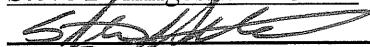


Author(s)

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Department

Mechanical Engineering

Date

05/20/03Program - 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

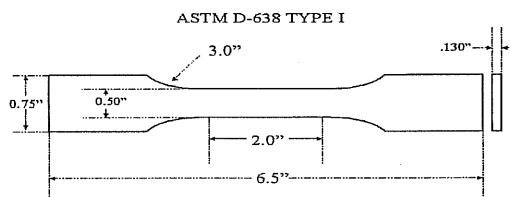
Fabricate tensile test samples on Fused Deposition Modeler (FDM) and Stereolithography (SLA) rapid prototyping machines. Tensile test samples that have been exposed to ionizing radiation and compare the results with control samples that have not been exposed to radiation.

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:

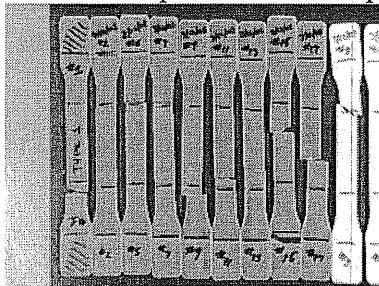


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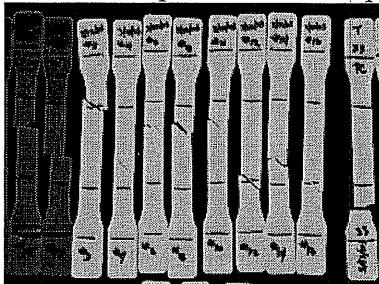
Department
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Materials

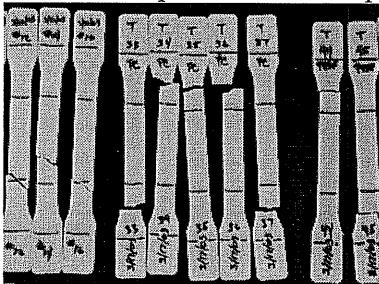
- 1.) **SLA** - Photo Epoxy Resin # 5170. Samples run in flat orientation where sample thickness is parallel to build platform. Built at LBNL RP lab.



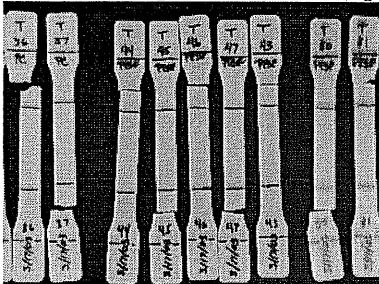
- 2.) **FDM** - ABS plastic # P-400. Samples run in flat orientation where sample thickness is parallel to build platform. Built at LBNL RP lab.



- 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.

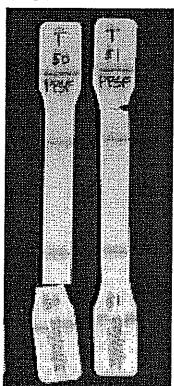


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- 5.) **FDM** – PPSF (polyphenylsulfone). Samples run on “edge orientation” where sample thickness is normal to build platform. Built at Stratasys Inc. RP lab.



Radiation

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

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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.

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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

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

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

Stress is calculated from the equation

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

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.

