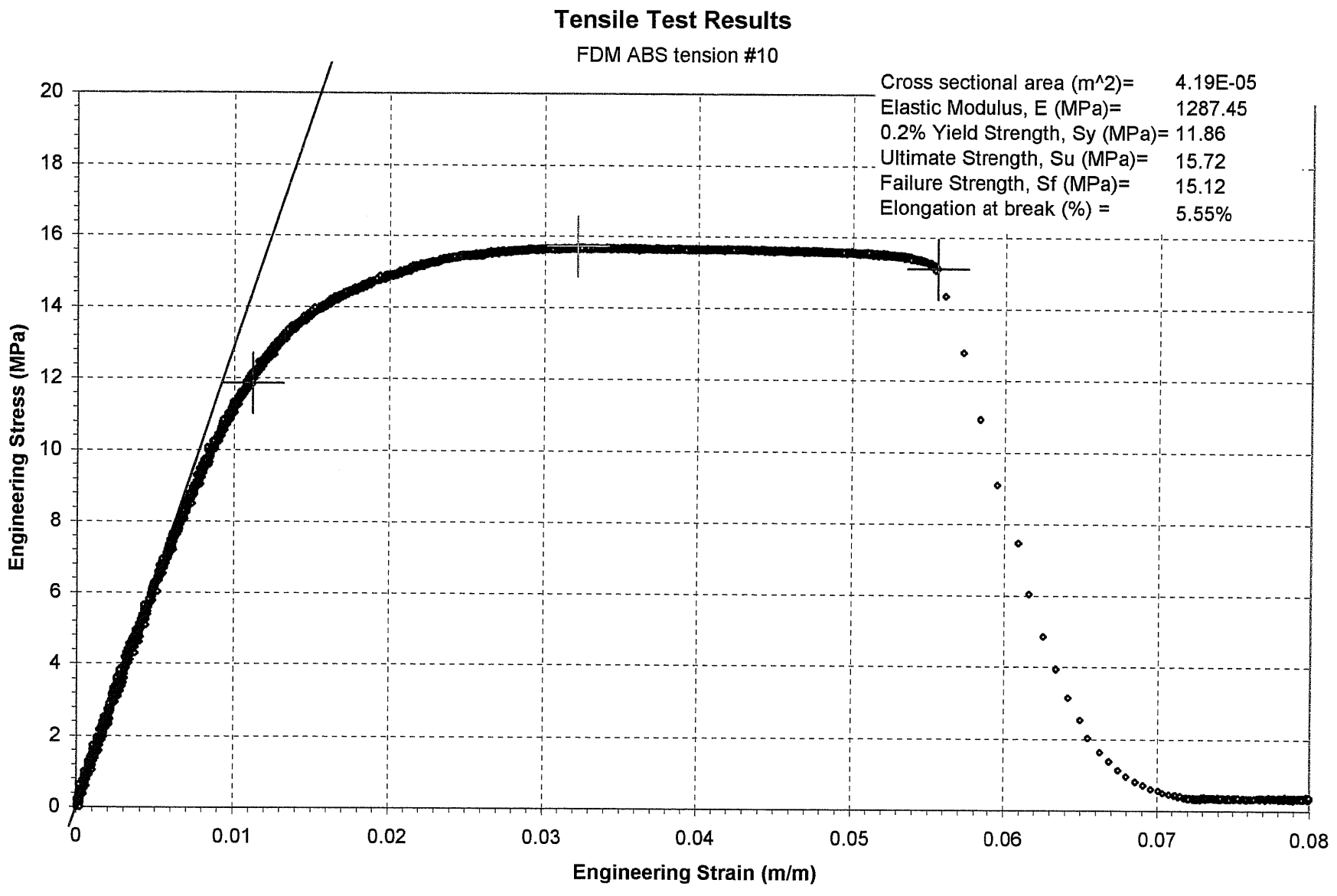
| # samples = | 5.00 |
| Average = | 1322.10 |
| Minimum = | 1258.82 |
| Maximum = | 1405.95 |
| Std dev = | 70.19 |

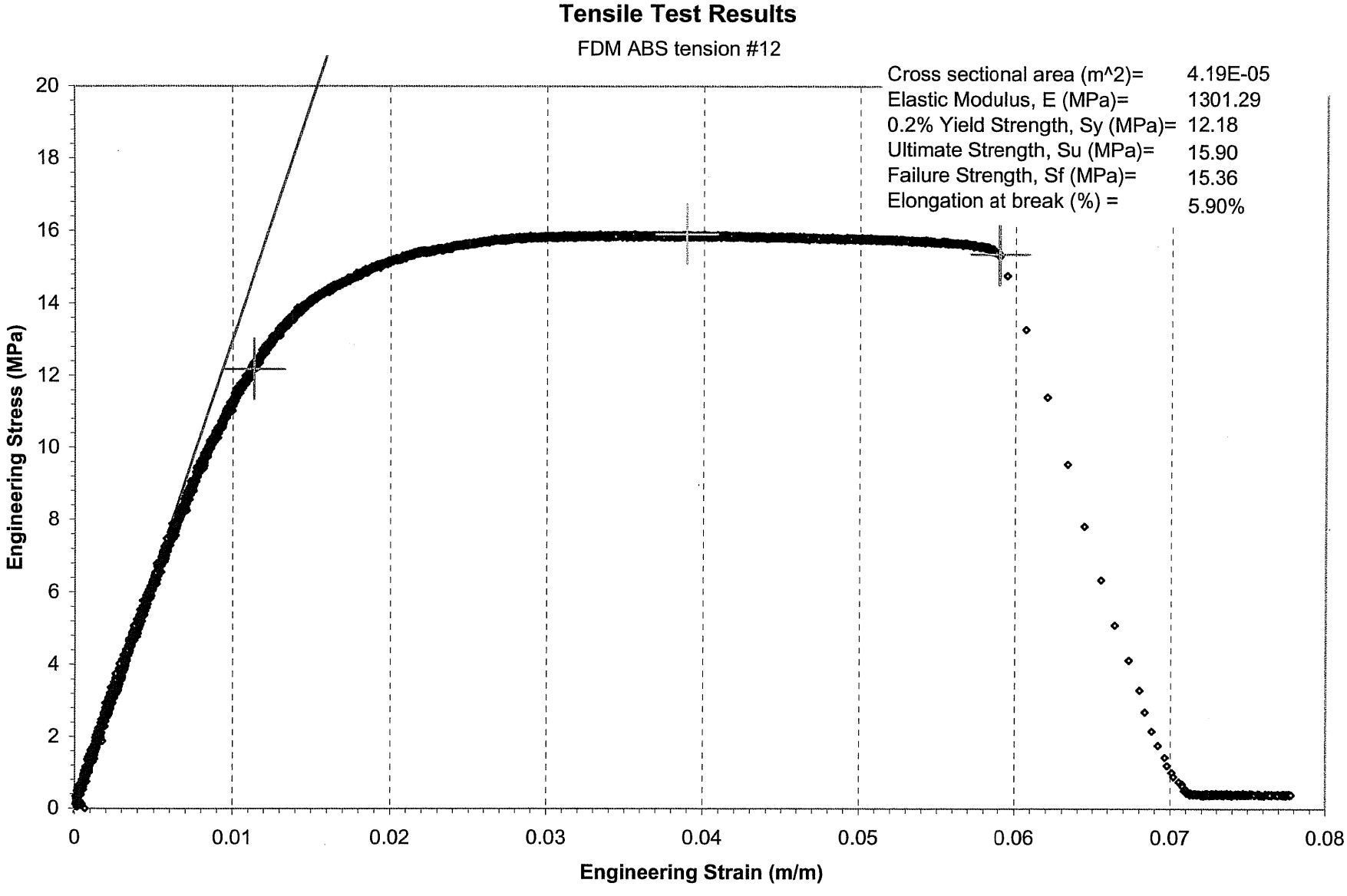


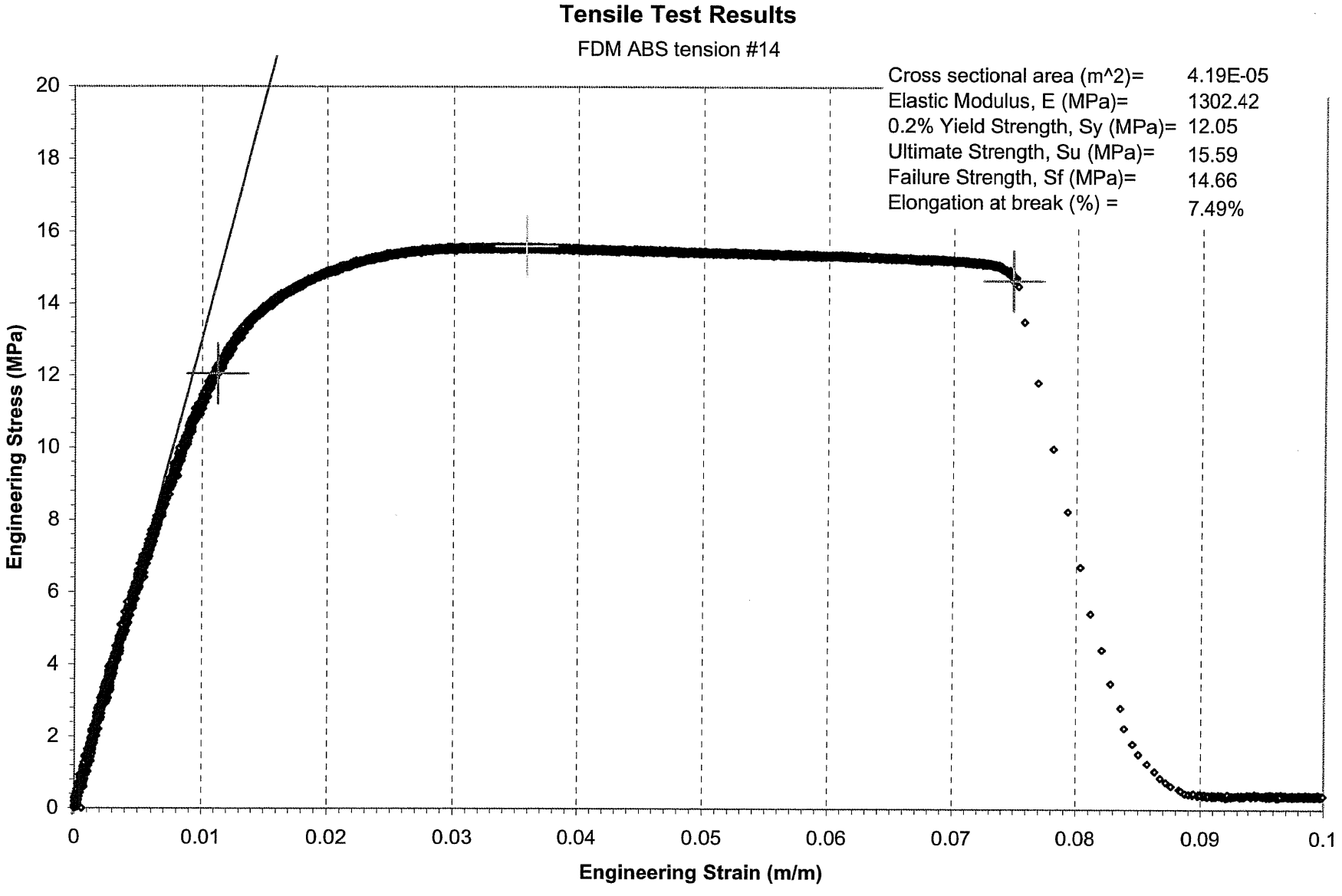


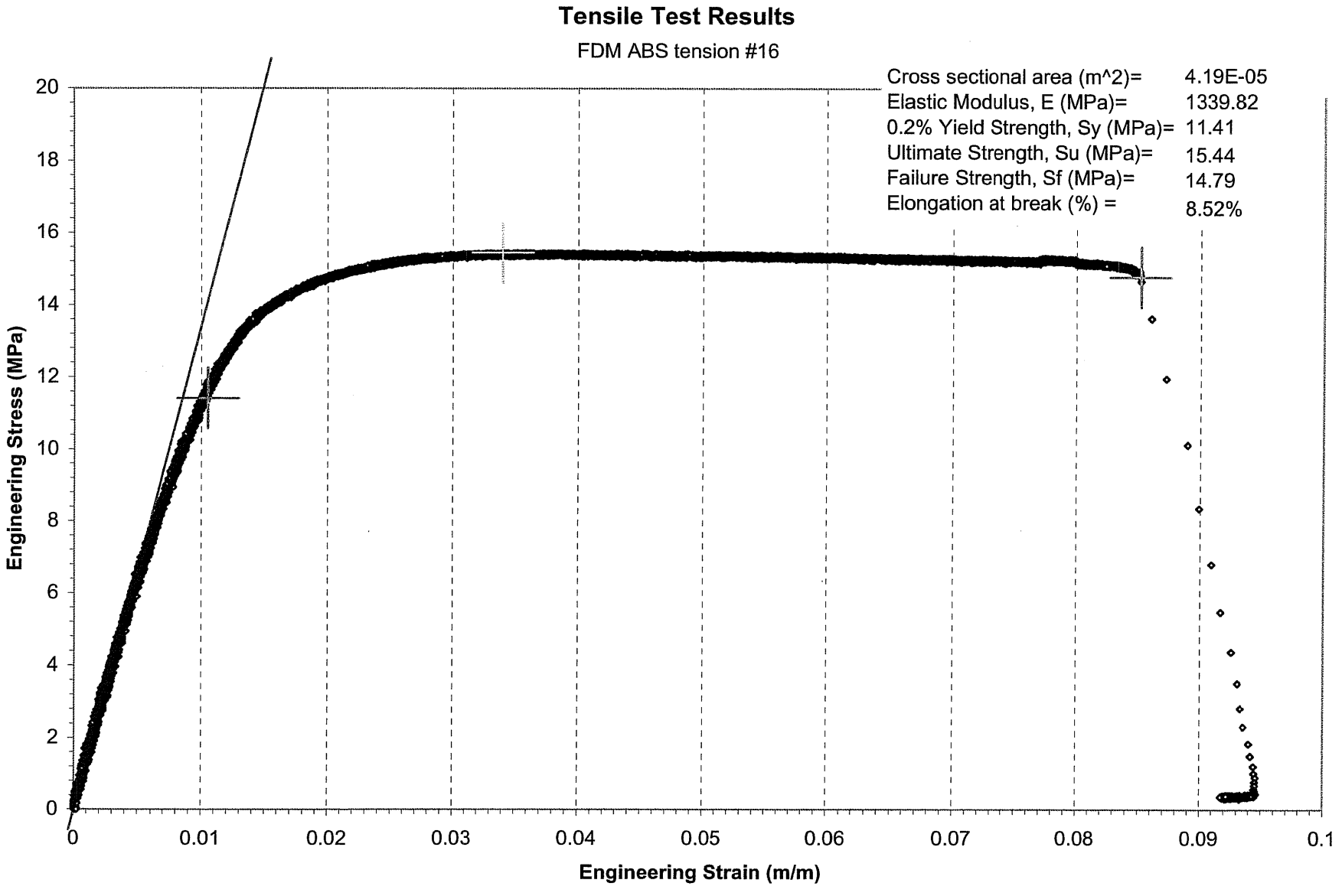


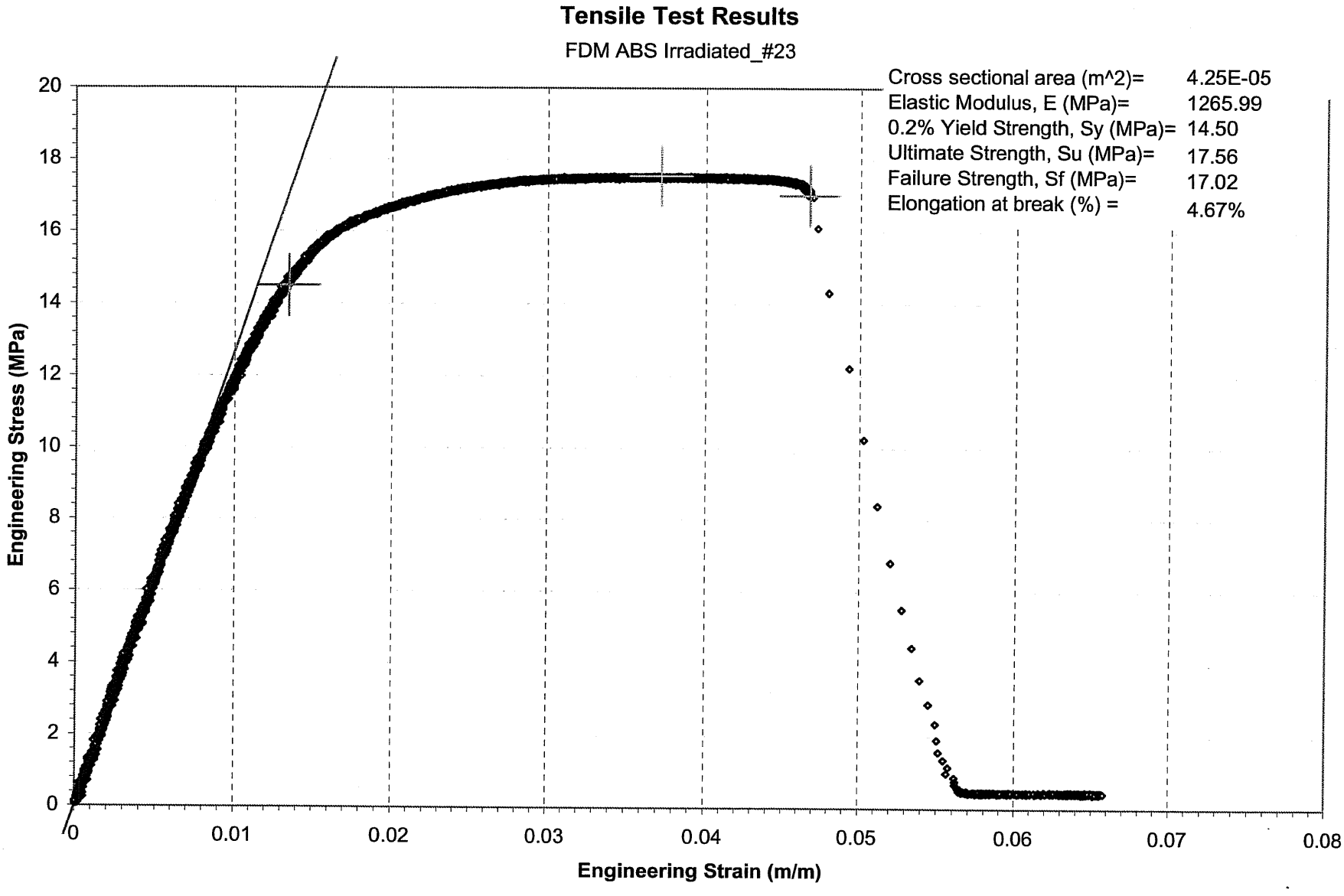


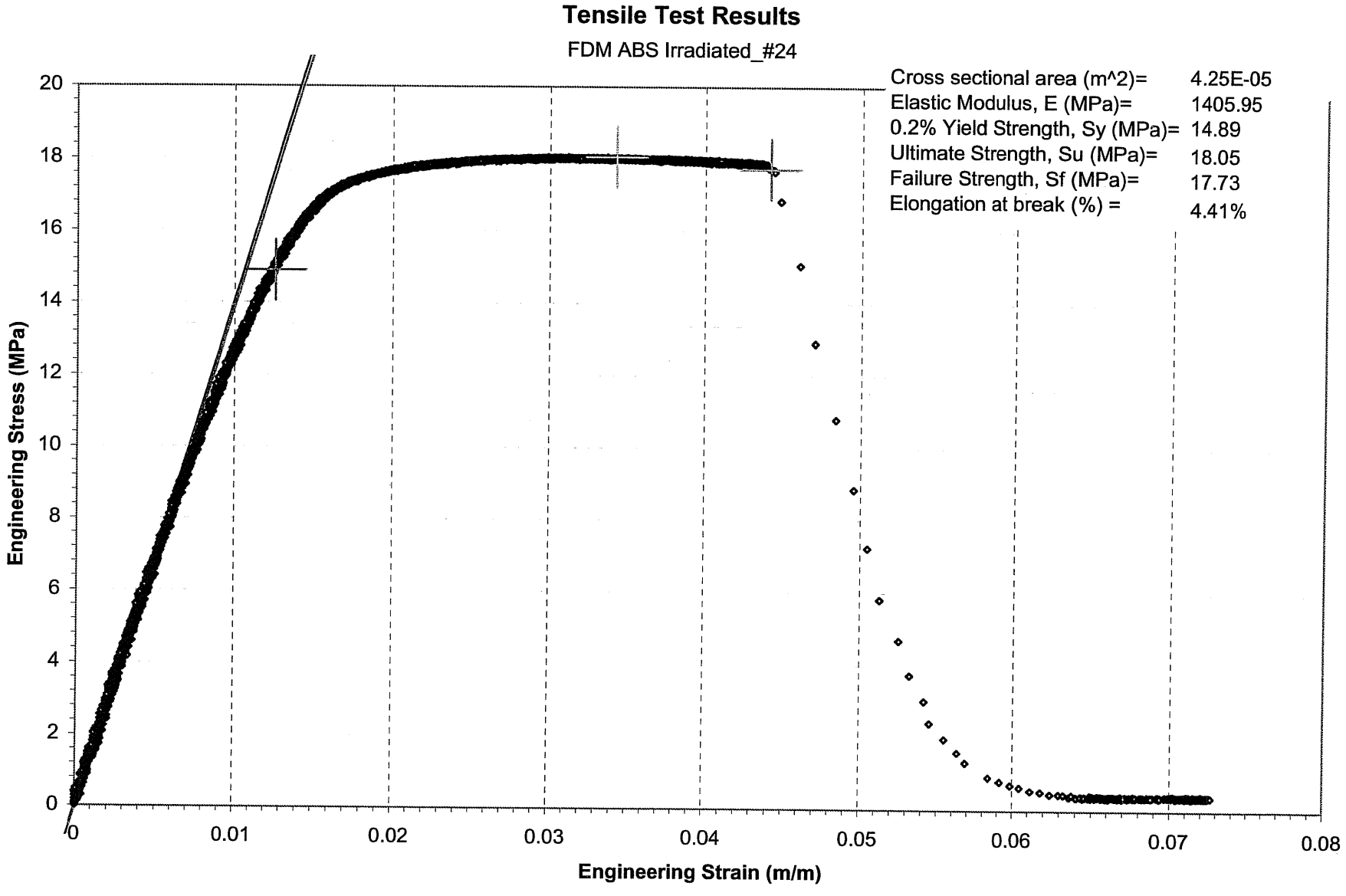






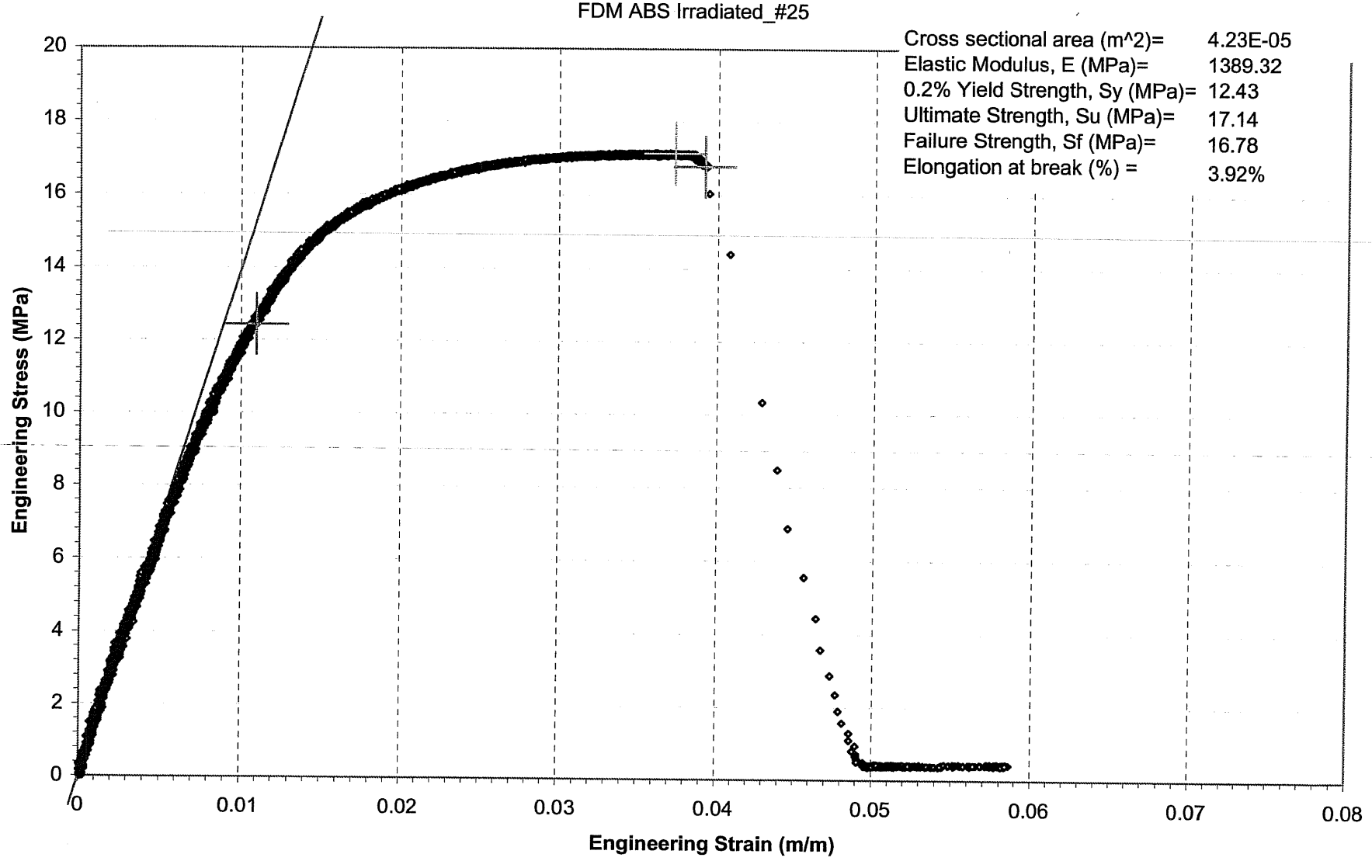




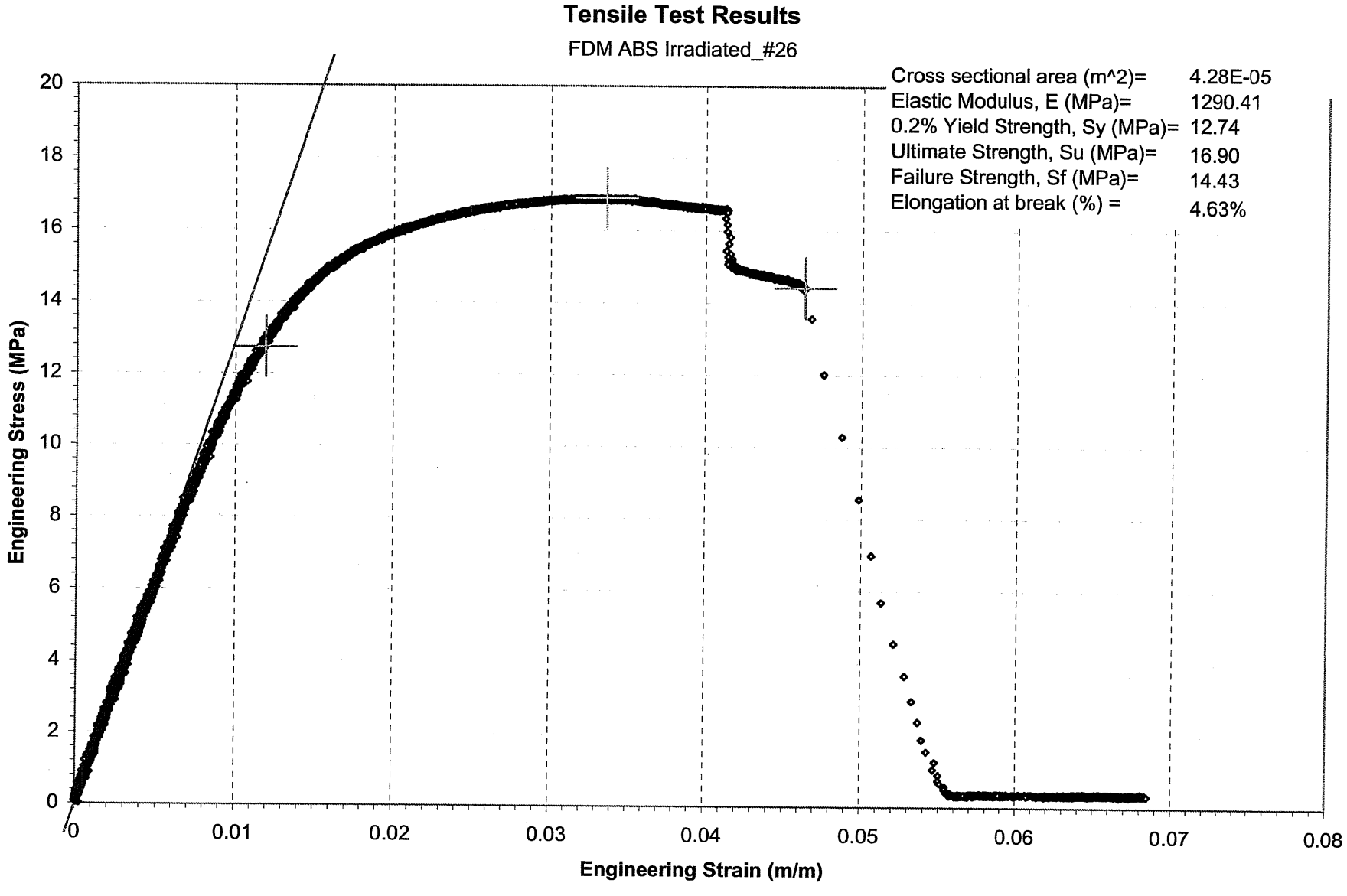


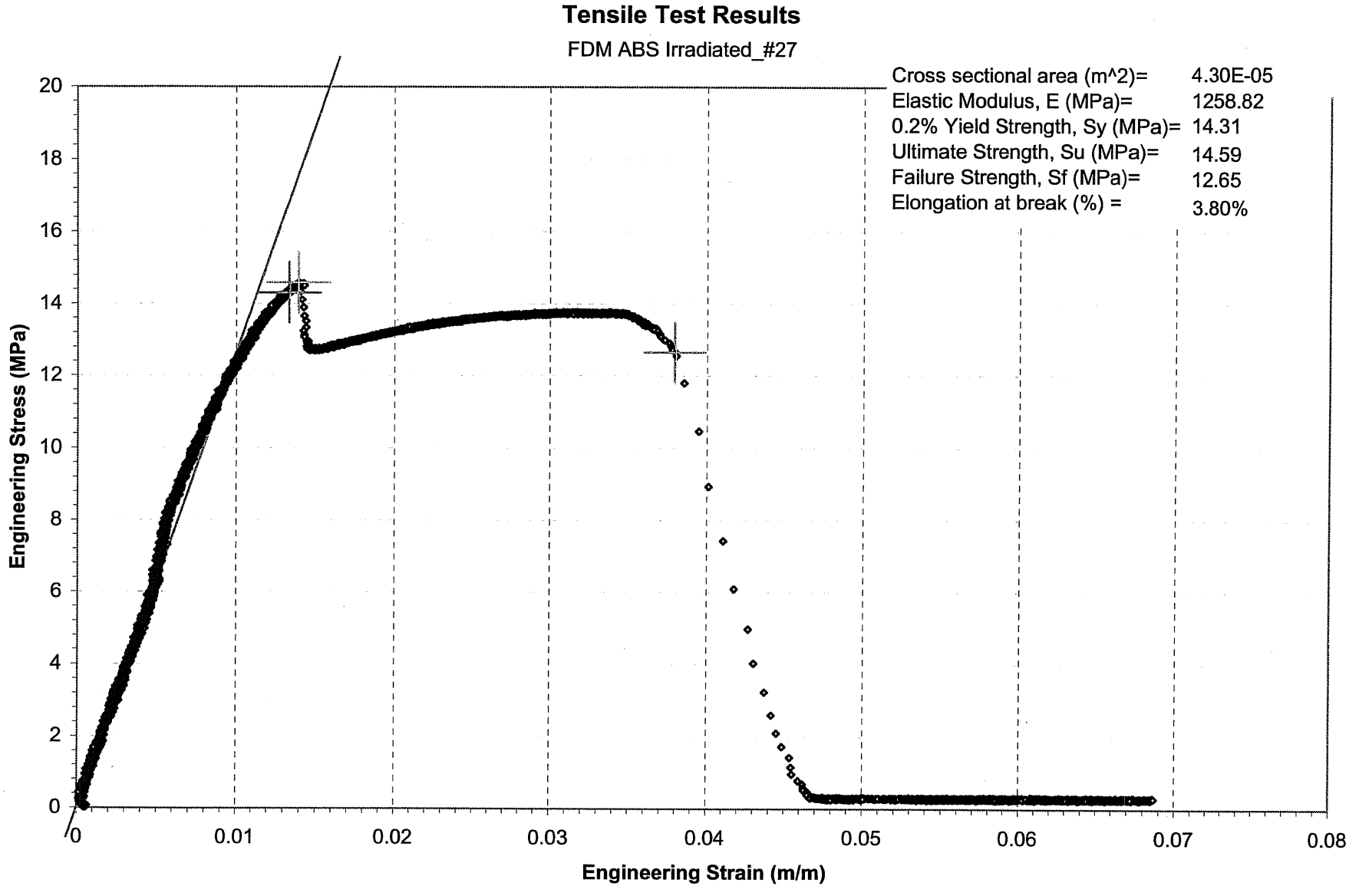
## Tensile Test Results

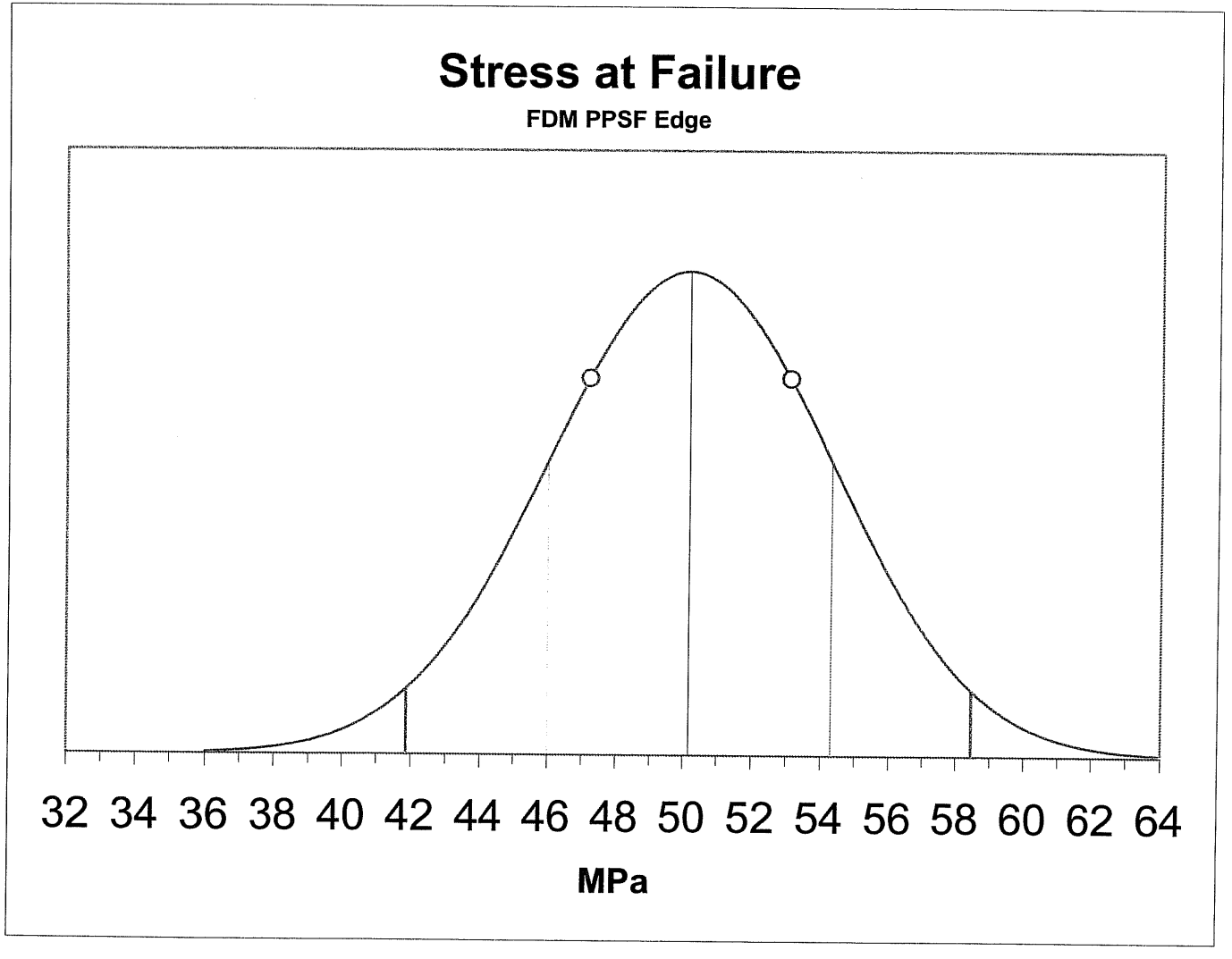
FDM ABS Irradiated_#25



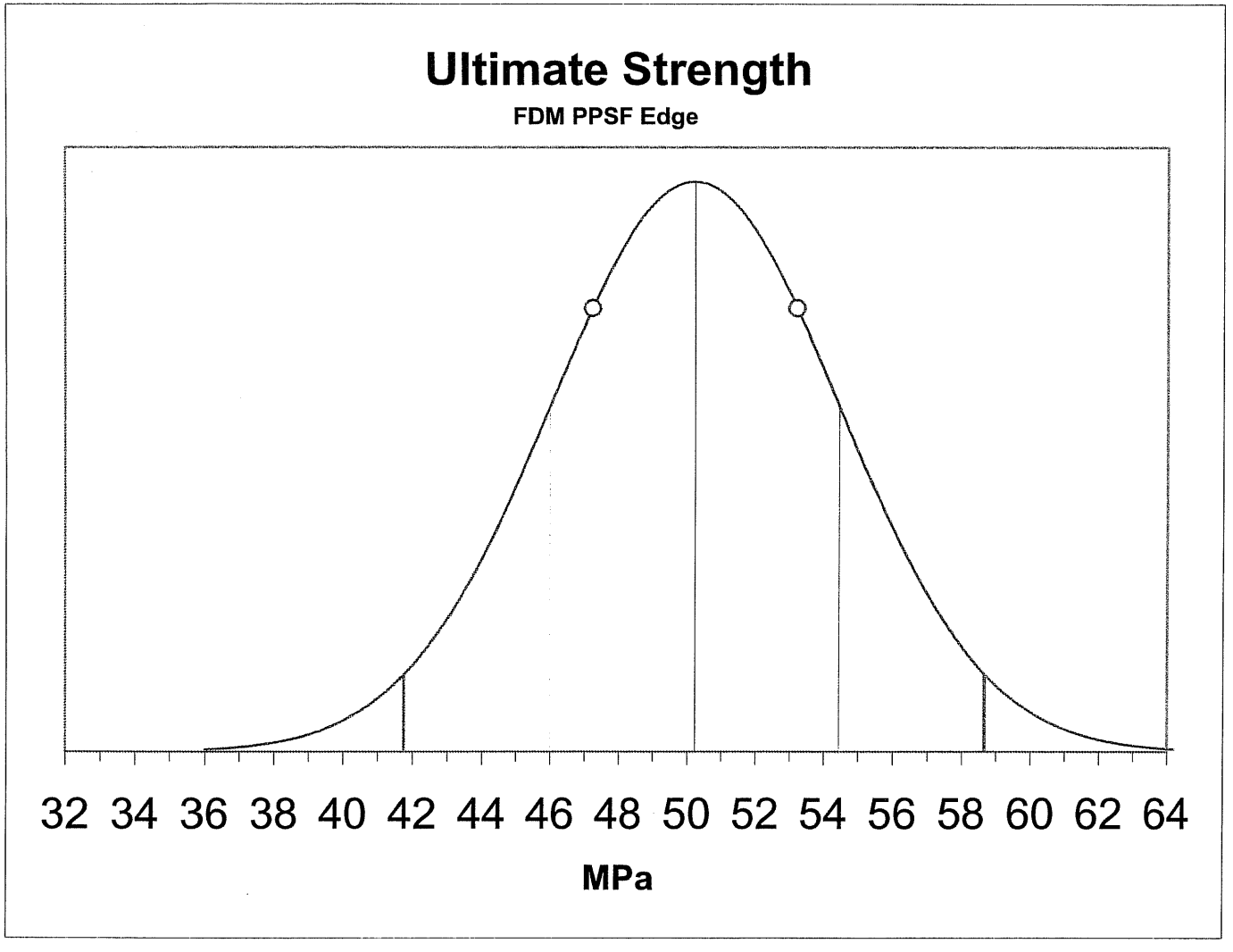

| | |
|---|---|
| Cross sectional area (m^2)= | 4.23E-05 |
| Elastic Modulus, E (MPa)= | 1389.32 |
| 0.2% Yield Strength, Sy (MPa)= | 12.43 |
| Ultimate Strength, Su (MPa)= | 17.14 |
| Failure Strength, Sf (MPa)= | 16.78 |
| Elongation at break (%) = | 3.92% |



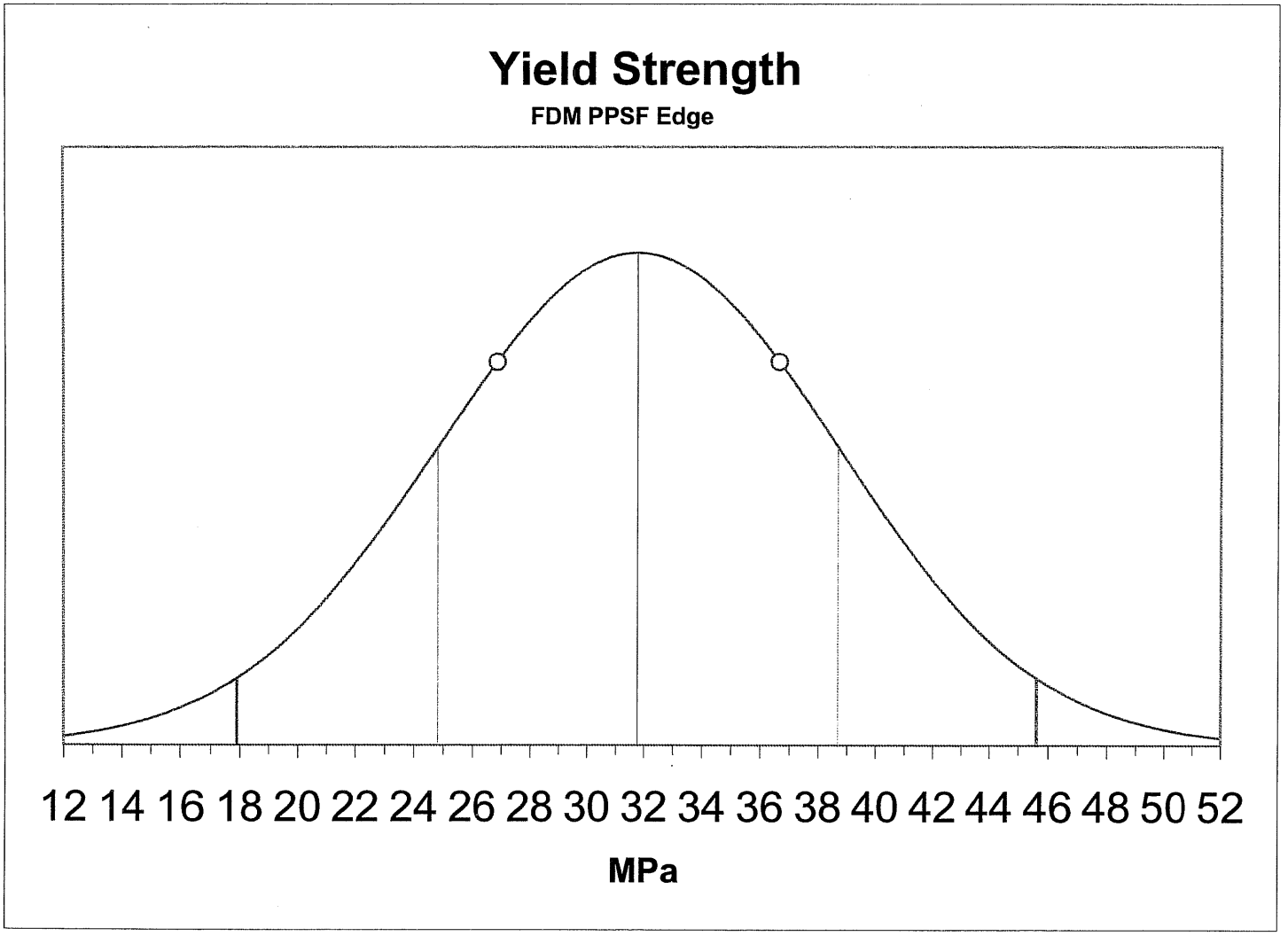




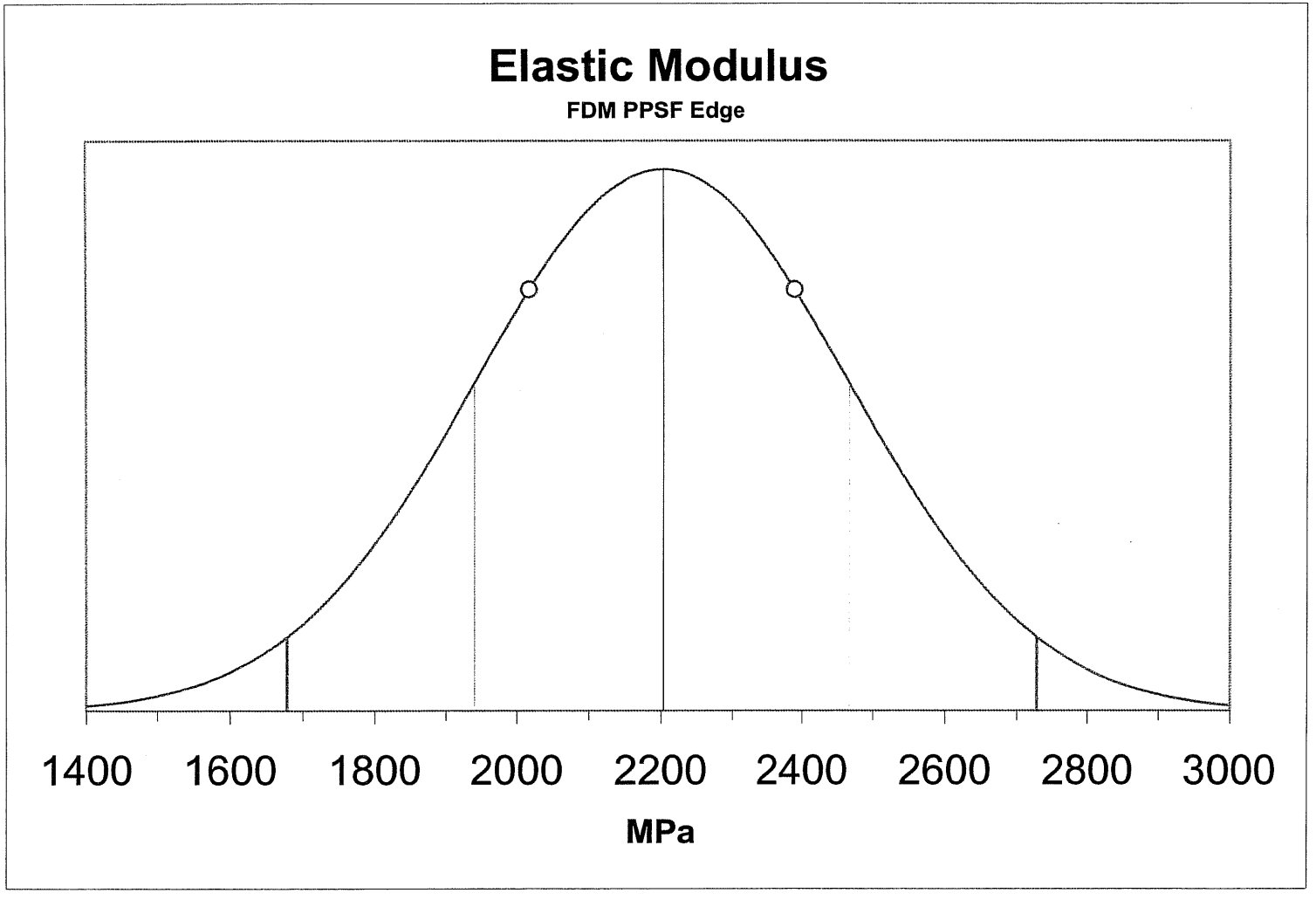

| | |
|---|---|
| # samples = | 2.00 |
| Average = | 50.17 |
| Minimum = | 47.24 |
| Maximum = | 53.11 |
| Std dev = | 4.15 |



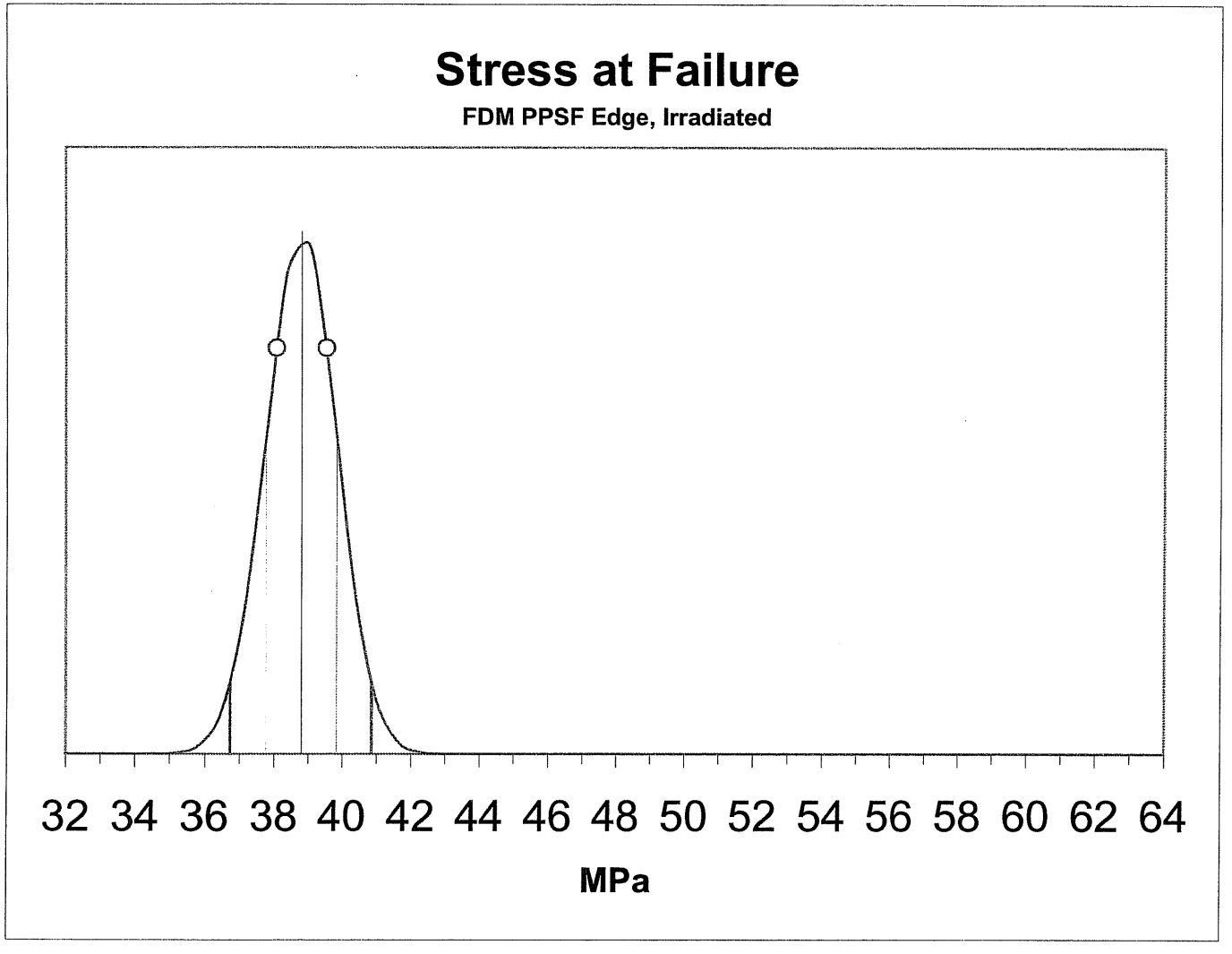

| | |
|---|---|
| # samples = | 2.00 |
| Average = | 50.23 |
| Minimum = | 47.24 |
| Maximum = | 53.22 |
| Std dev = | 4.23 |



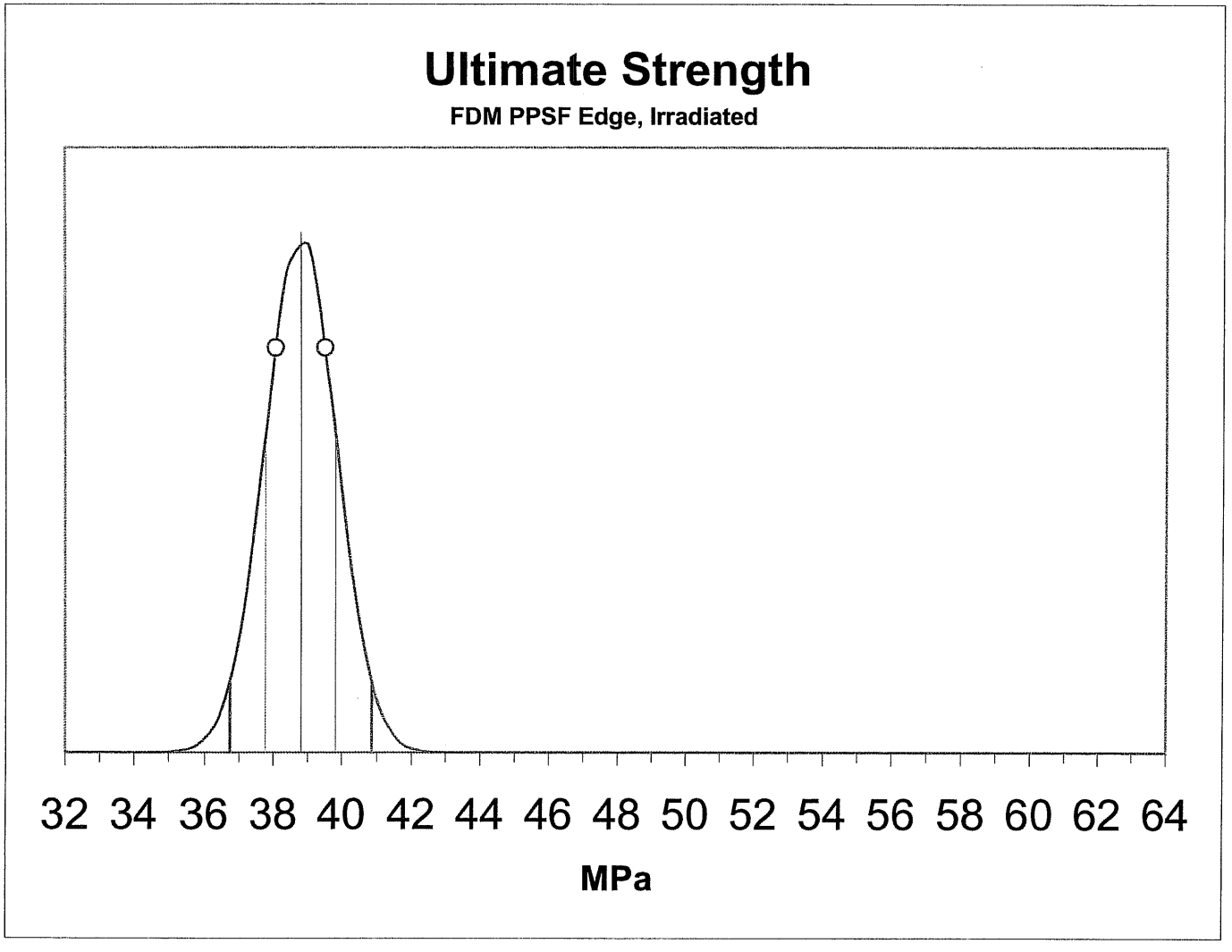

| | |
|---|---|
| # samples = | 2.00 |
| Average = | 31.77 |
| Minimum = | 26.87 |
| Maximum = | 36.67 |
| Std dev = | 6.93 |




| | |
|---|---|
| # samples = | 2.00 |
| Average = | 2203.24 |
| Minimum = | 2017.59 |
| Maximum = | 2388.89 |
| Std dev = | 262.55 |



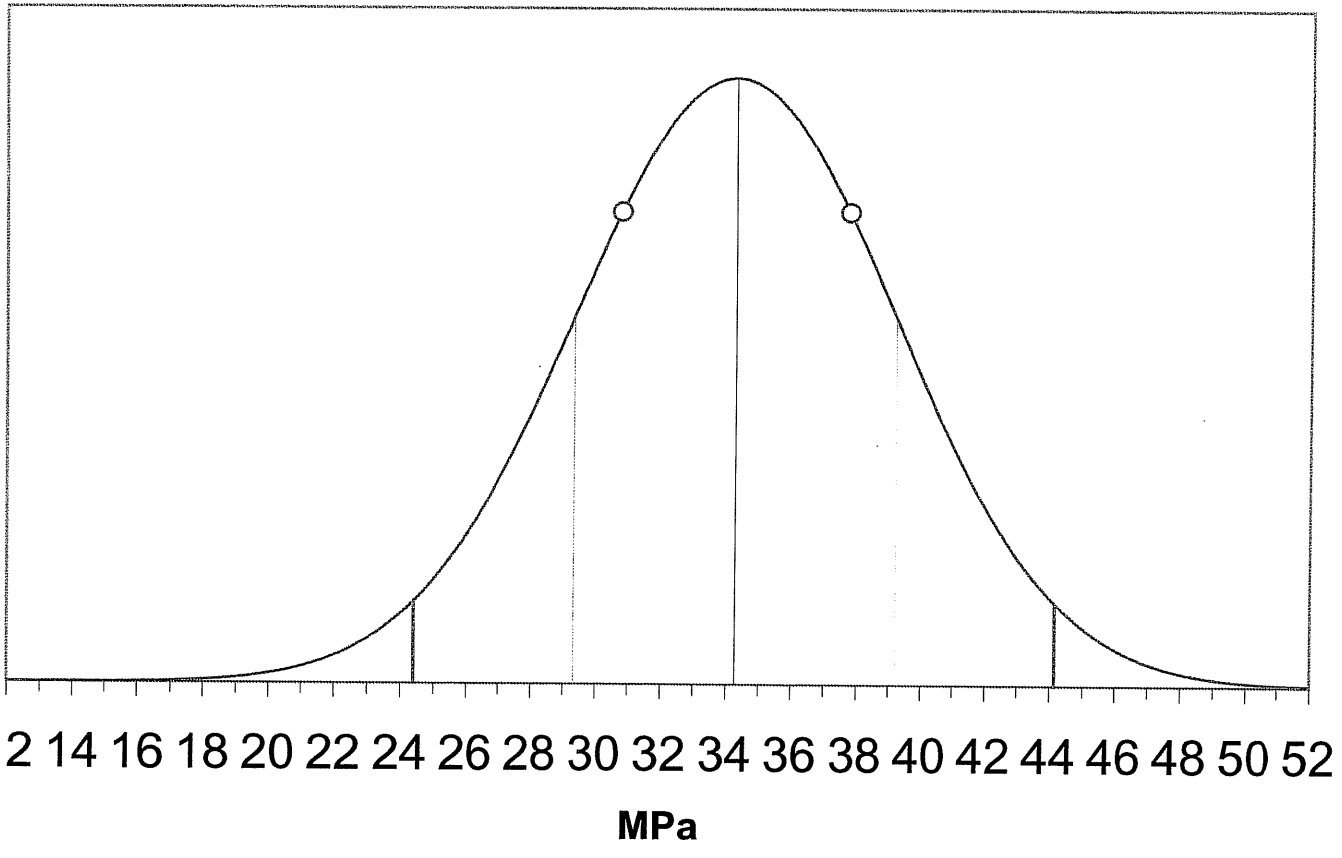

| | |
|---|---|
| # samples = | 2.00 |
| Average = | 38.81 |
| Minimum = | 38.08 |
| Maximum = | 39.53 |
| Std dev = | 1.03 |



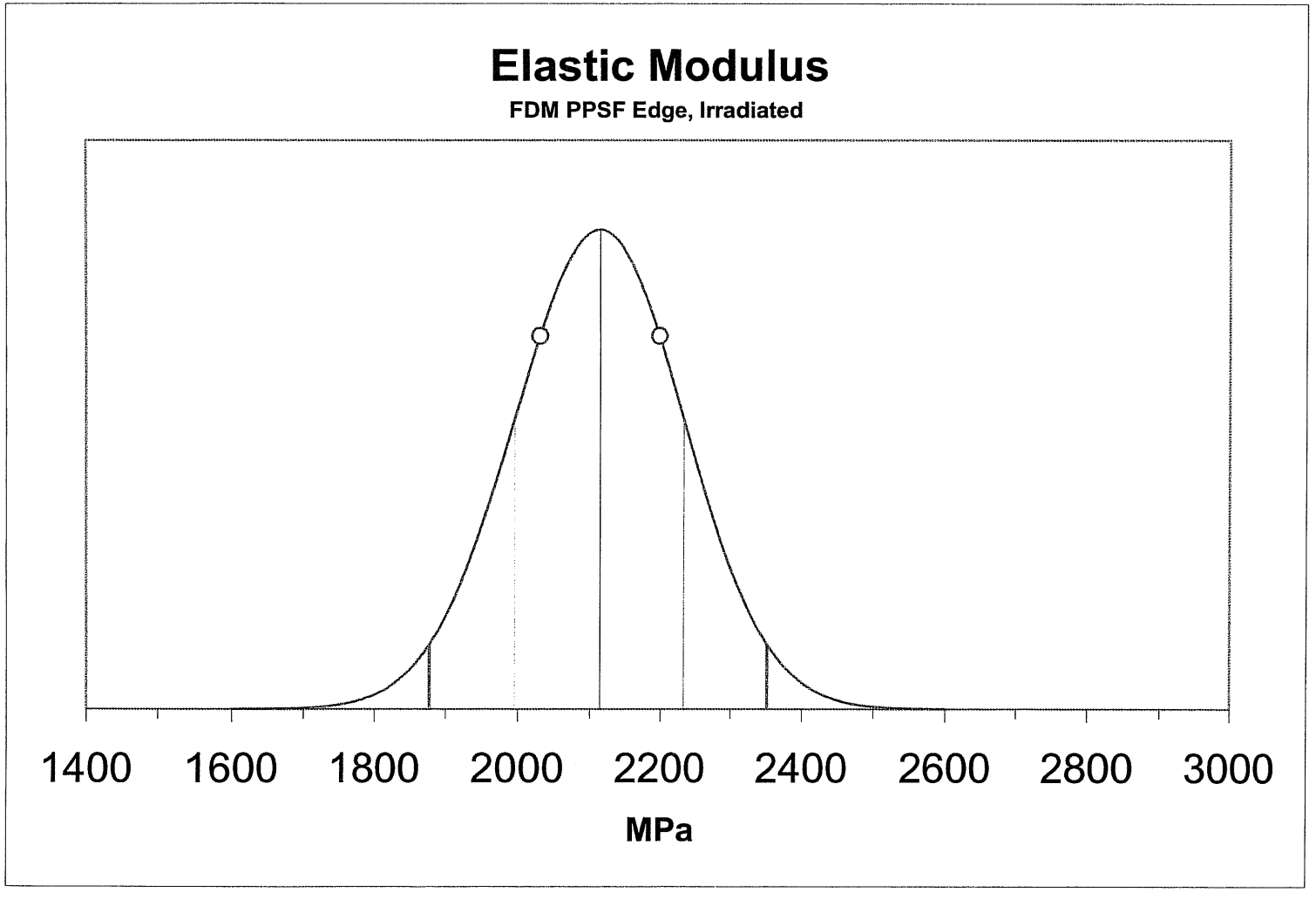

| | |
|---|---|
| # samples = | 2.00 |
| Average = | 38.81 |
| Minimum = | 38.08 |
| Maximum = | 39.53 |
| Std dev = | 1.03 |

# Yield Strength

**FDM PPSF Edge, Irradiated**



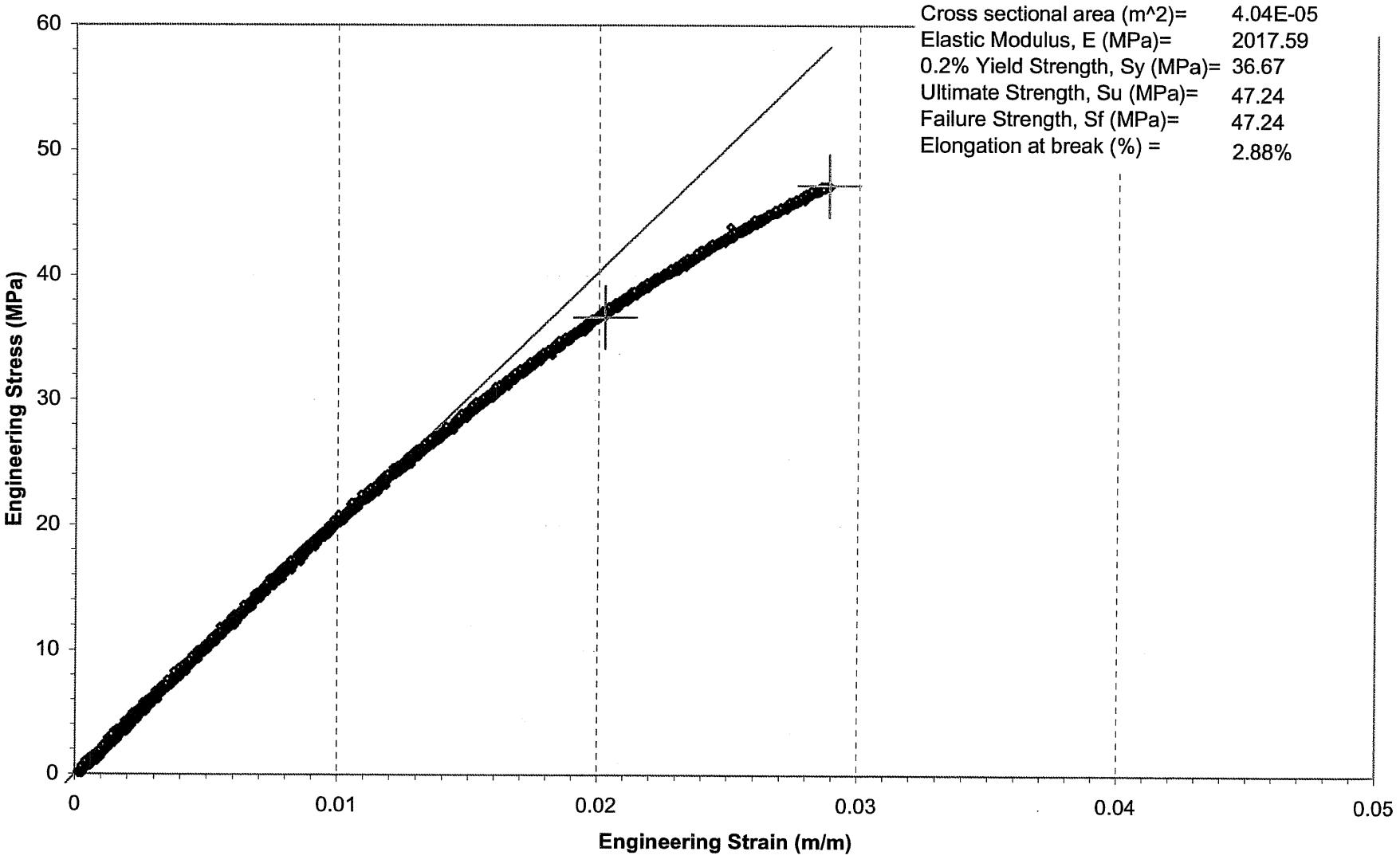

| | |
|---|---|
| # samples = | 2.00 |
| Average = | 34.27 |
| Minimum = | 30.78 |
| Maximum = | 37.77 |
| Std dev = | 4.94 |

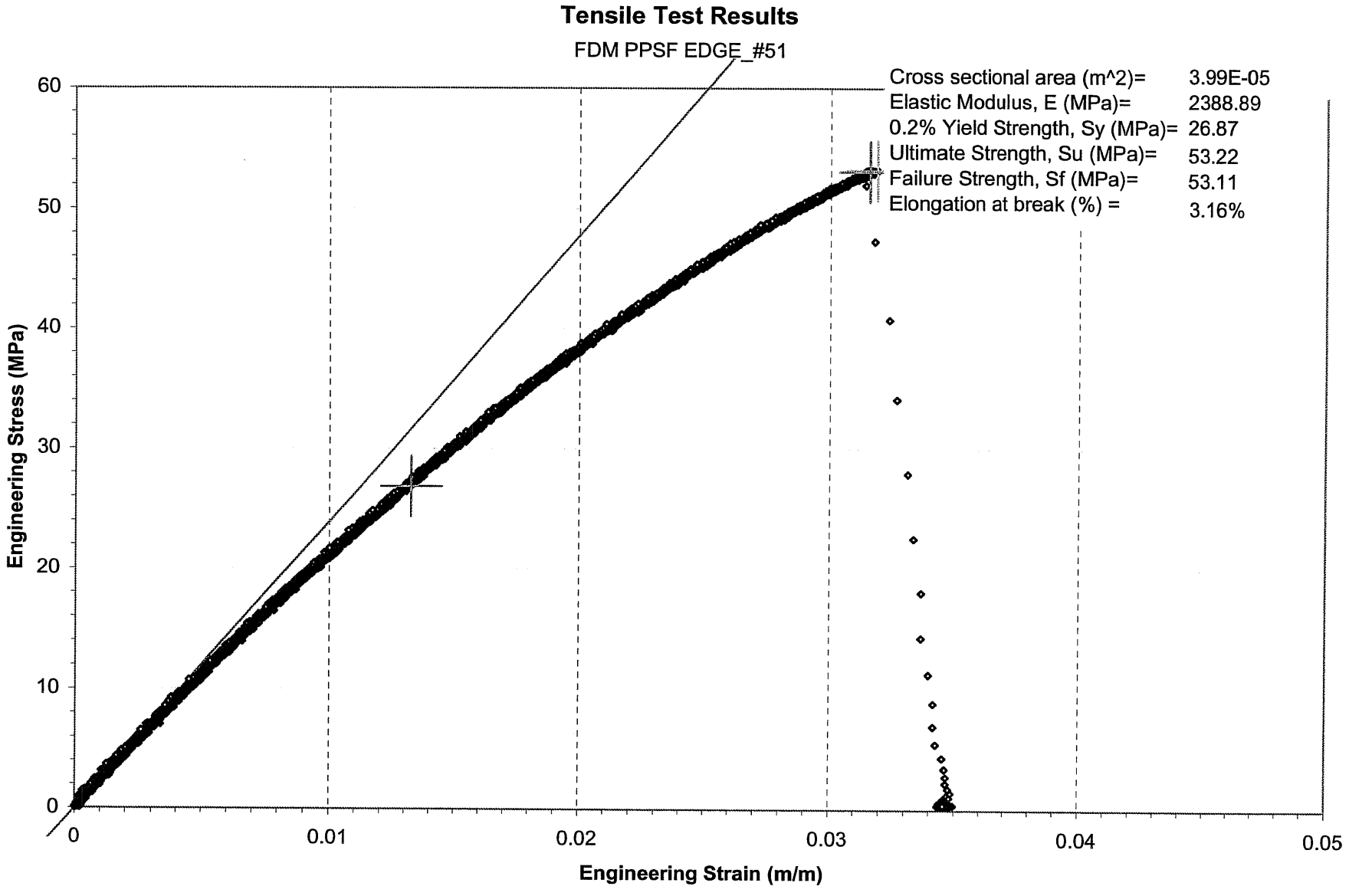



| | |
|---|---|
| # samples = | 2.00 |
| Average = | 2114.42 |
| Minimum = | 2030.81 |
| Maximum = | 2198.03 |
| Std dev = | 118.24 |

## Tensile Test Results

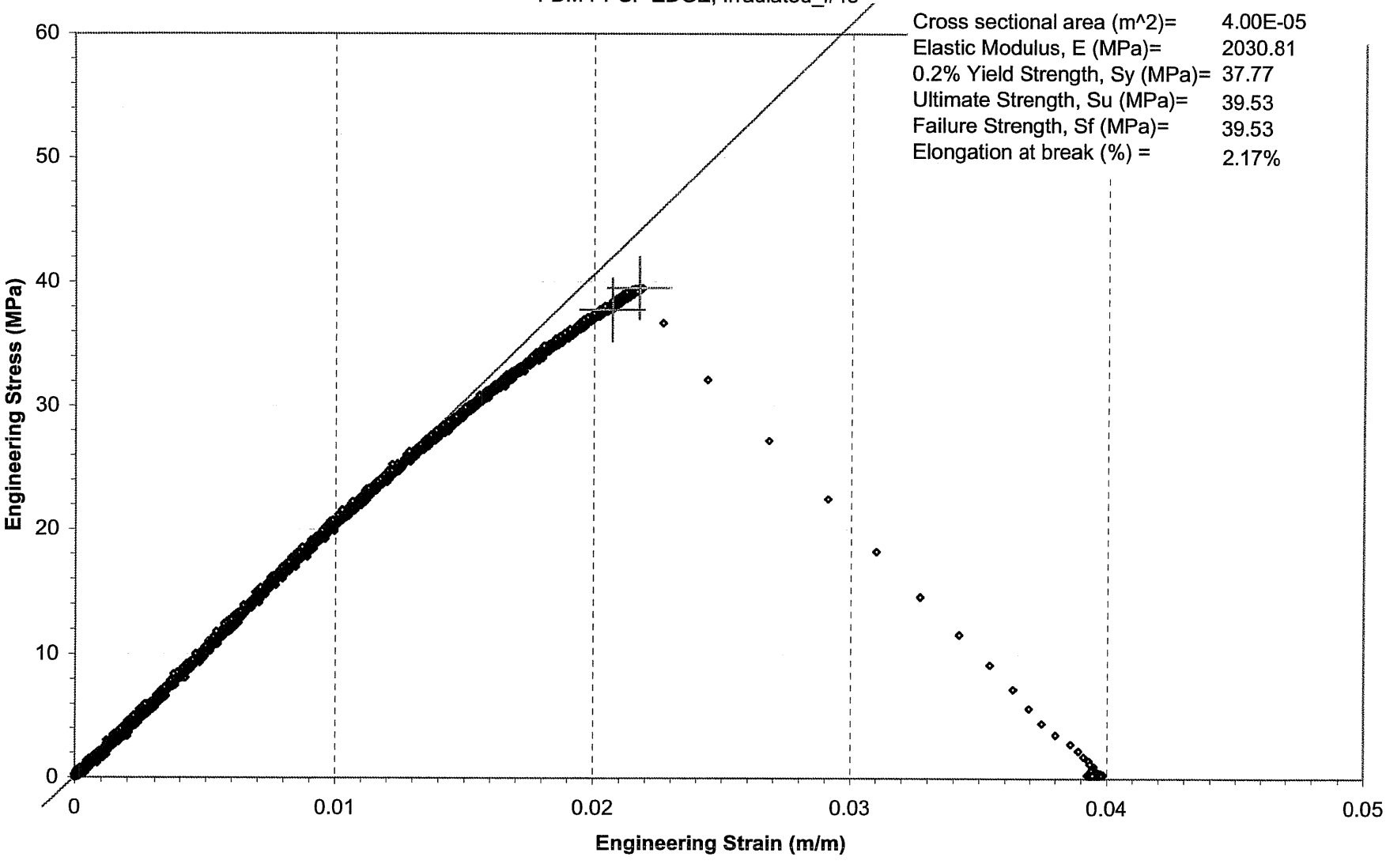
FDM PPSF EDGE_#50

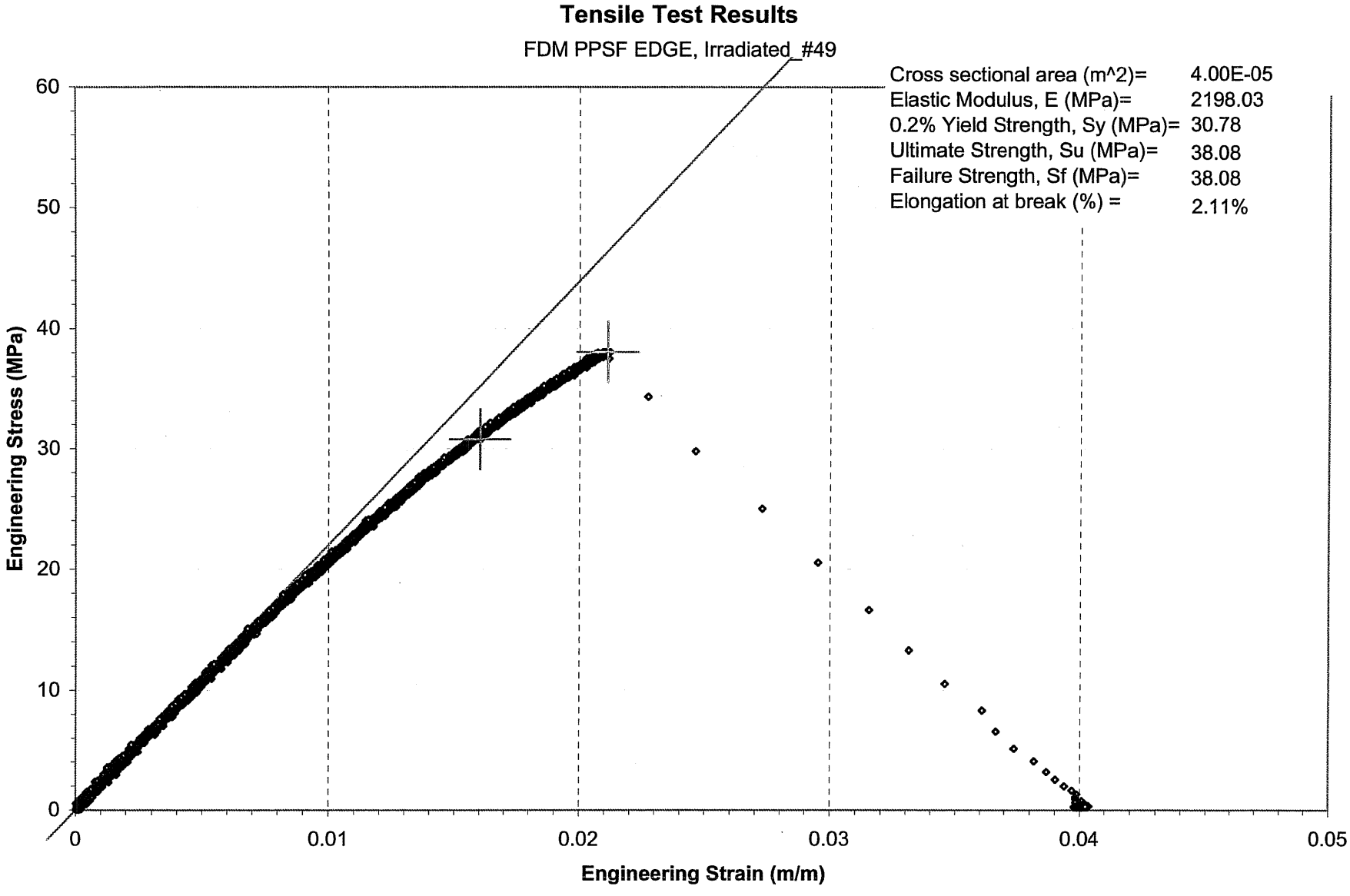


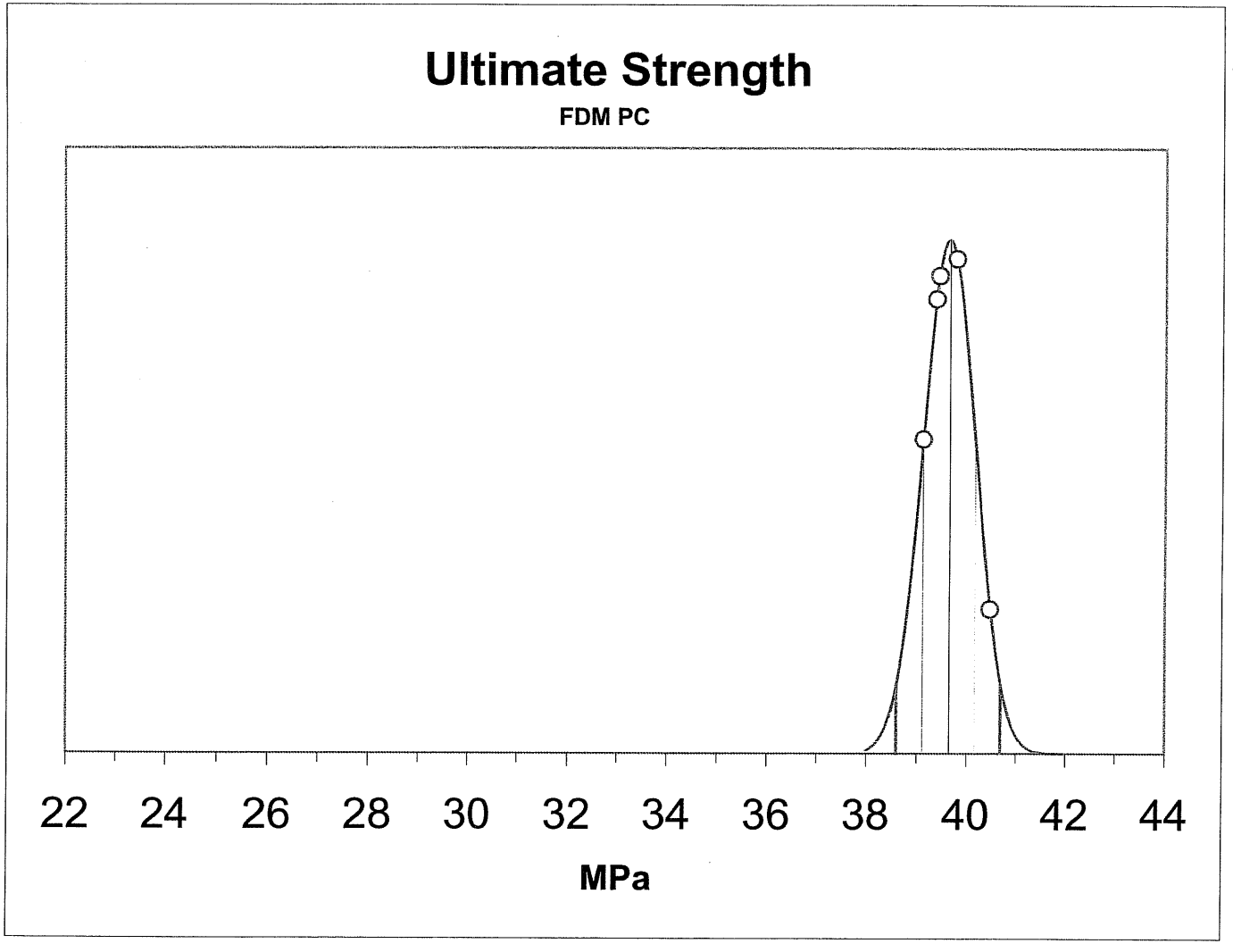


## Tensile Test Results

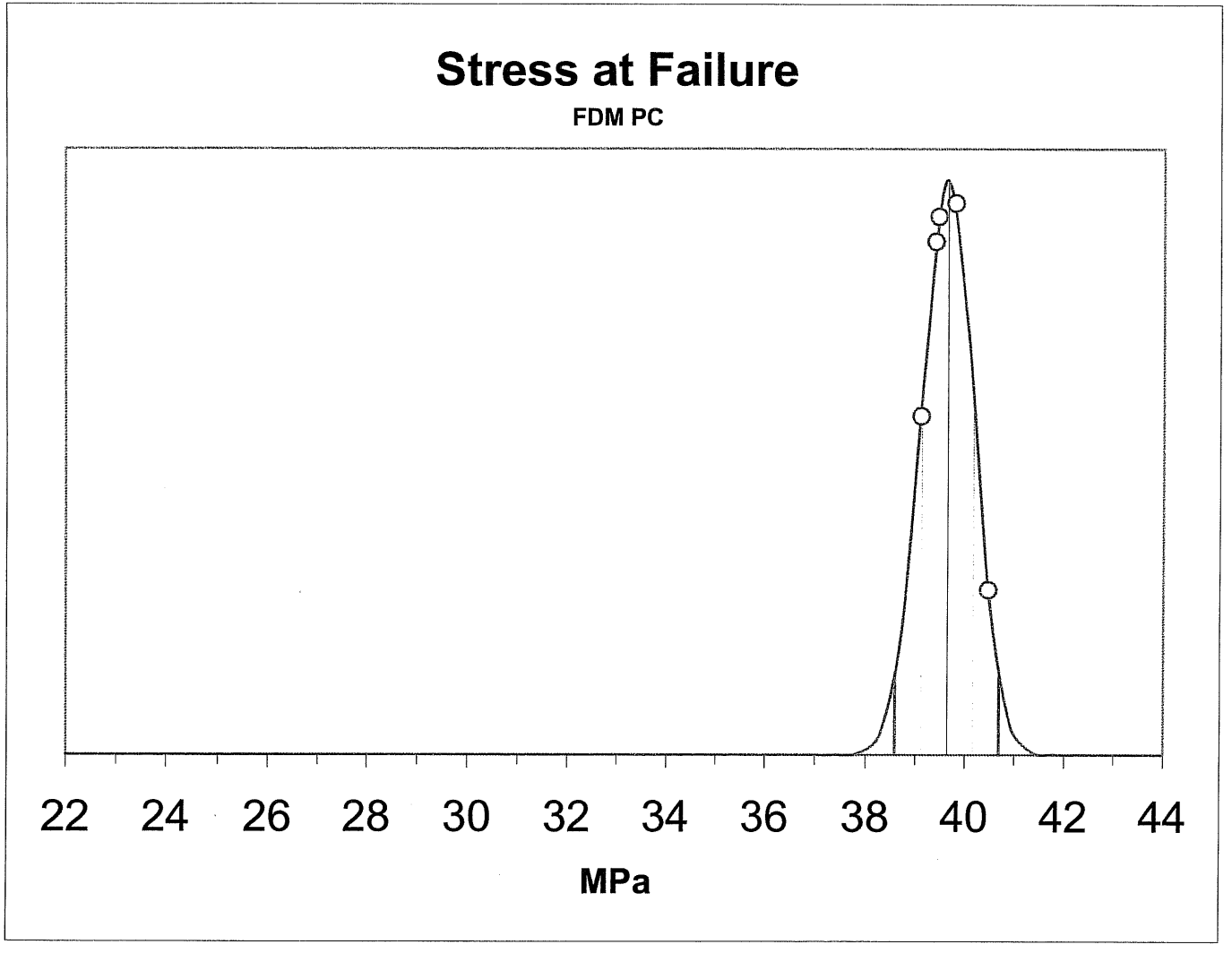
FDM PPSF EDGE, Irradiated_#48



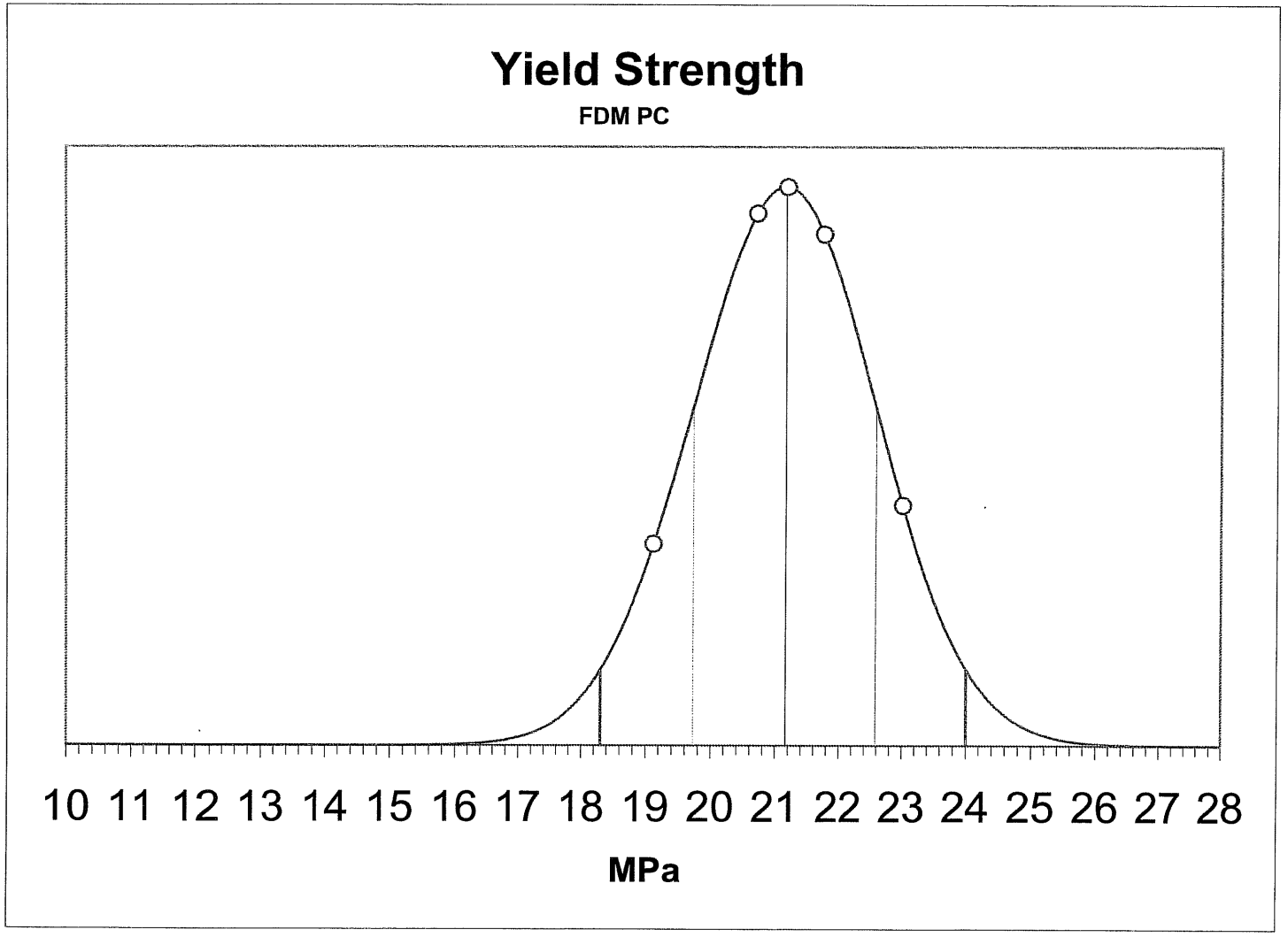




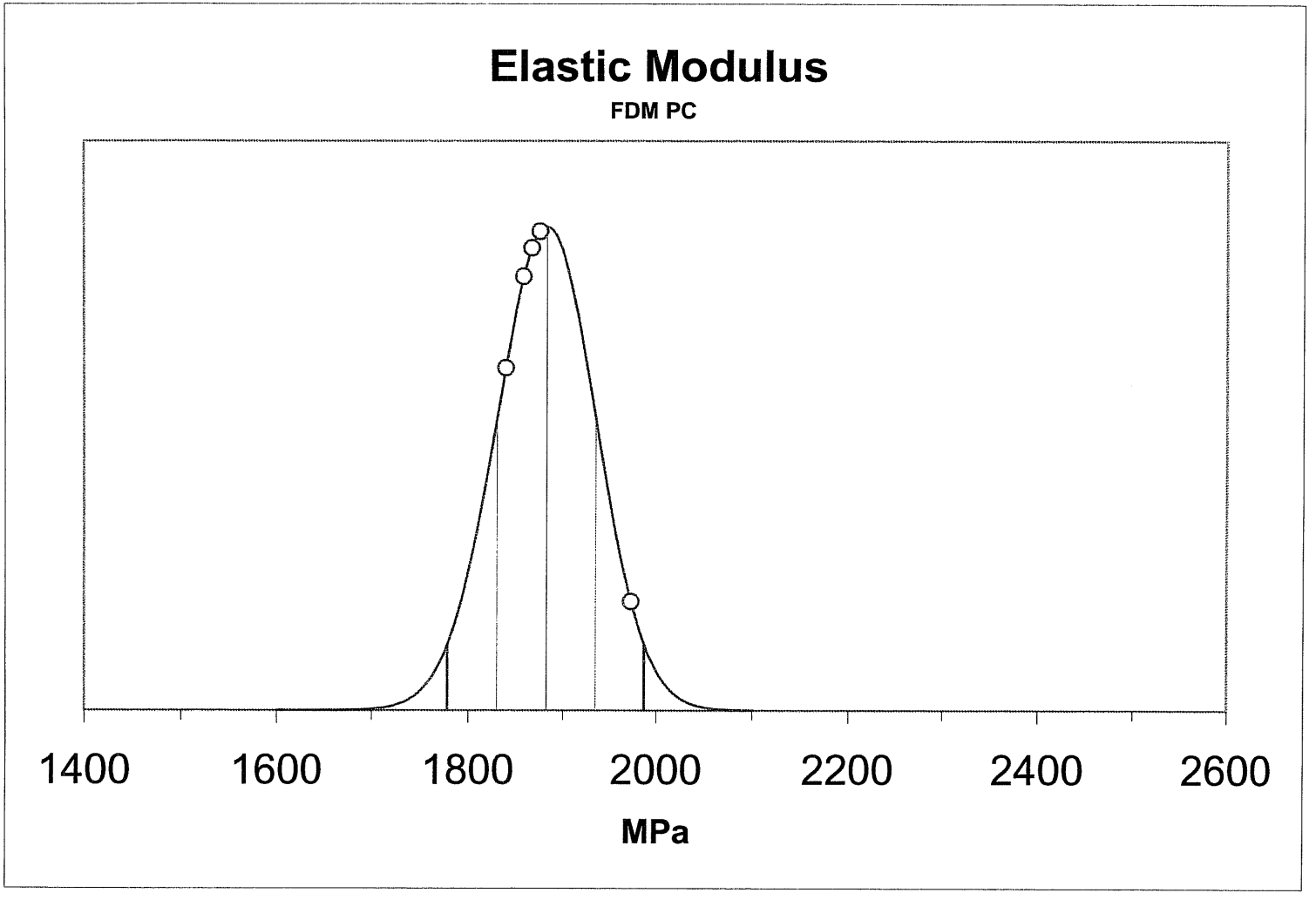

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 39.65 |
| Minimum = | 39.13 |
| Maximum = | 40.48 |
| Std dev = | 0.52 |



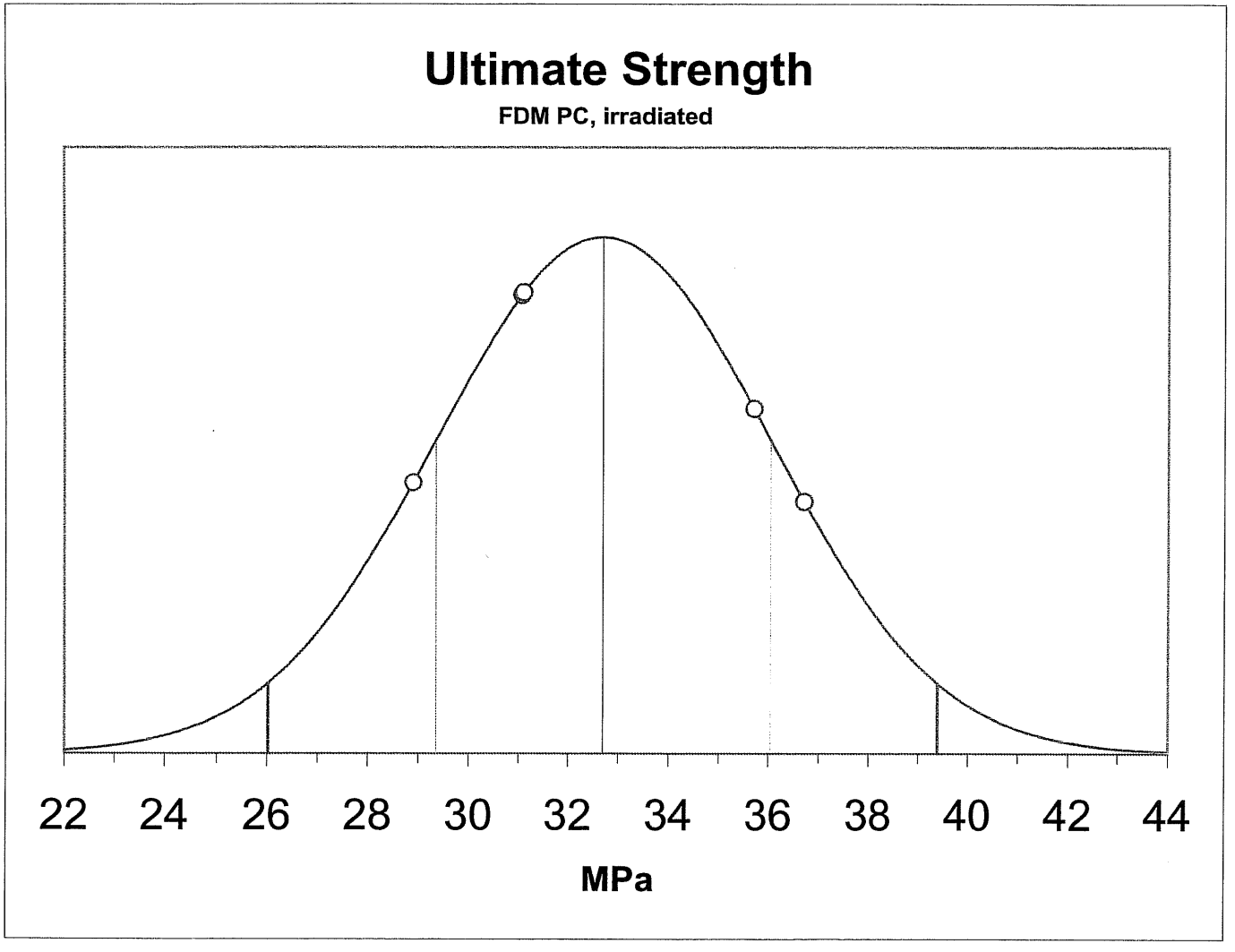

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 39.64 |
| Minimum = | 39.10 |
| Maximum = | 40.47 |
| Std dev = | 0.52 |



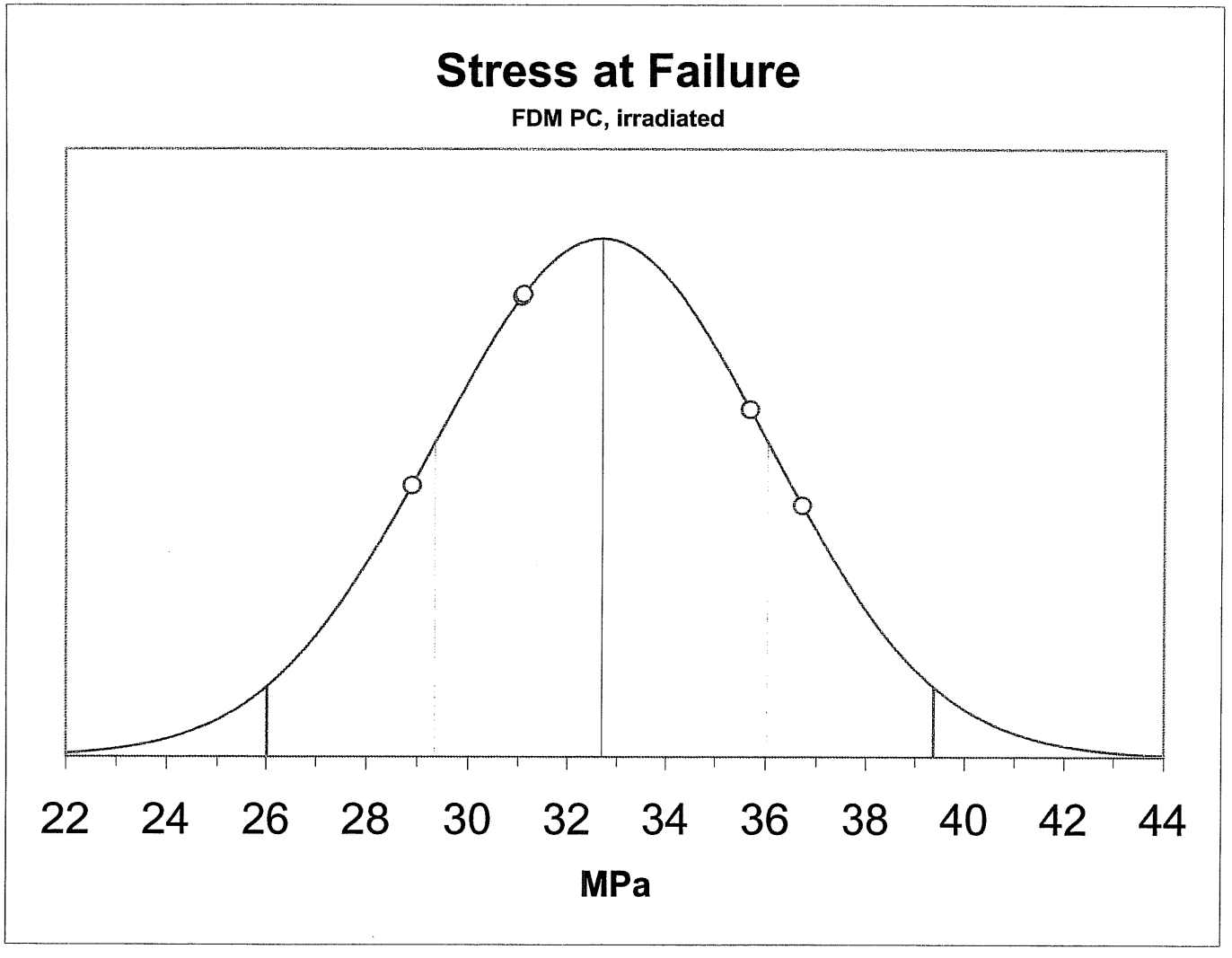

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 21.16 |
| Minimum = | 19.13 |
| Maximum = | 23.01 |
| Std dev = | 1.42 |



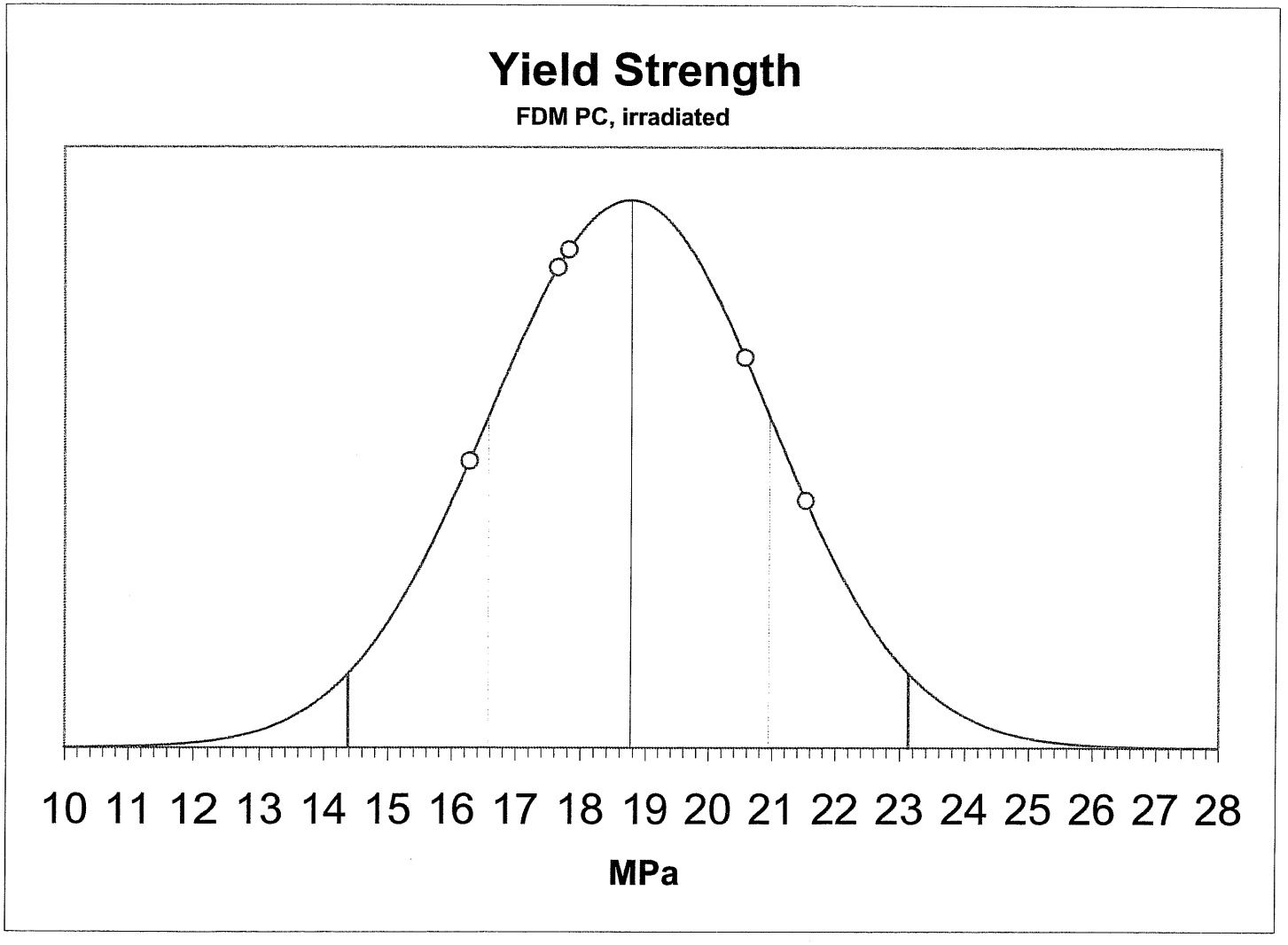

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 1882.74 |
| Minimum = | 1839.47 |
| Maximum = | 1972.96 |
| Std dev = | 52.19 |



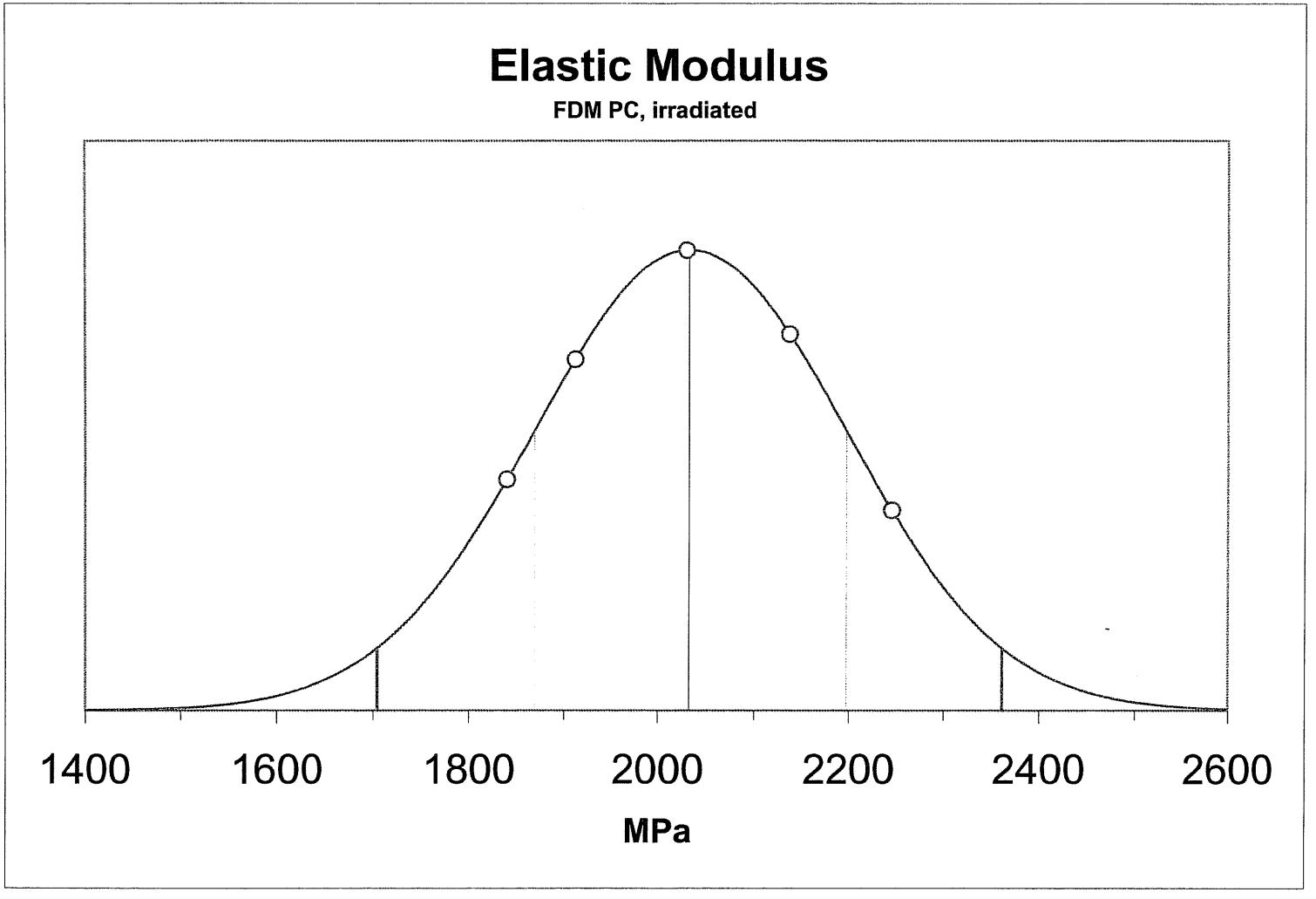

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 32.70 |
| Minimum = | 28.90 |
| Maximum = | 36.71 |
| Std dev = | 3.34 |



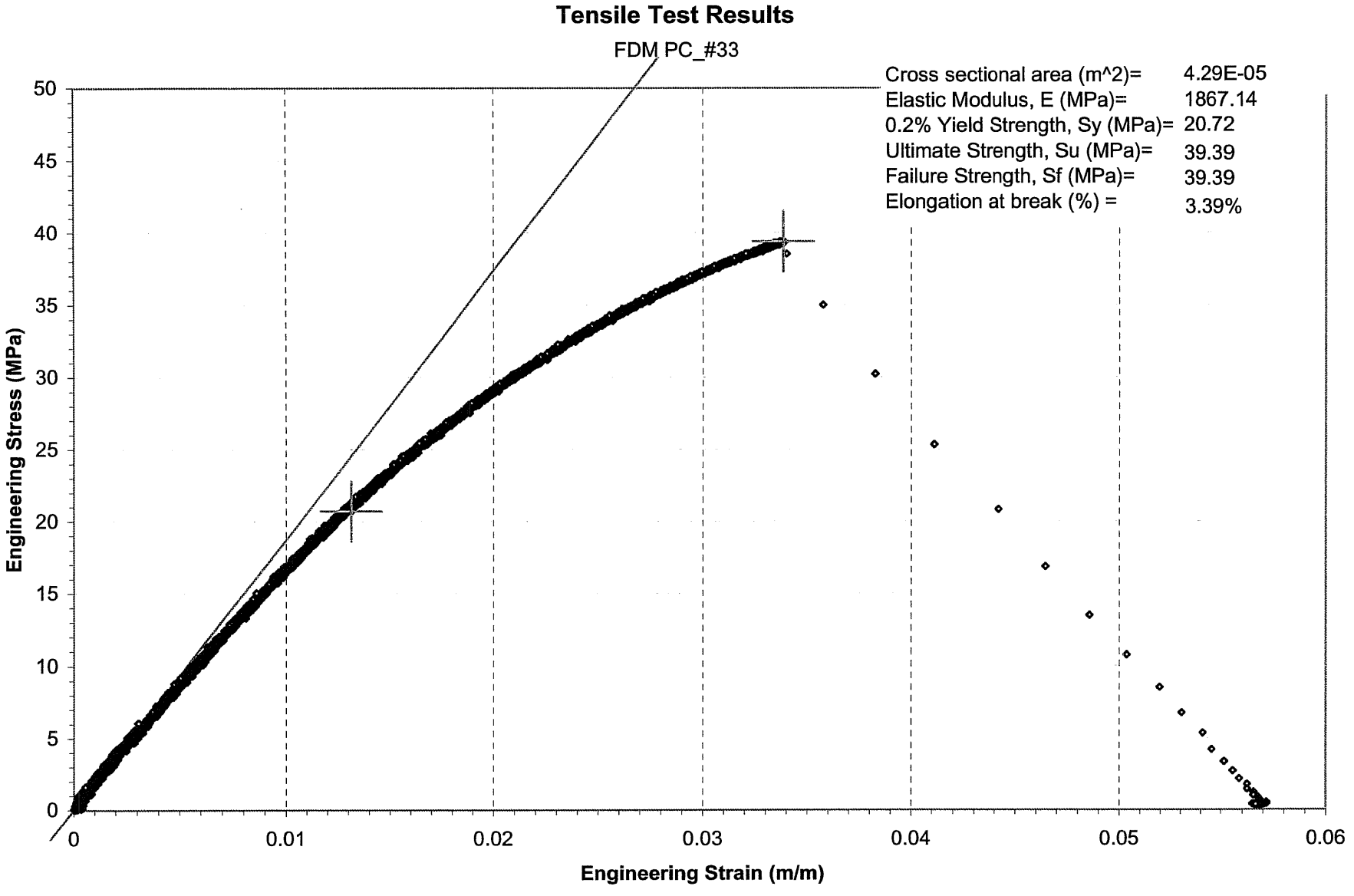

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 32.69 |
| Minimum = | 28.90 |
| Maximum = | 36.71 |
| Std dev = | 3.34 |

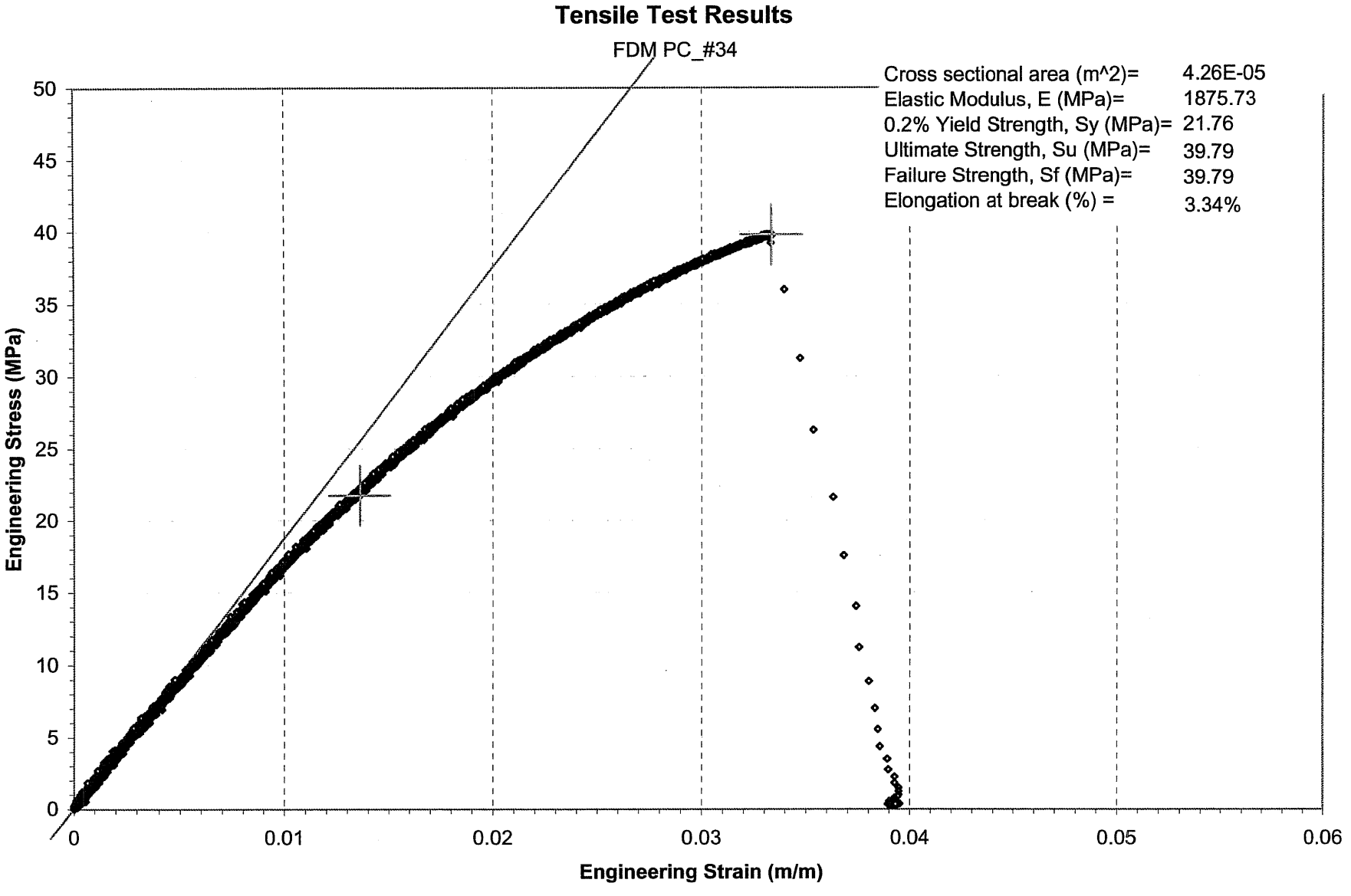


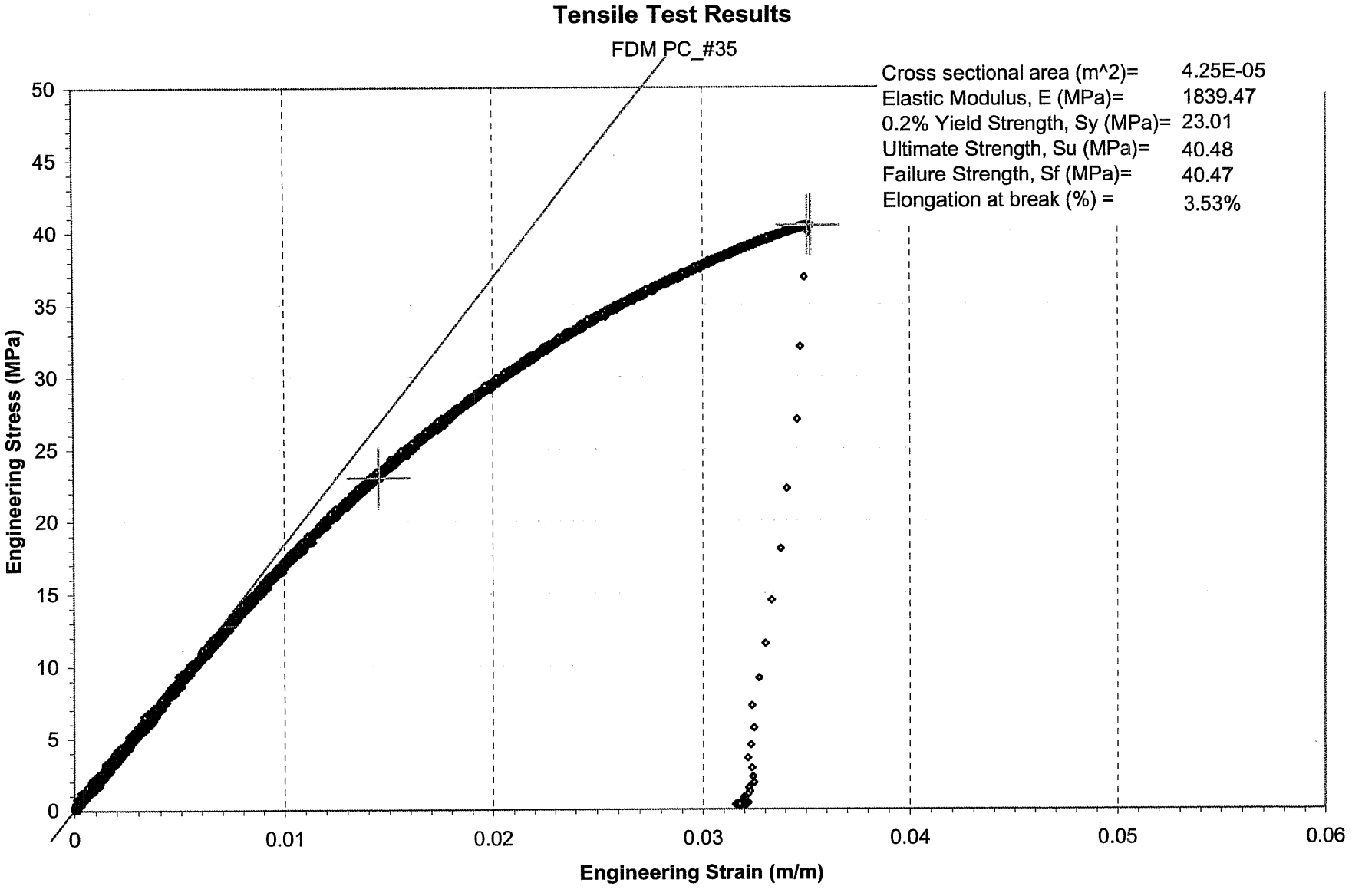

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 18.76 |
| Minimum = | 16.28 |
| Maximum = | 21.52 |
| Std dev = | 2.19 |

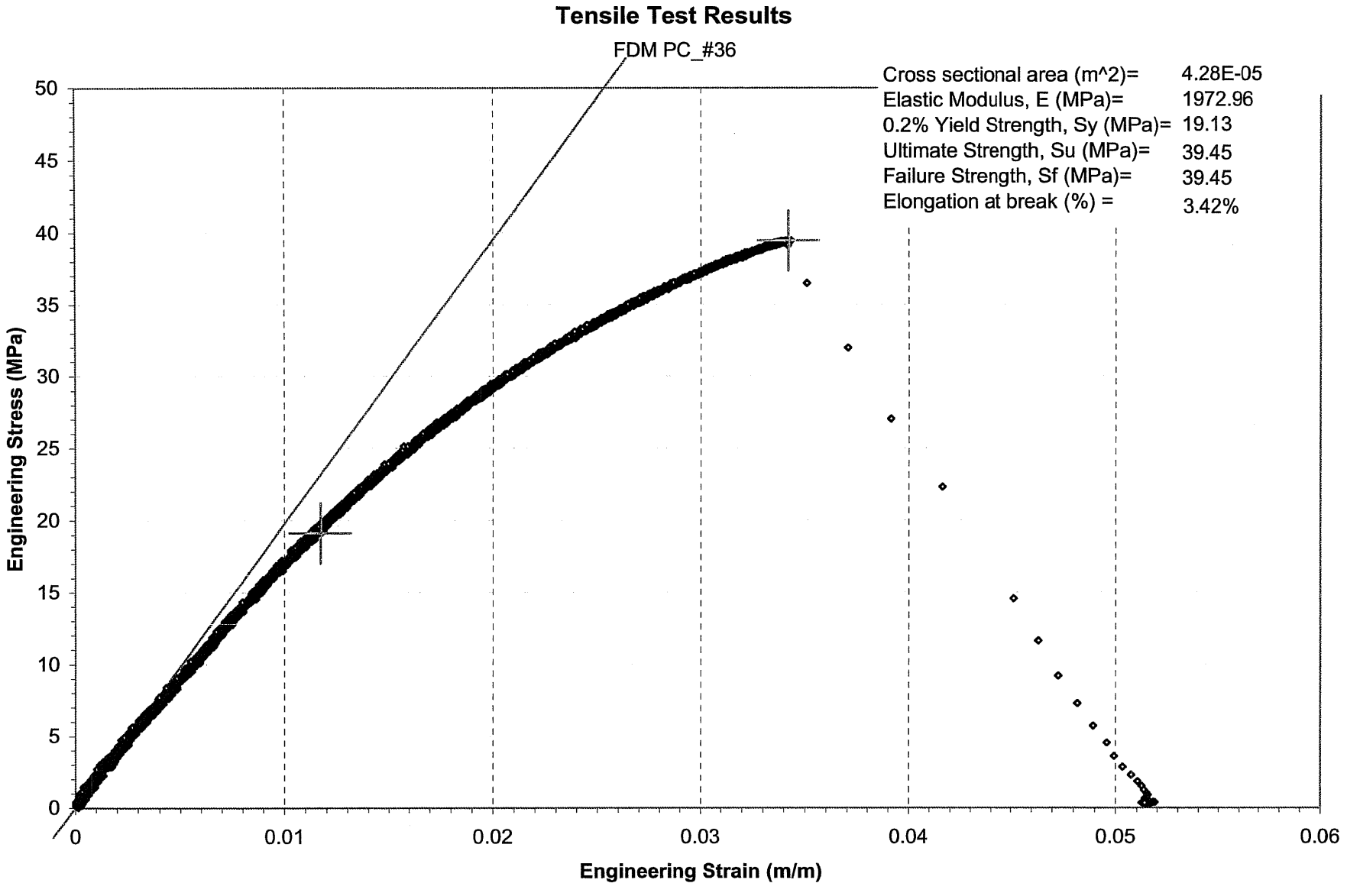


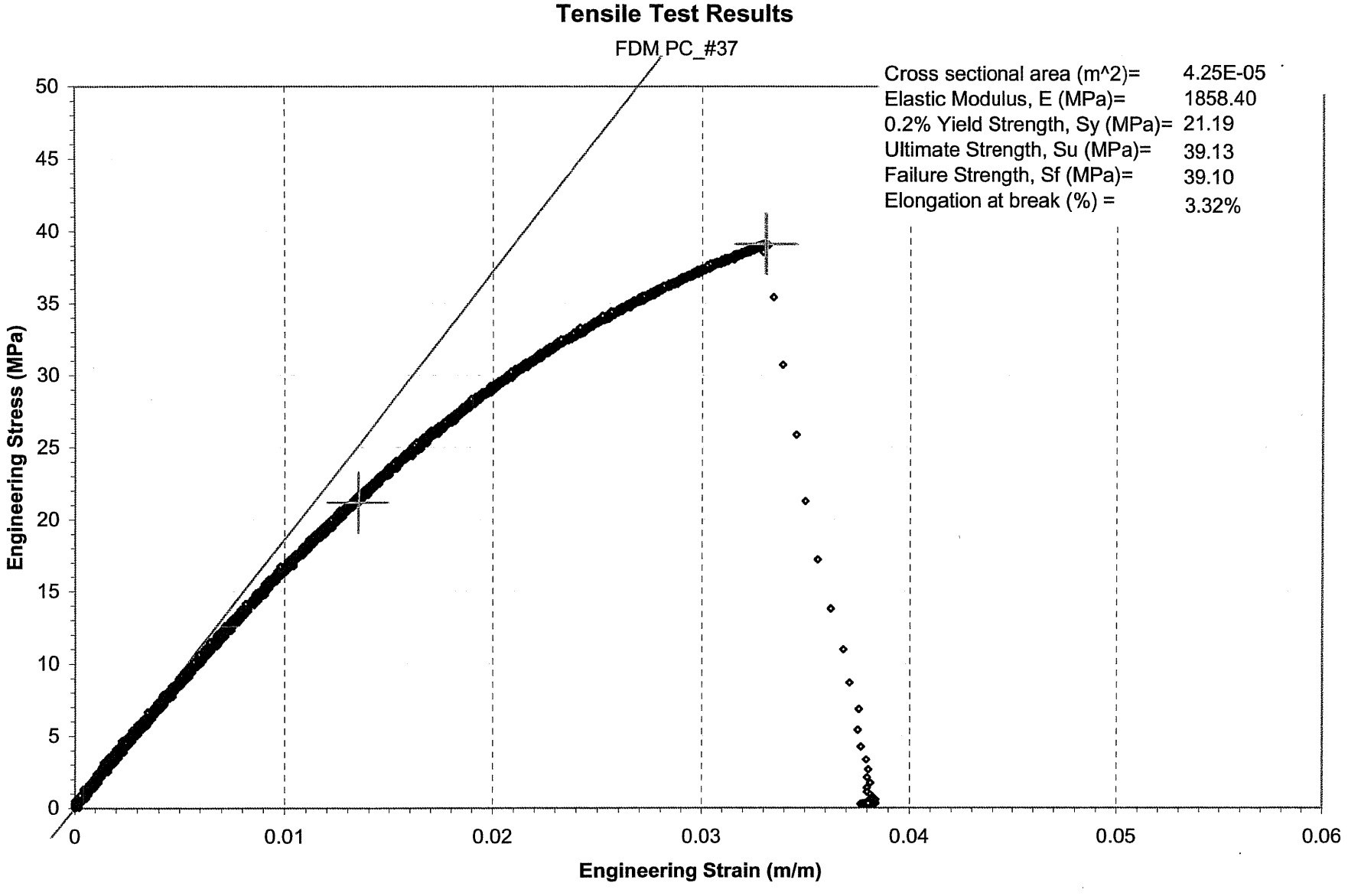

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 2032.91 |
| Minimum = | 1839.72 |
| Maximum = | 2245.32 |
| Std dev = | 164.34 |





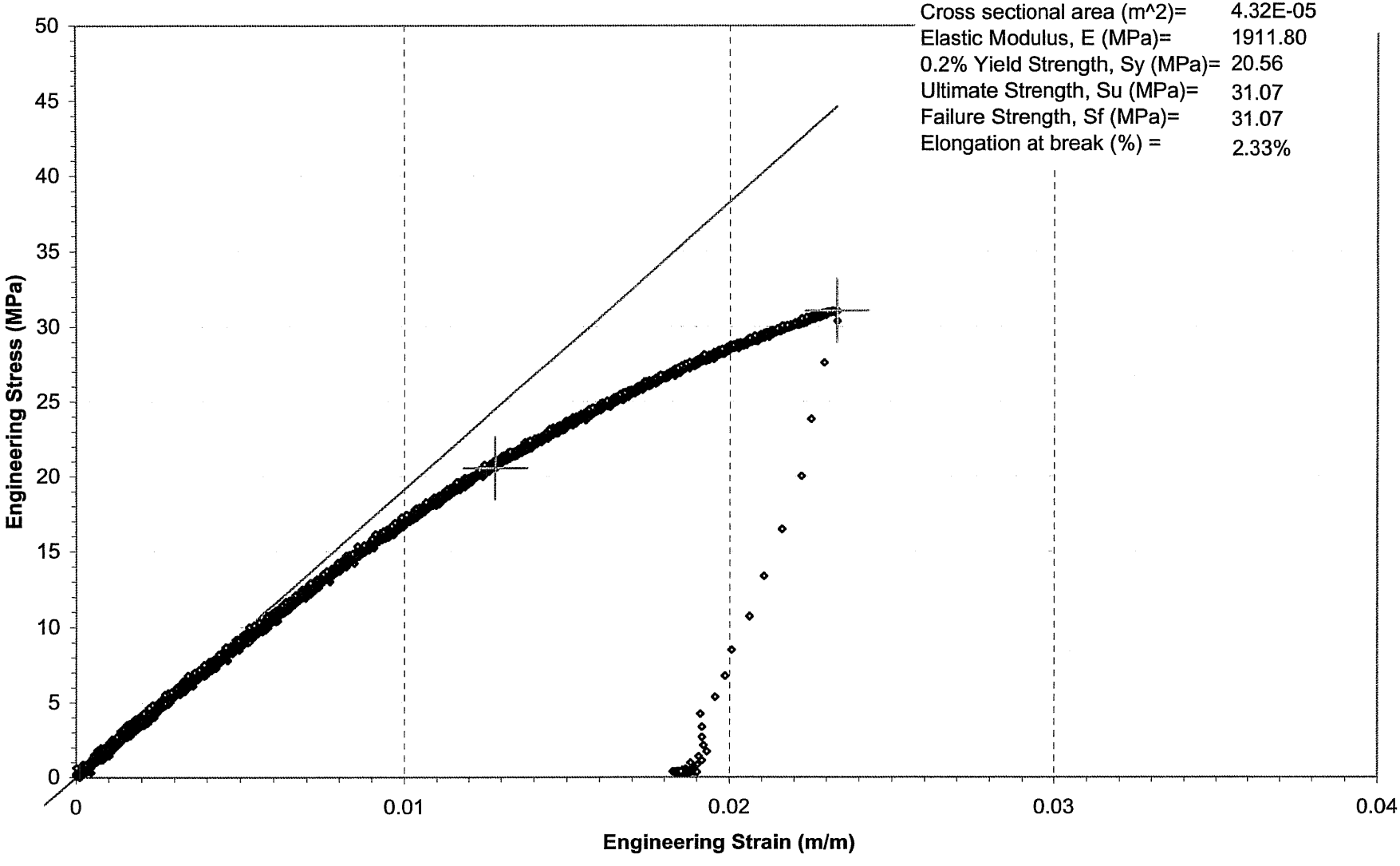


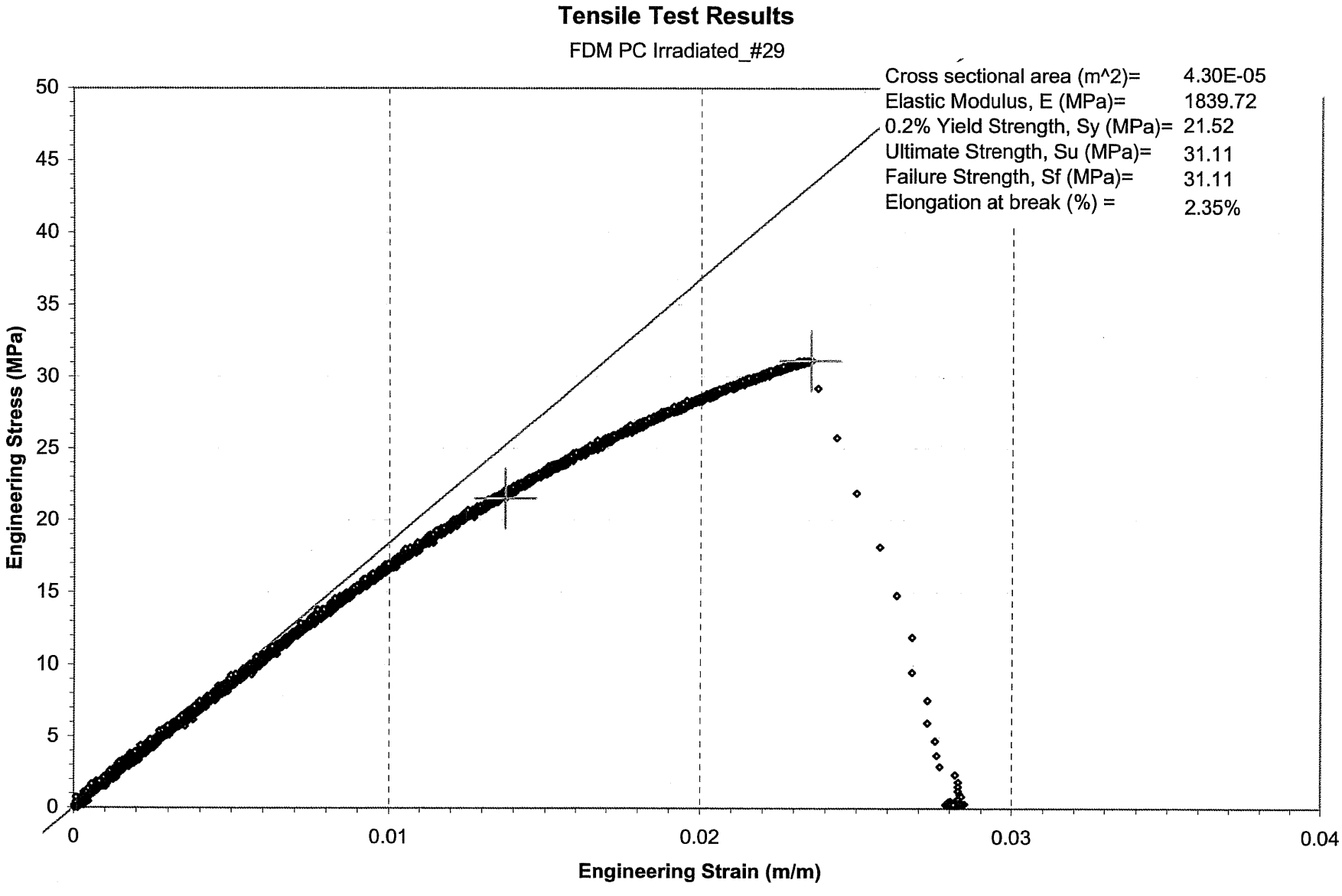


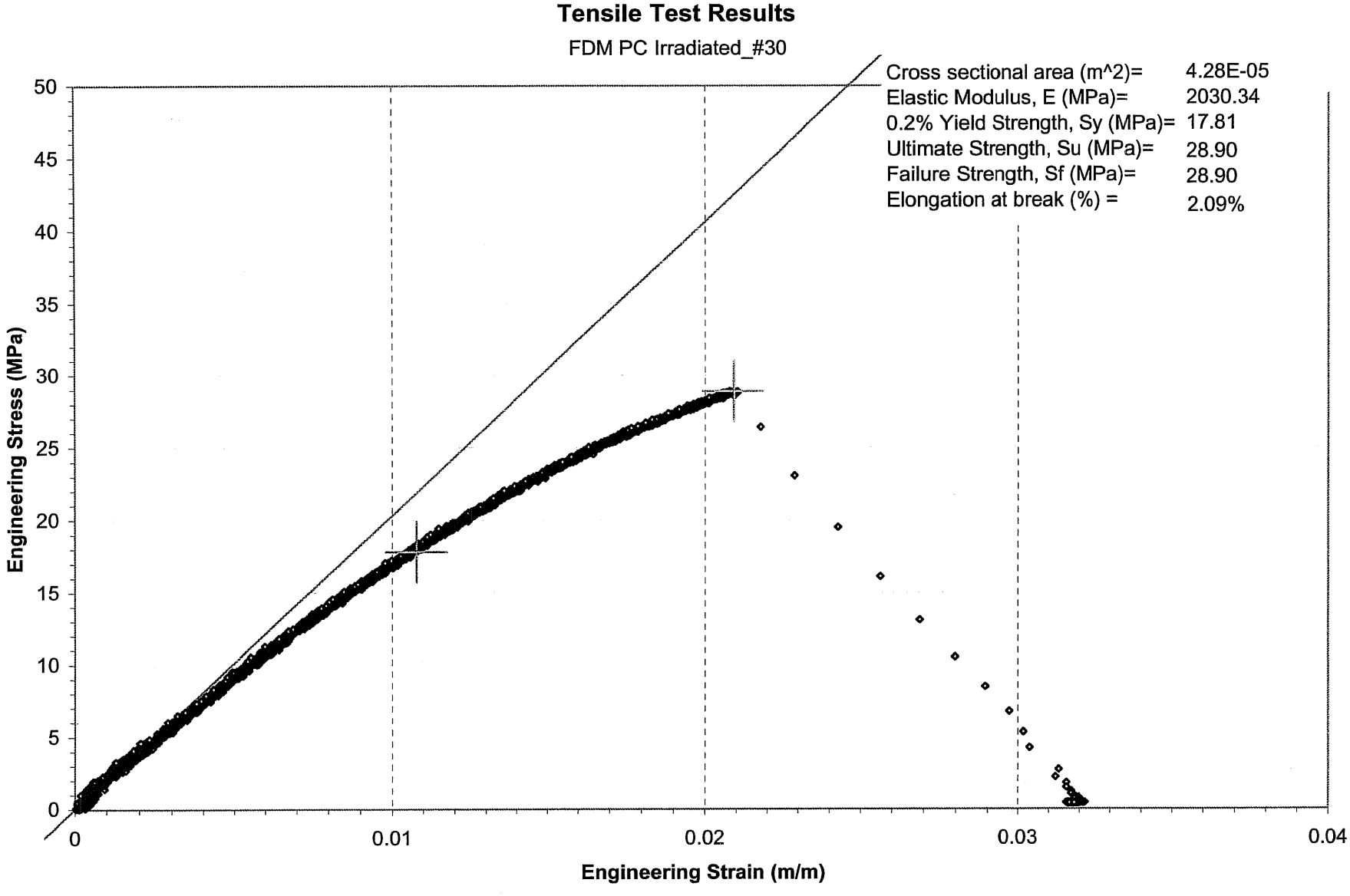


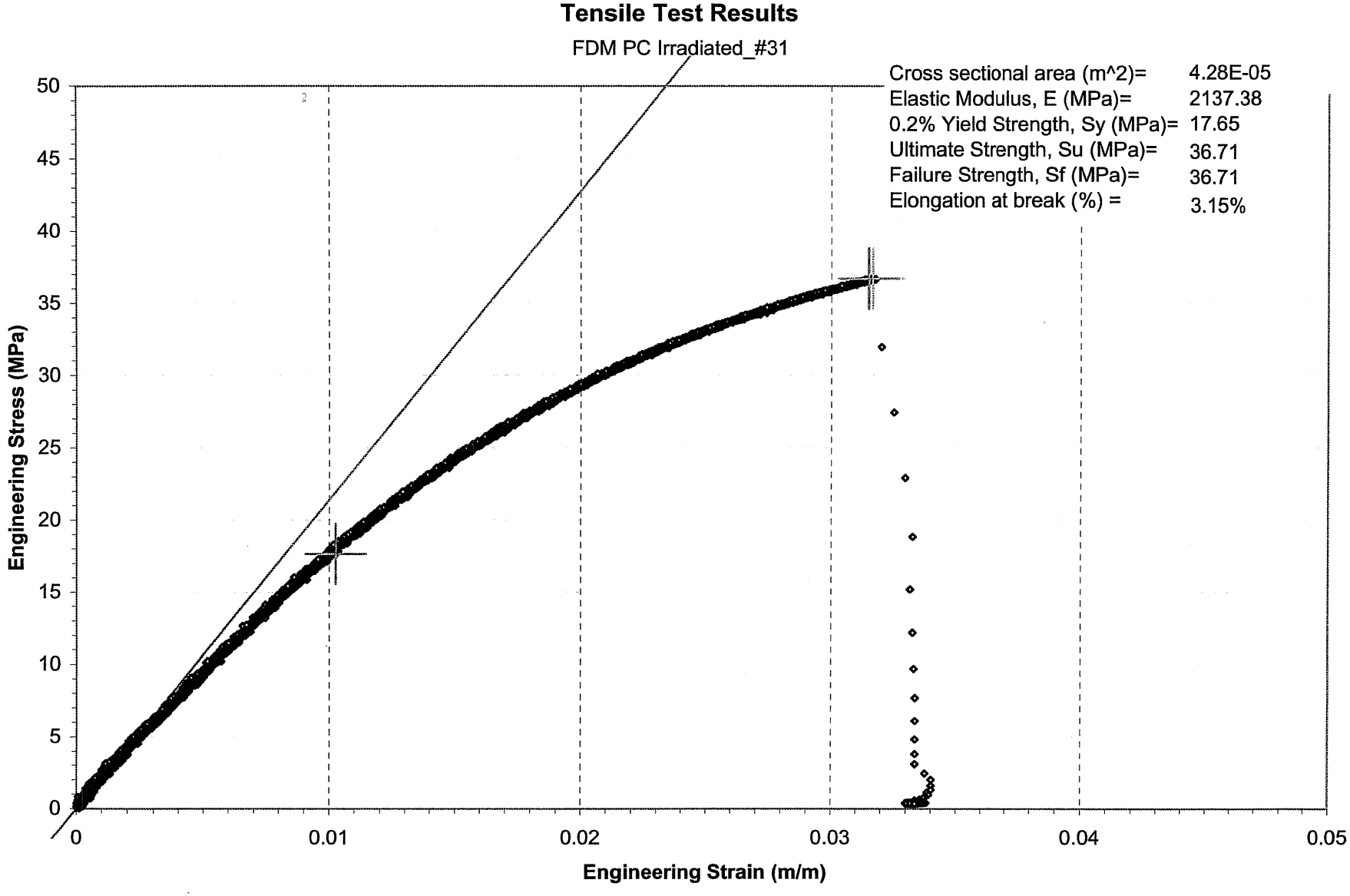
## Tensile Test Results

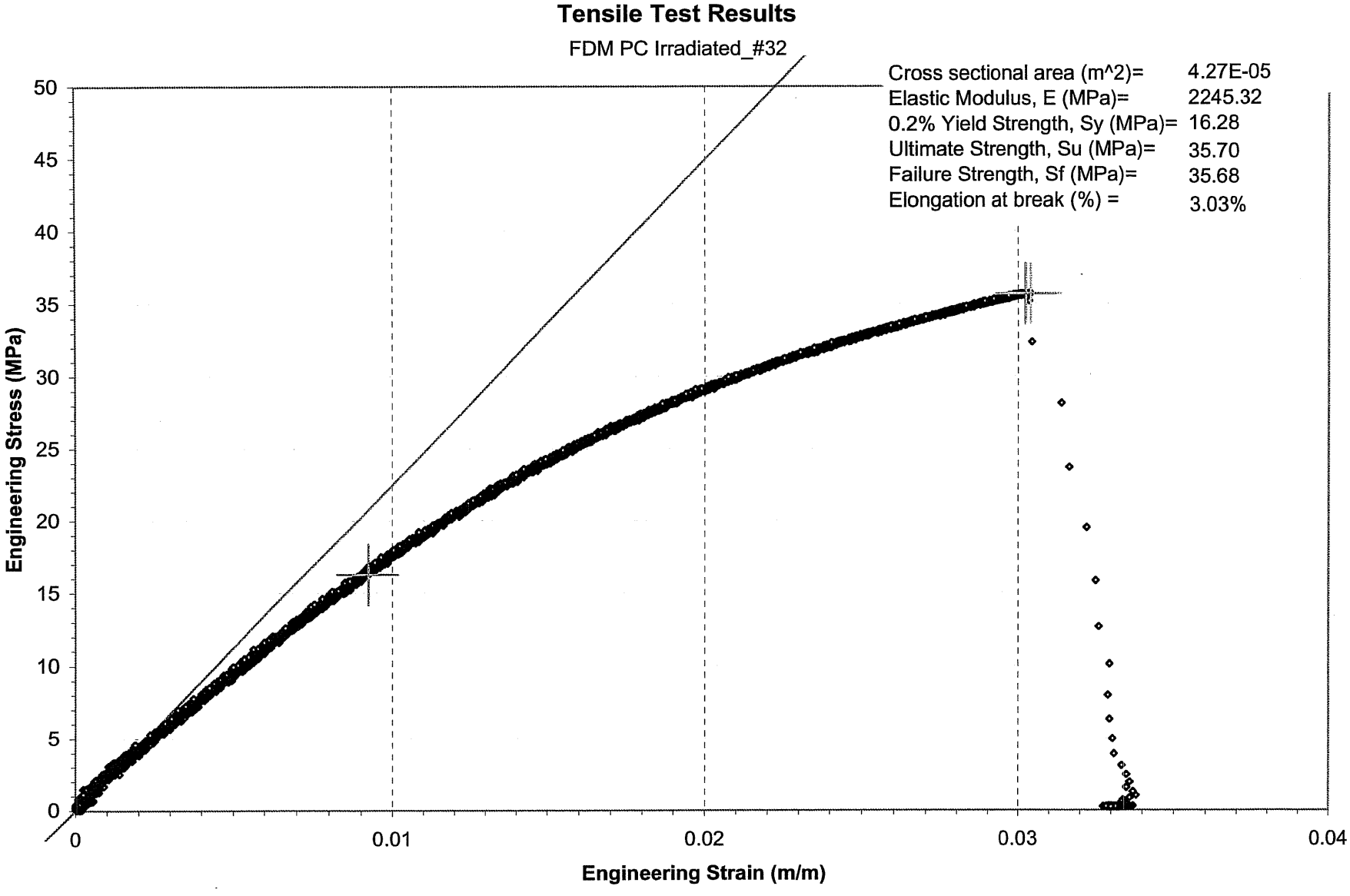
FDM PC Irradiated_#28

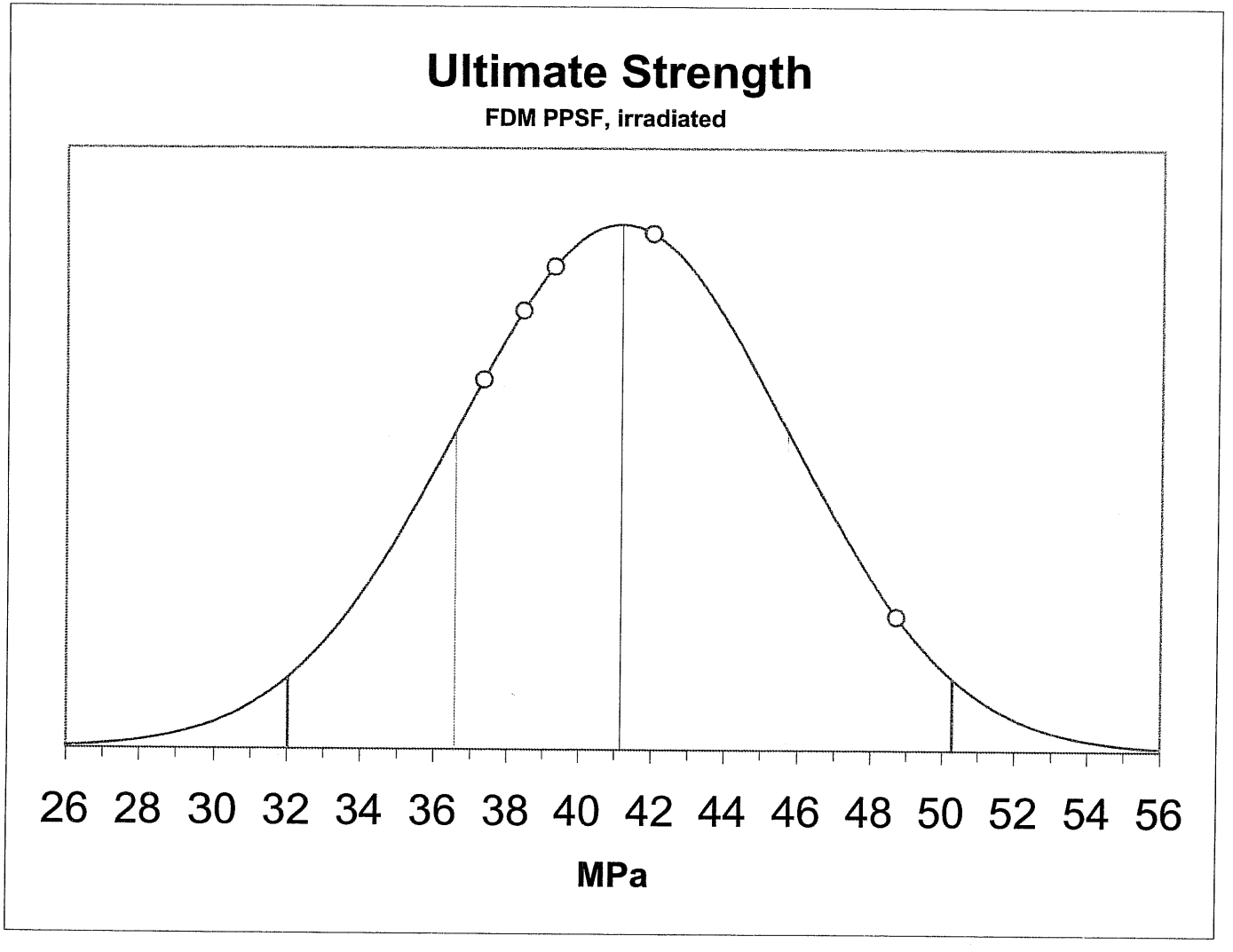




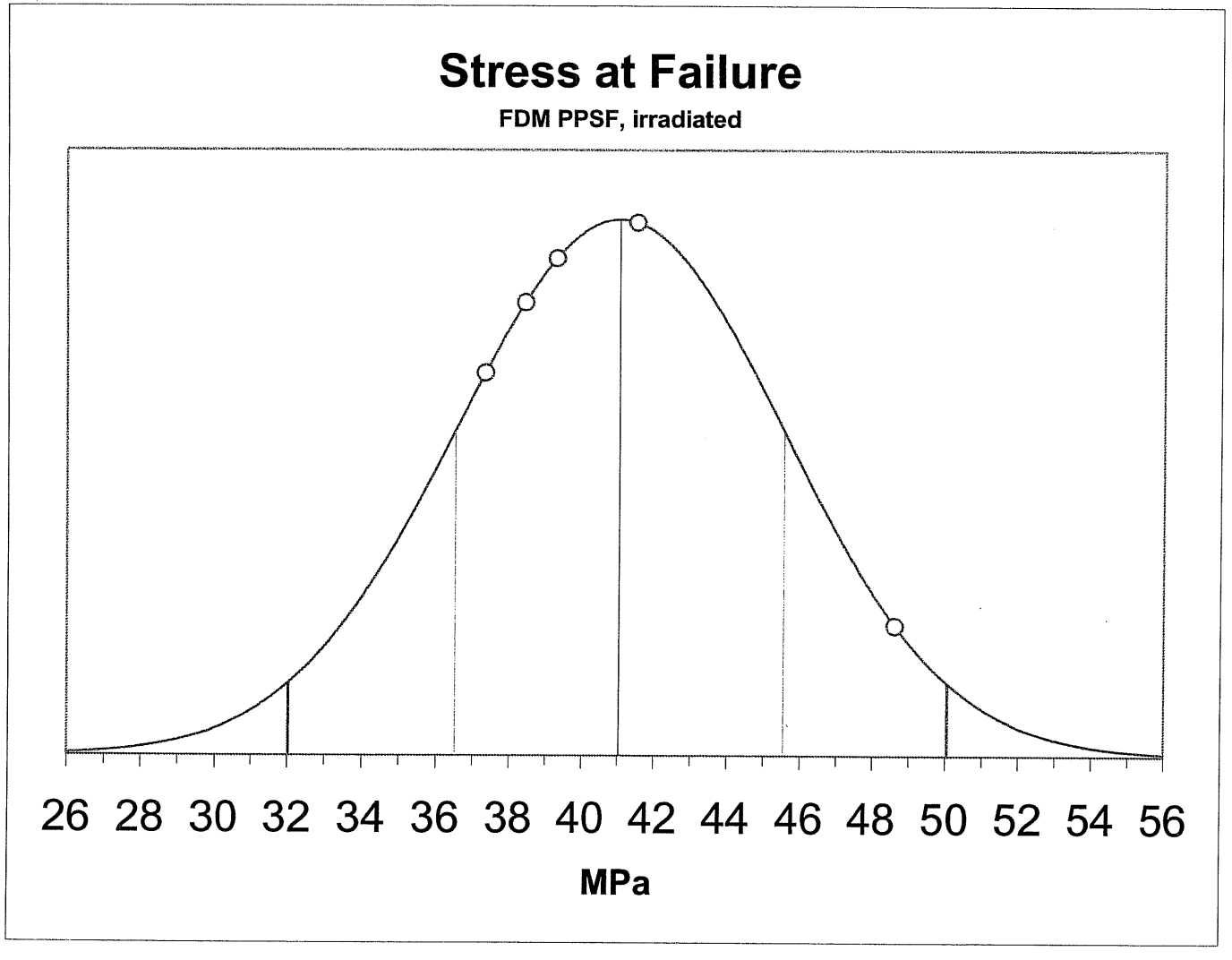




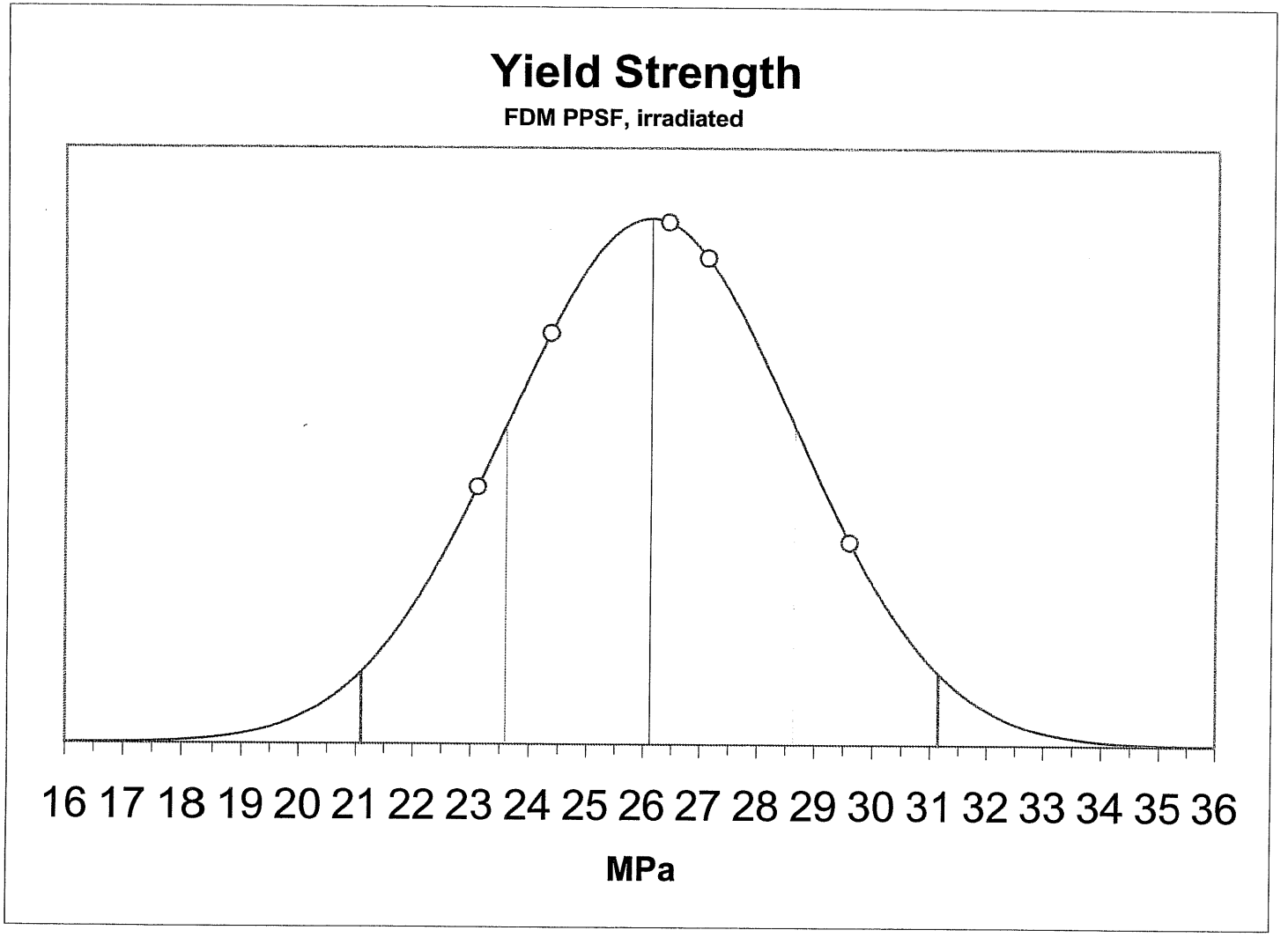




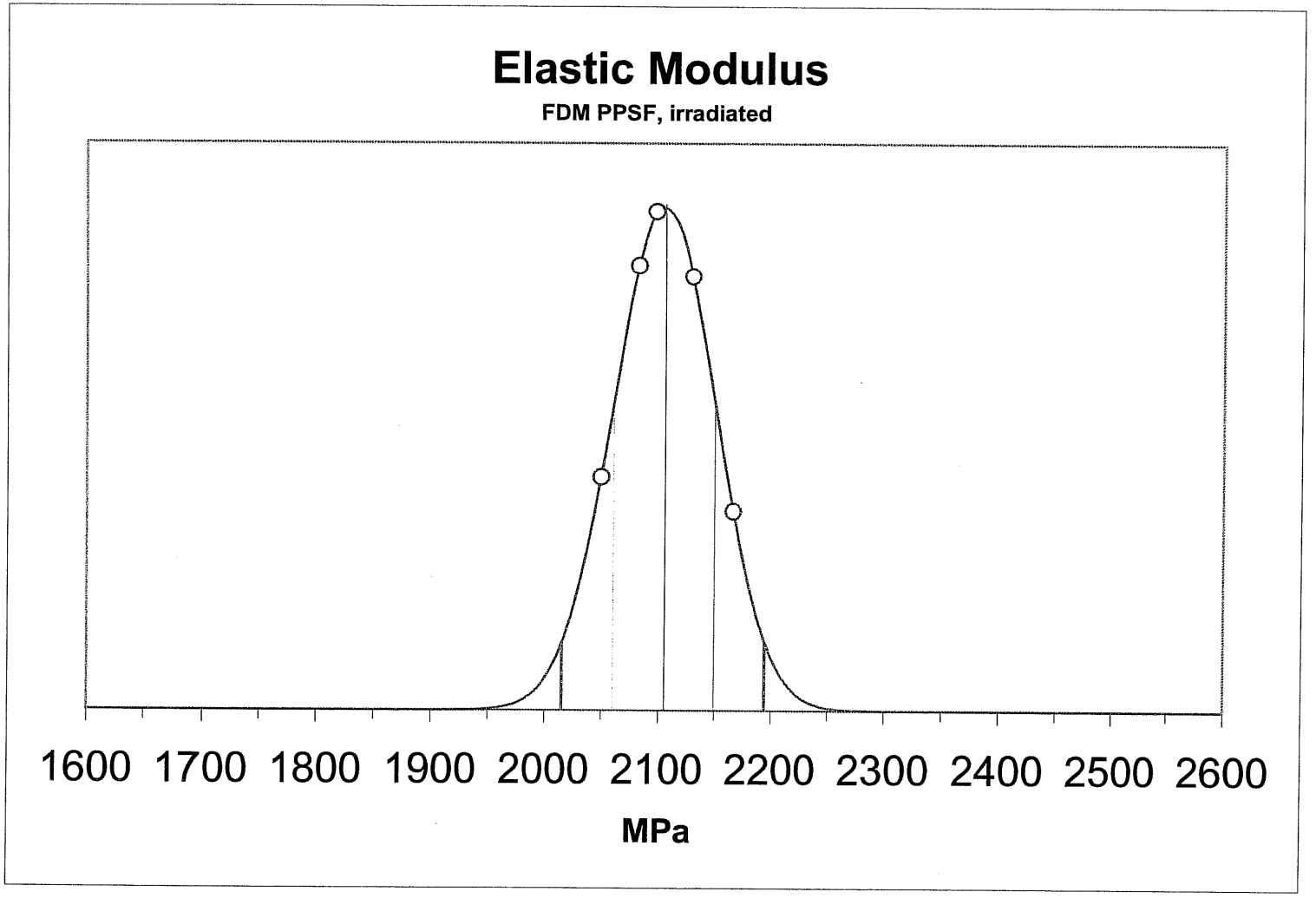

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 41.16 |
| Minimum = | 37.34 |
| Maximum = | 48.71 |
| Std dev = | 4.56 |



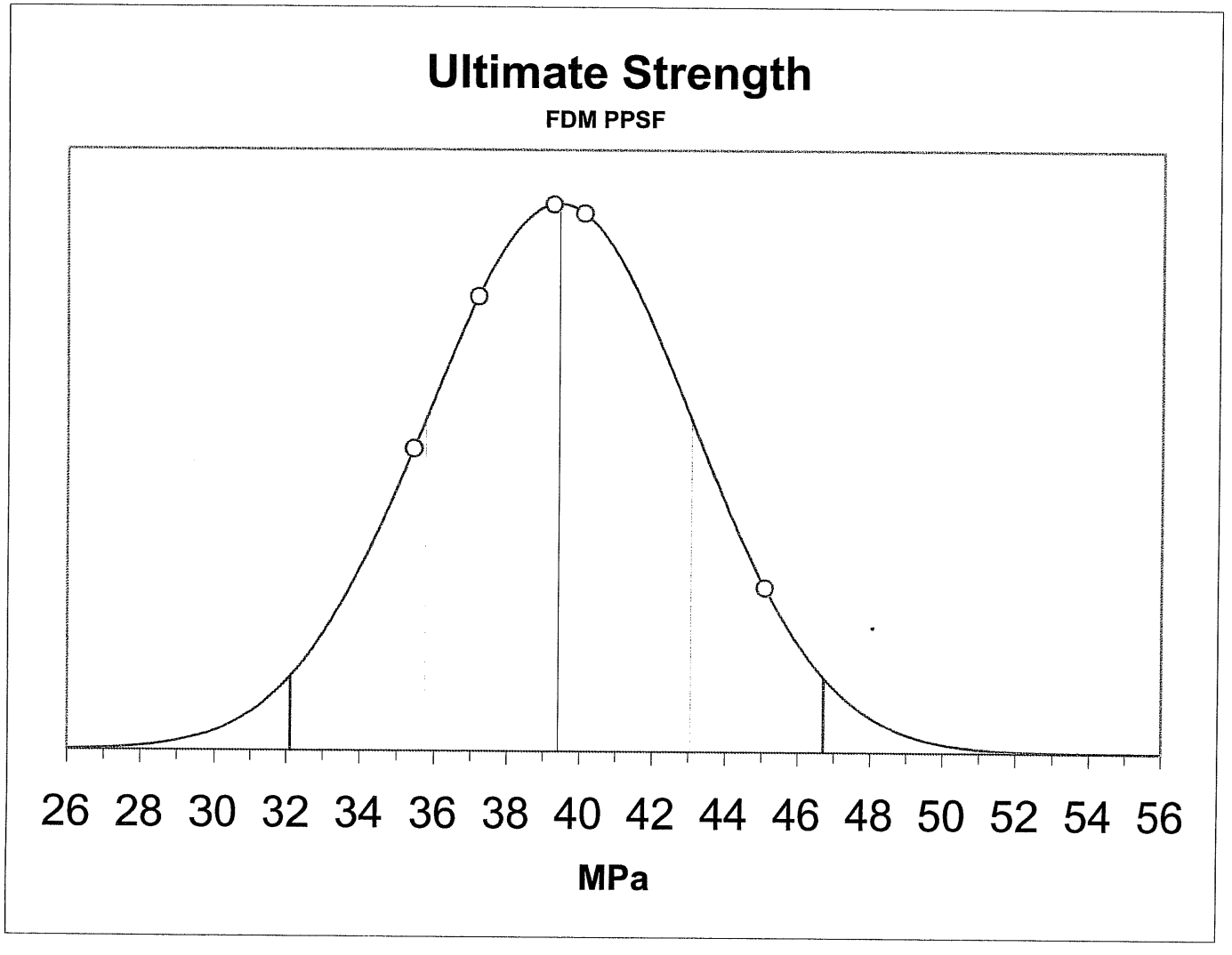

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 41.04 |
| Minimum = | 37.34 |
| Maximum = | 48.62 |
| Std dev = | 4.51 |



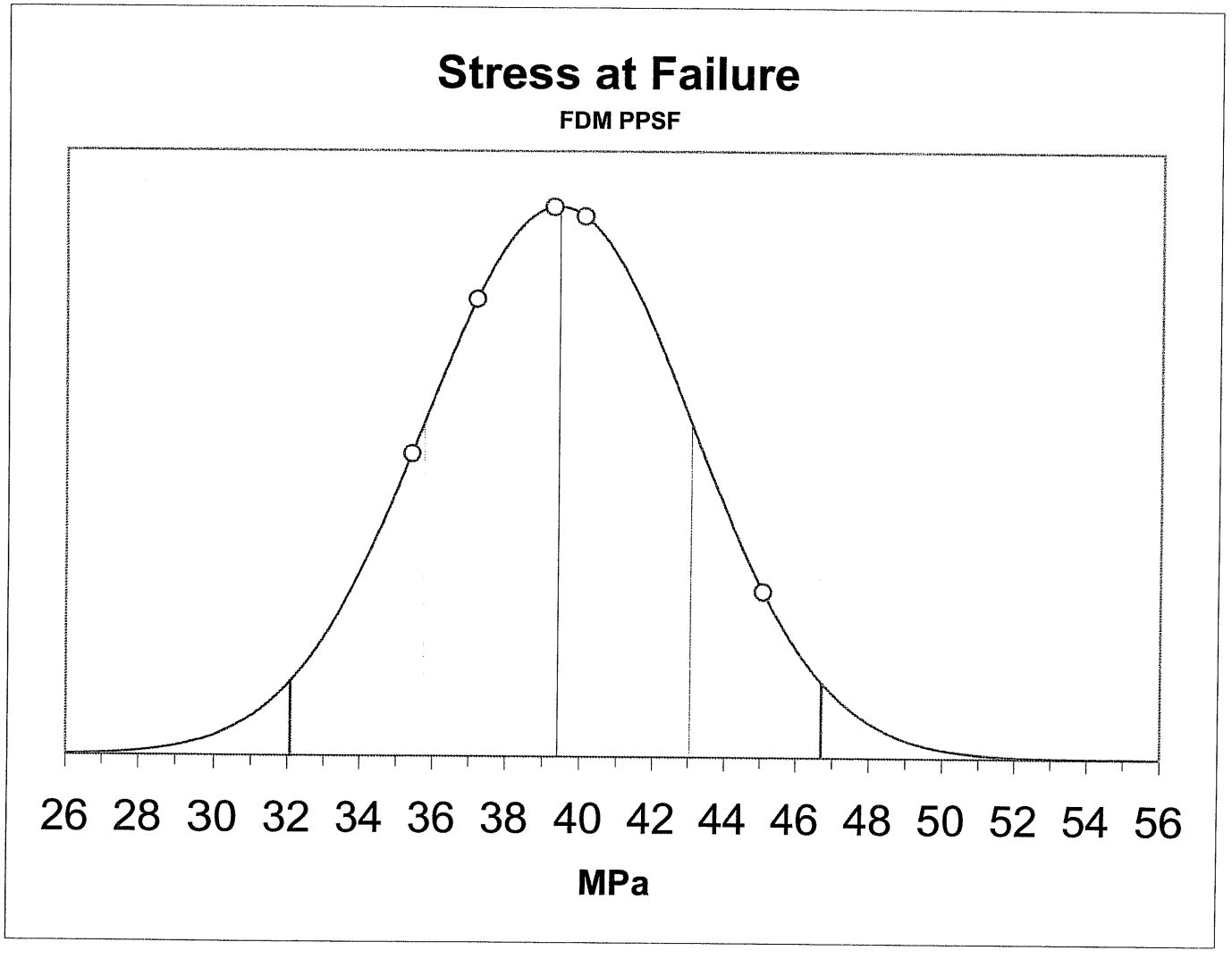

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 26.12 |
| Minimum = | 23.11 |
| Maximum = | 29.59 |
| Std dev = | 2.51 |



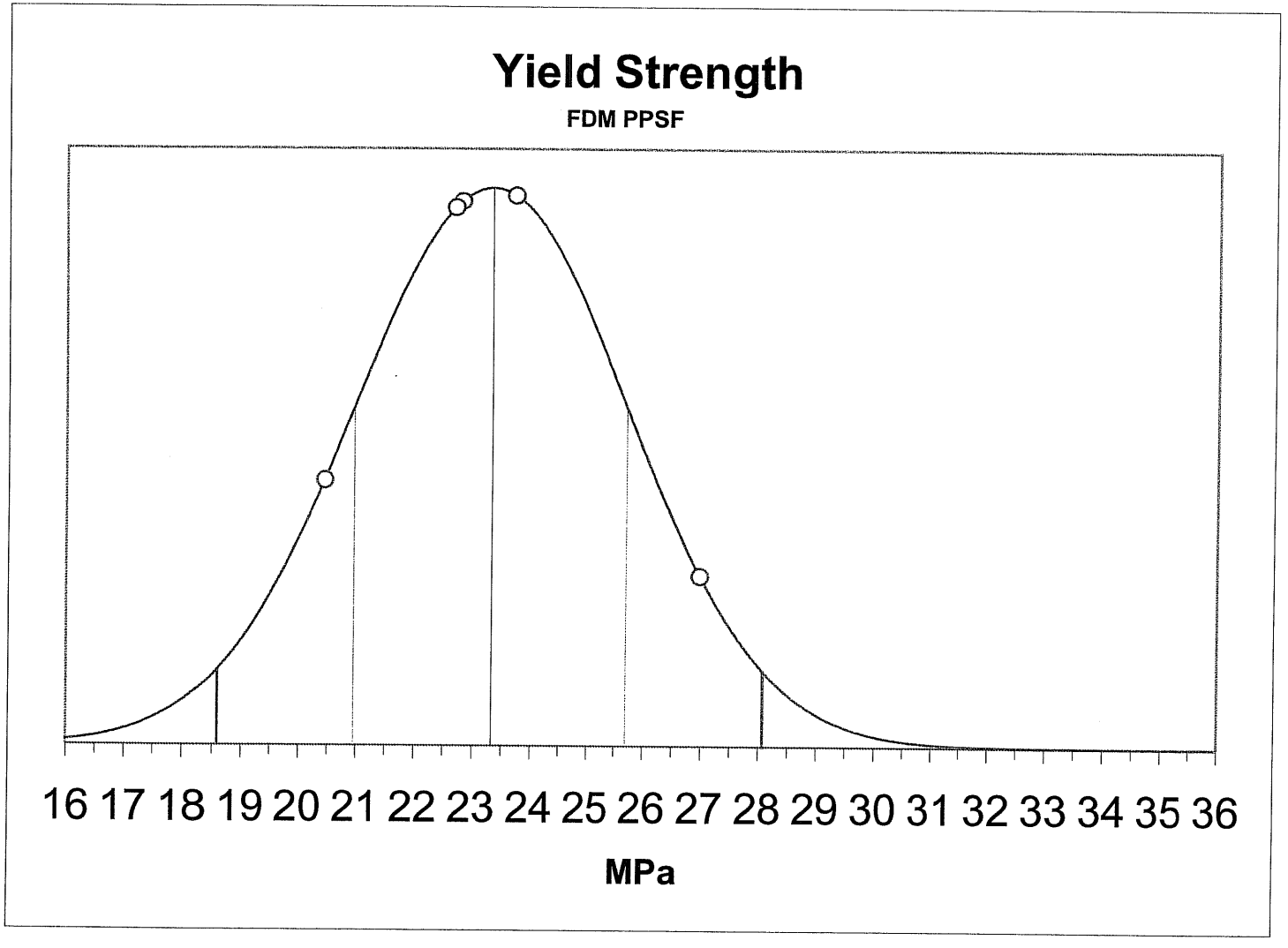

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 2105.22 |
| Minimum = | 2049.68 |
| Maximum = | 2166.22 |
| Std dev = | 44.69 |



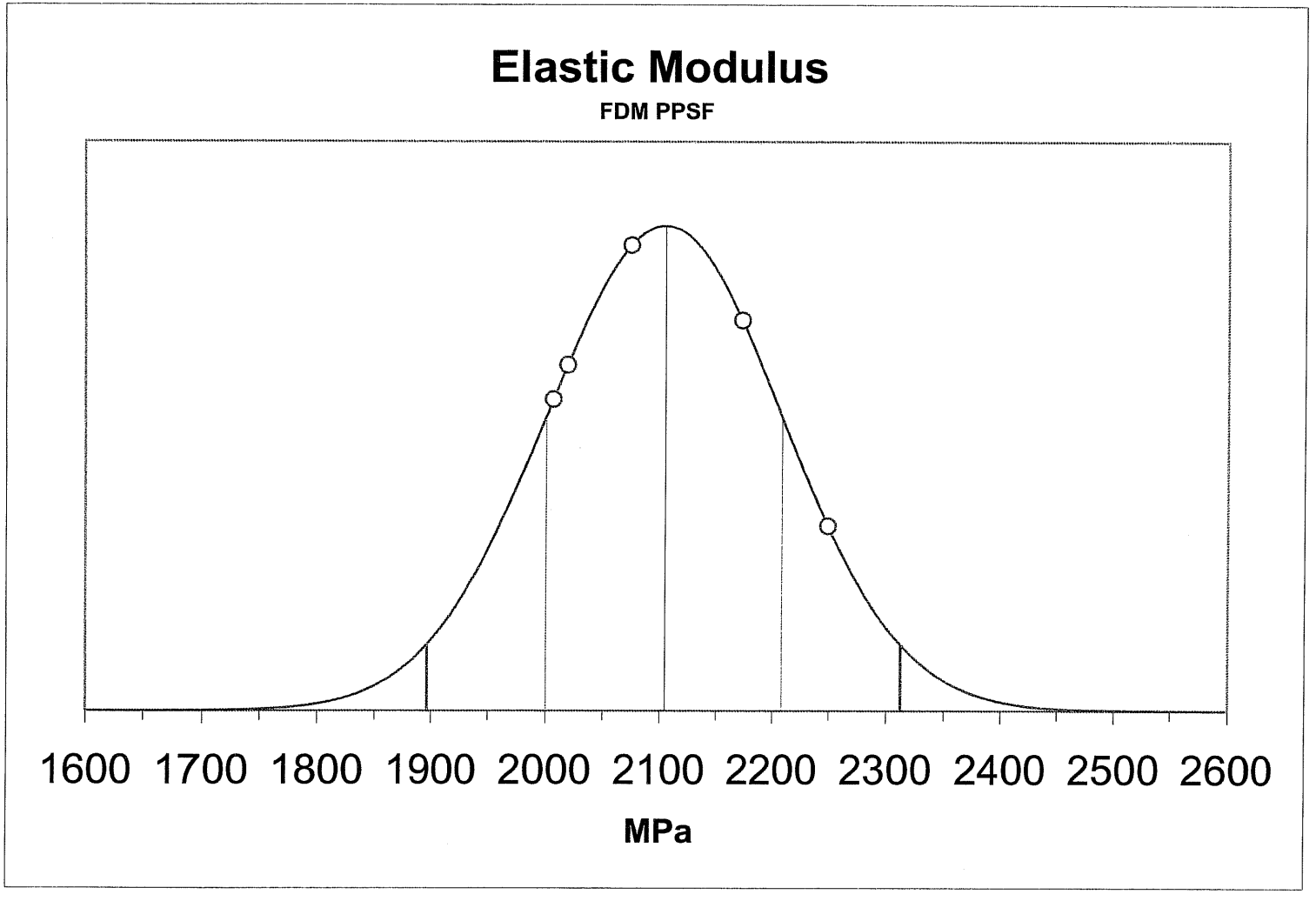

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 39.41 |
| Minimum = | 35.44 |
| Maximum = | 45.08 |
| Std dev = | 3.65 |



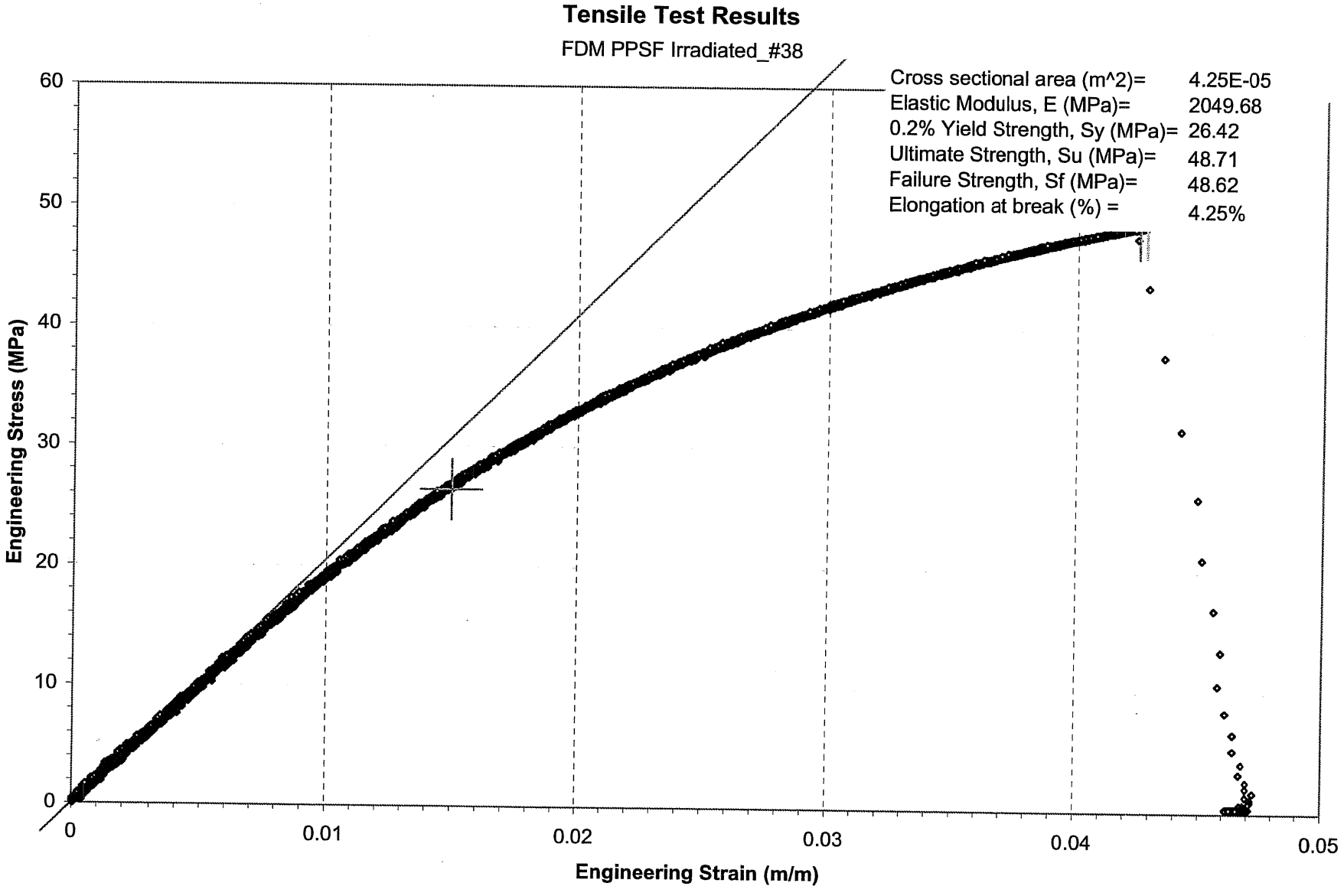

| | |
|---|---|
| # samples = | 5.00 |
| Average = | 39.40 |
| Minimum = | 35.41 |
| Maximum = | 45.07 |
| Std dev = | 3.66 |




| | |
|---|---|
| # samples = | 5.00 |
| Average = | 23.33 |
| Minimum = | 20.44 |
| Maximum = | 26.98 |
| Std dev = | 2.37 |

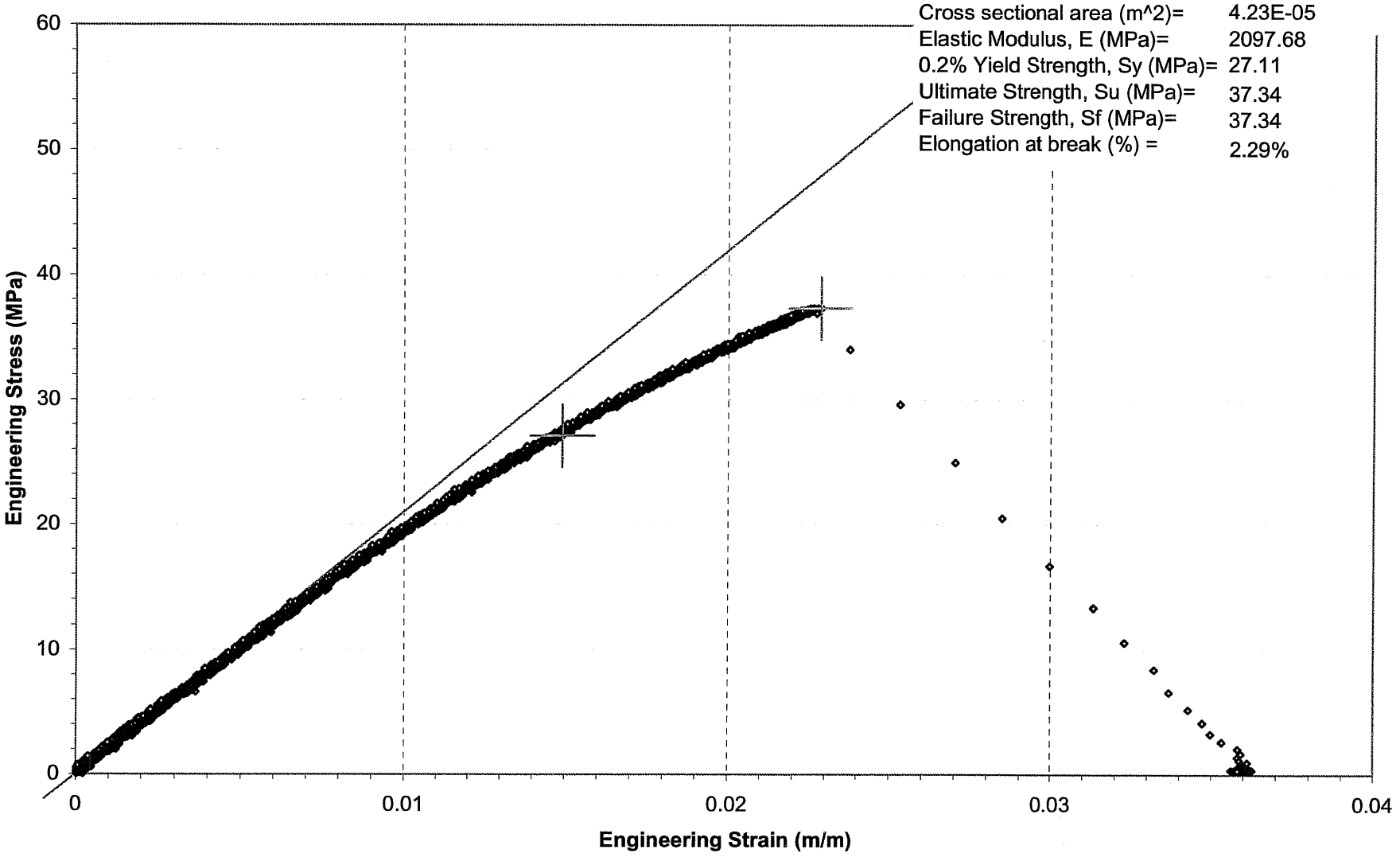



| | |
|---|---|
| # samples = | 5.00 |
| Average = | 2104.63 |
| Minimum = | 2006.81 |
| Maximum = | 2249.19 |
| Std dev = | 104.03 |



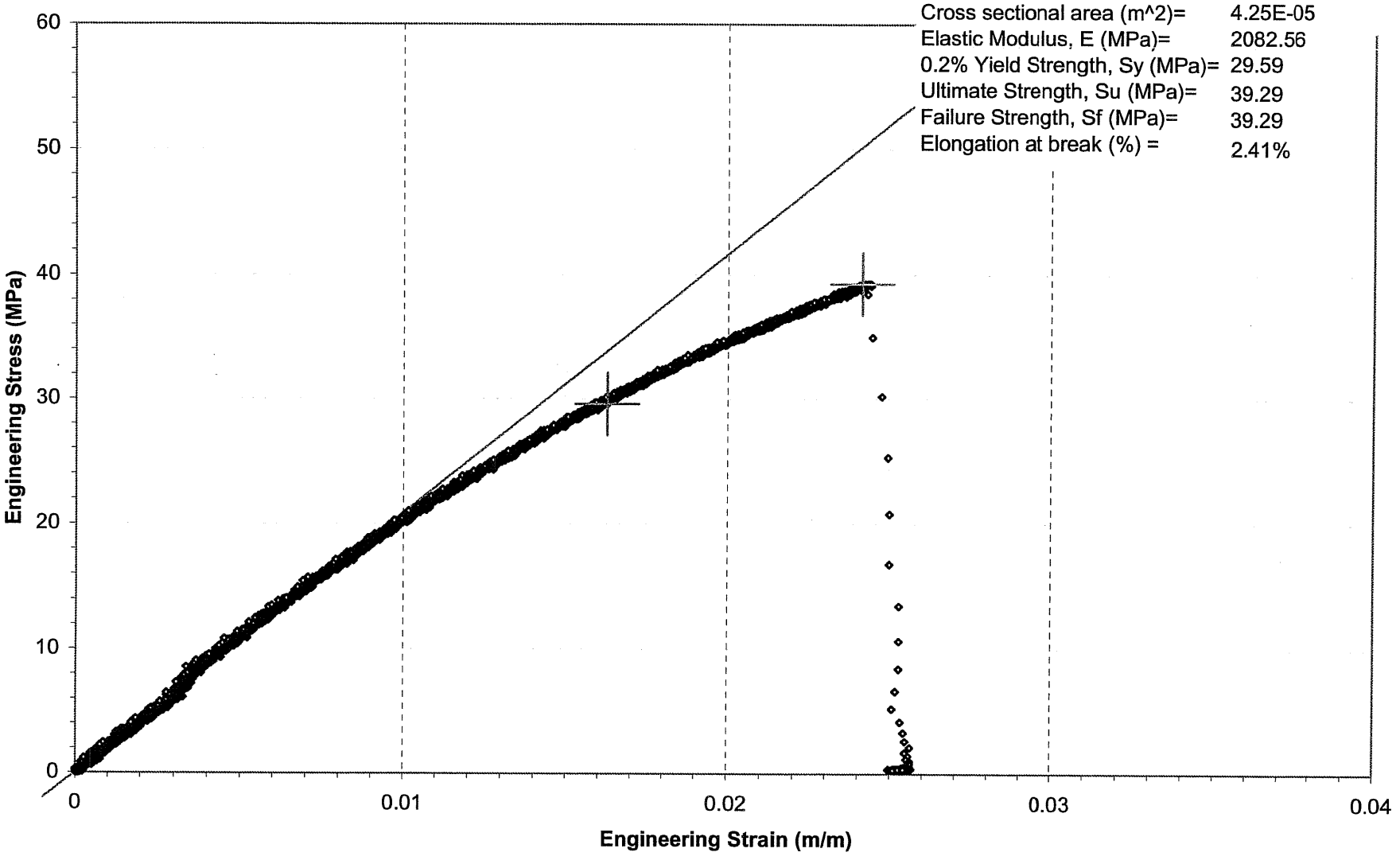
## Tensile Test Results

FDM PPSF Irradiated_#39



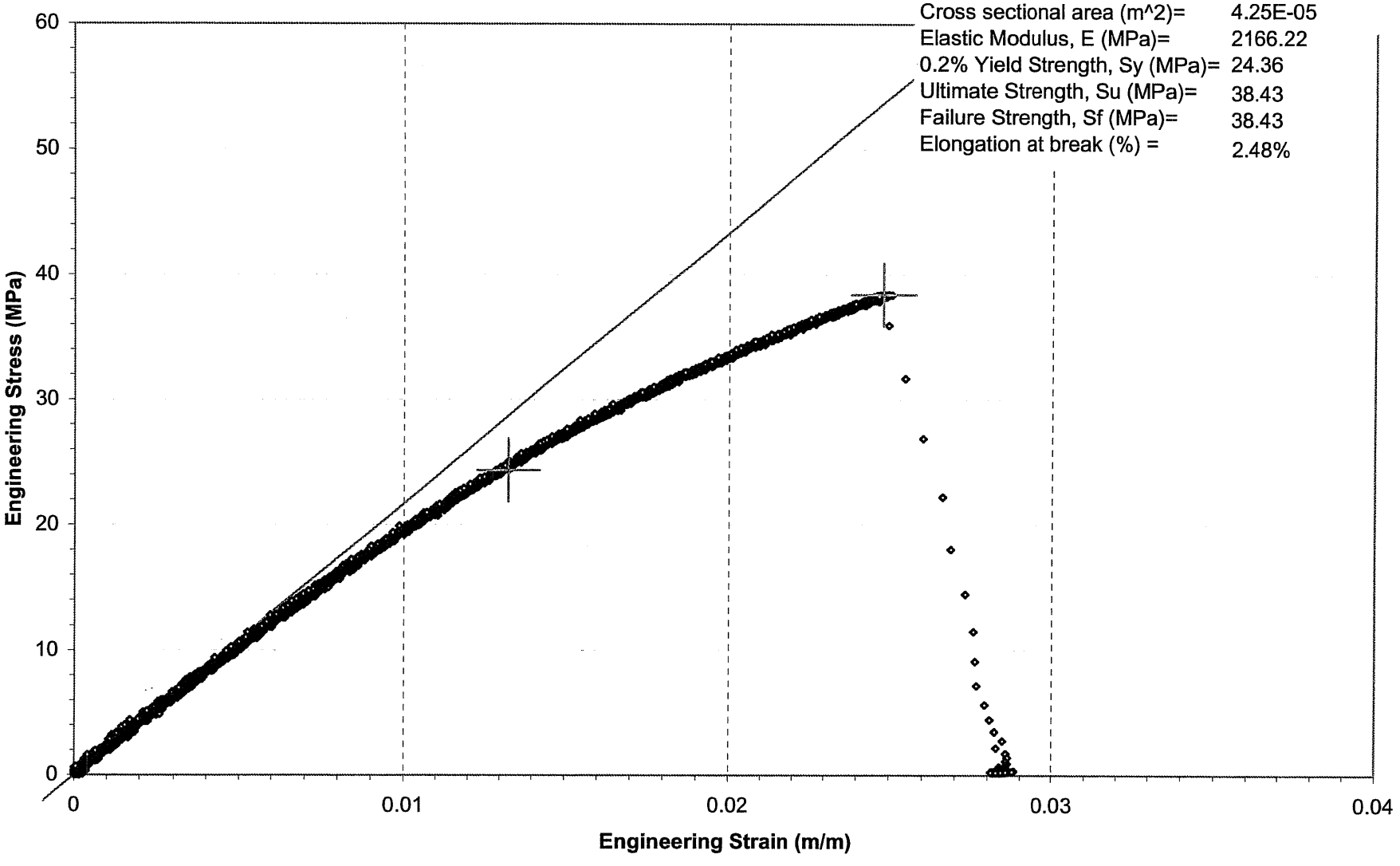
## Tensile Test Results

FDM PPSF Irradiated_#40



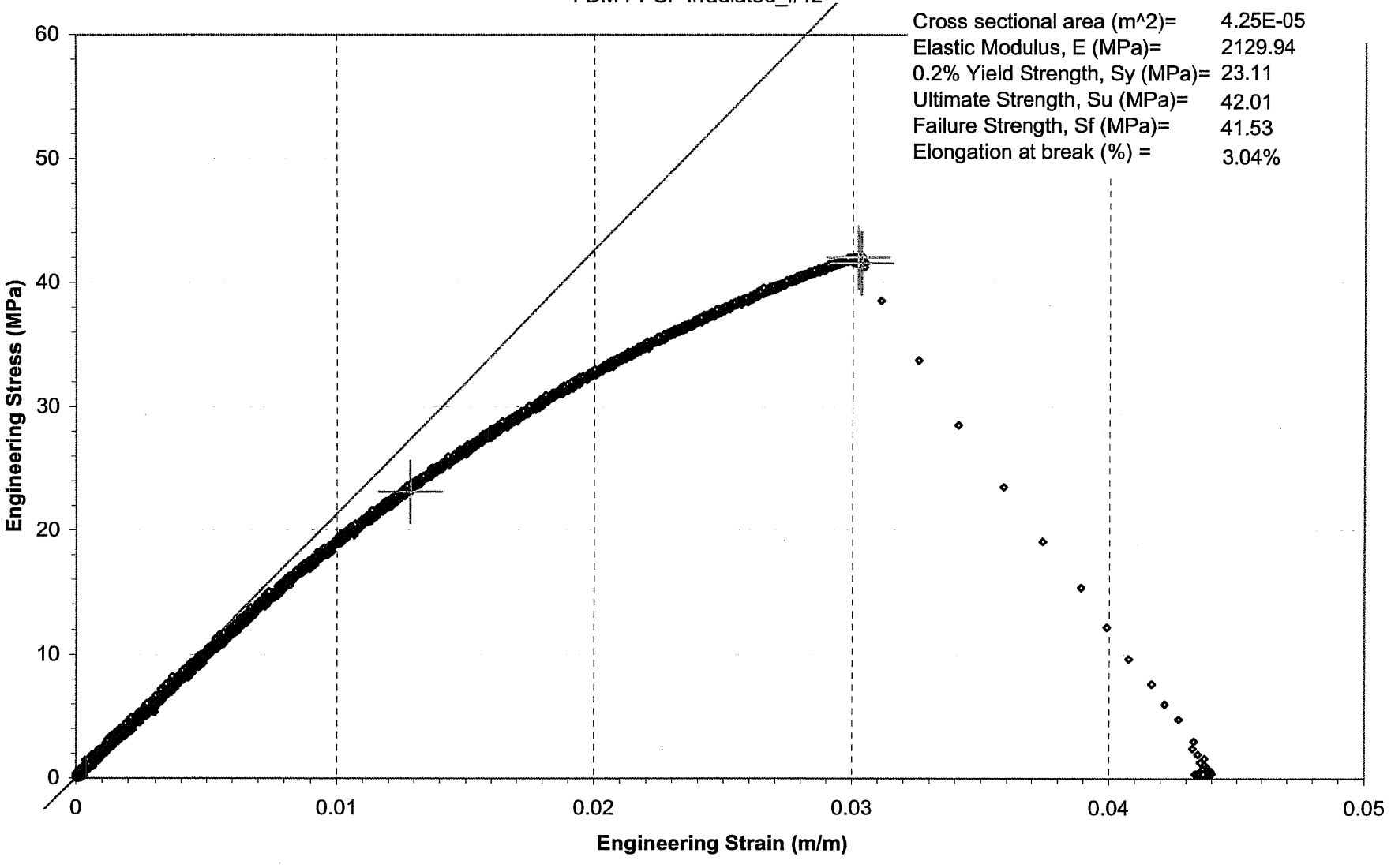
## Tensile Test Results

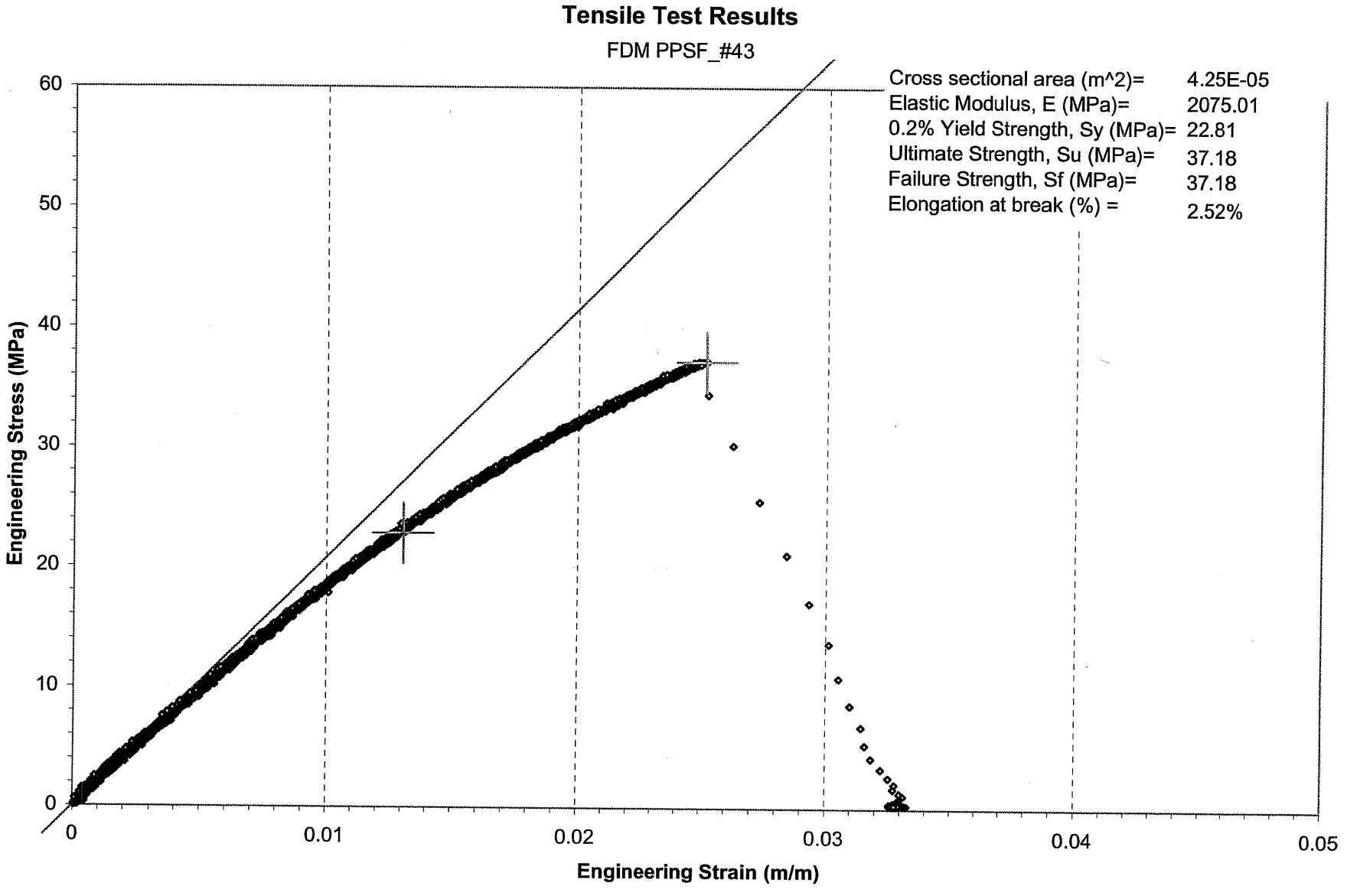
FDM PPSF Irradiated_#41



## Tensile Test Results

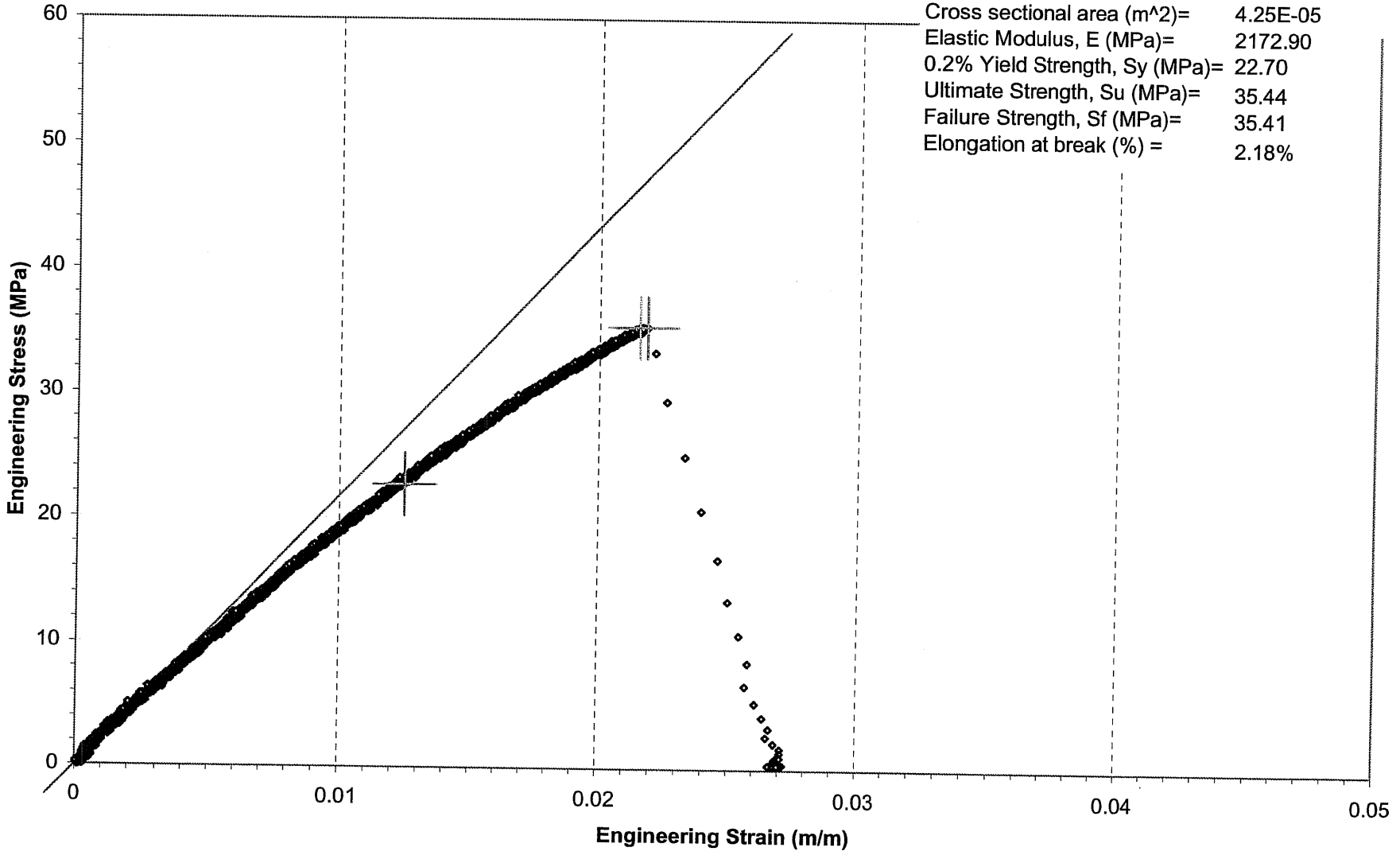
FDM PPSF Irradiated_#42

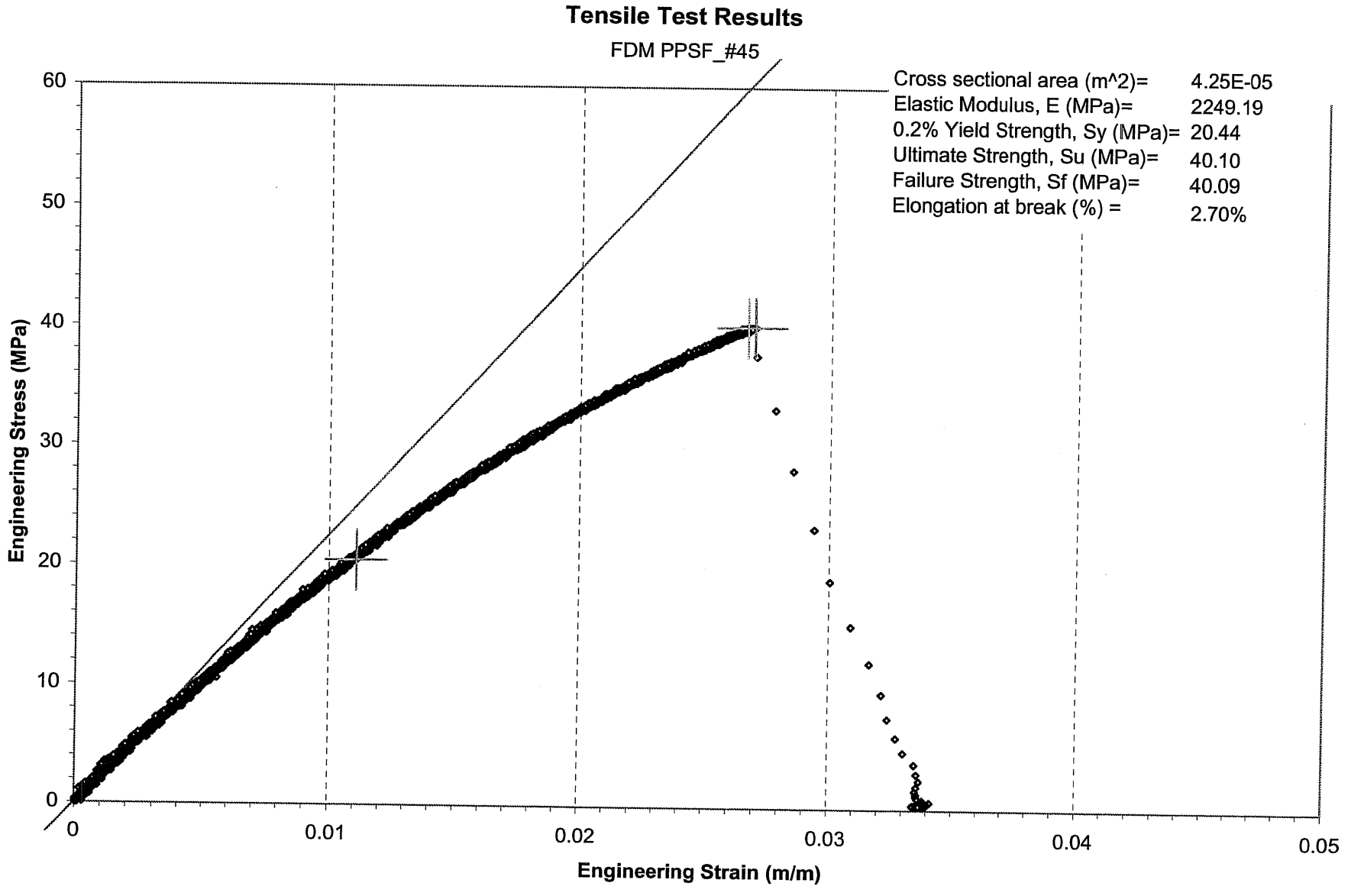


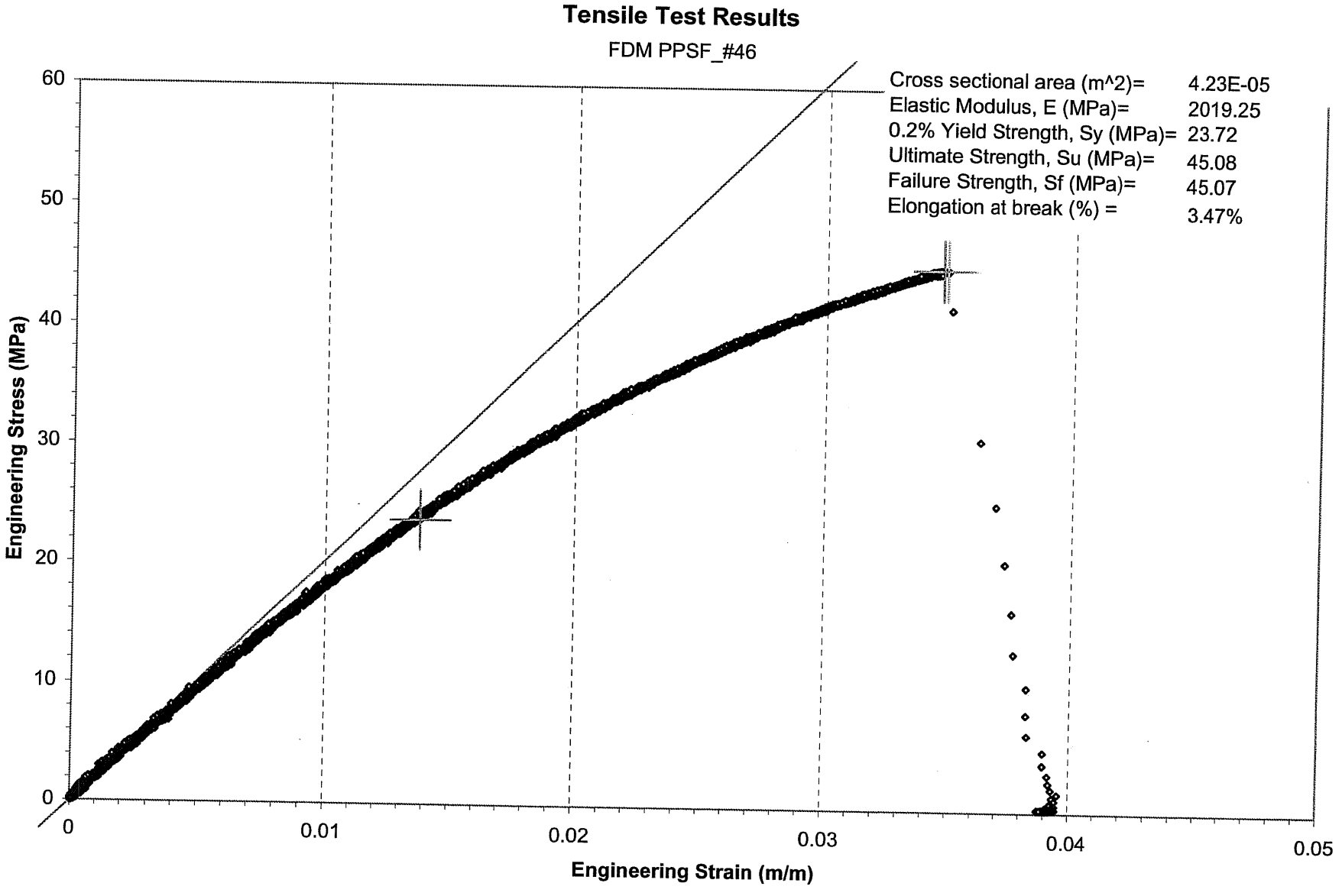


## Tensile Test Results

FDM PPSF_#44







## Tensile Test Results

FDM PPSF_#47