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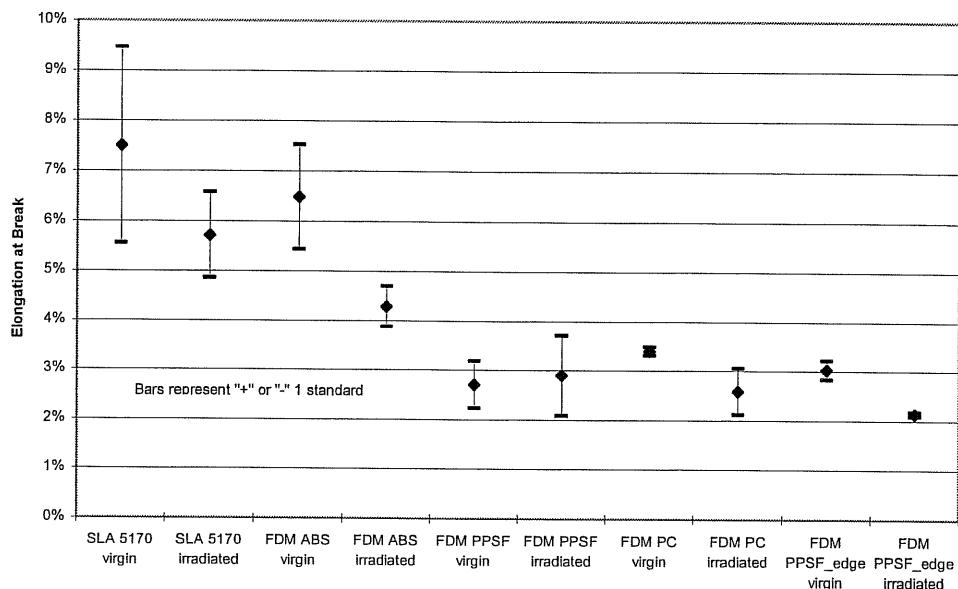
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Observations / Comments

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

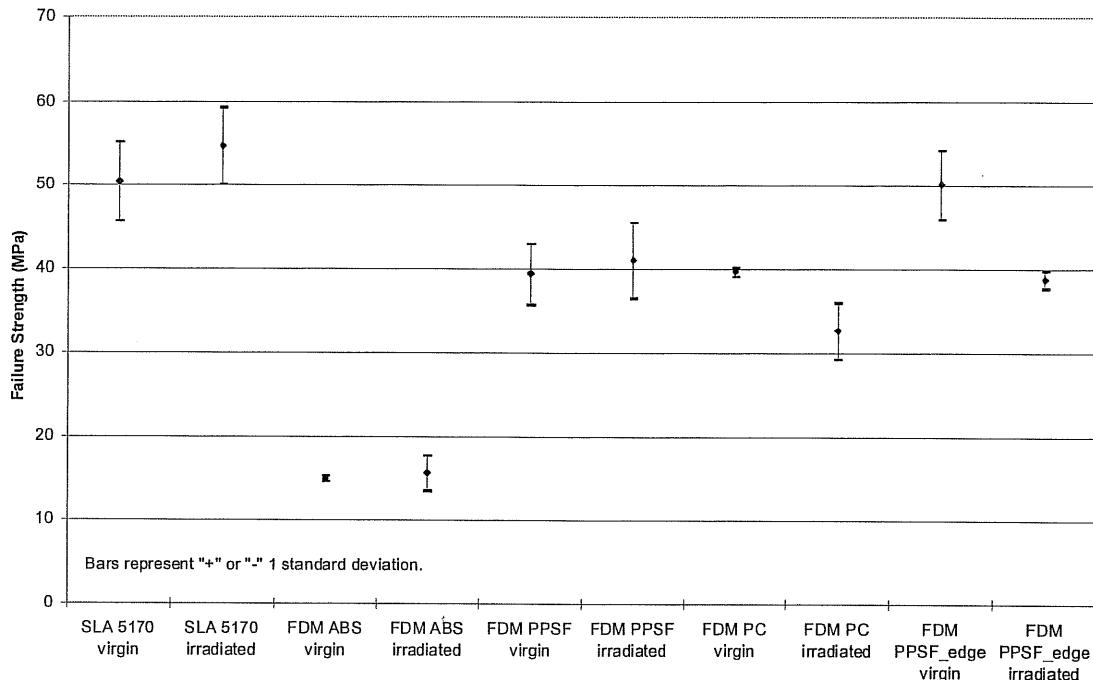
Summary Chart: Elongation at Break



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Summary Chart: Stress at Failure

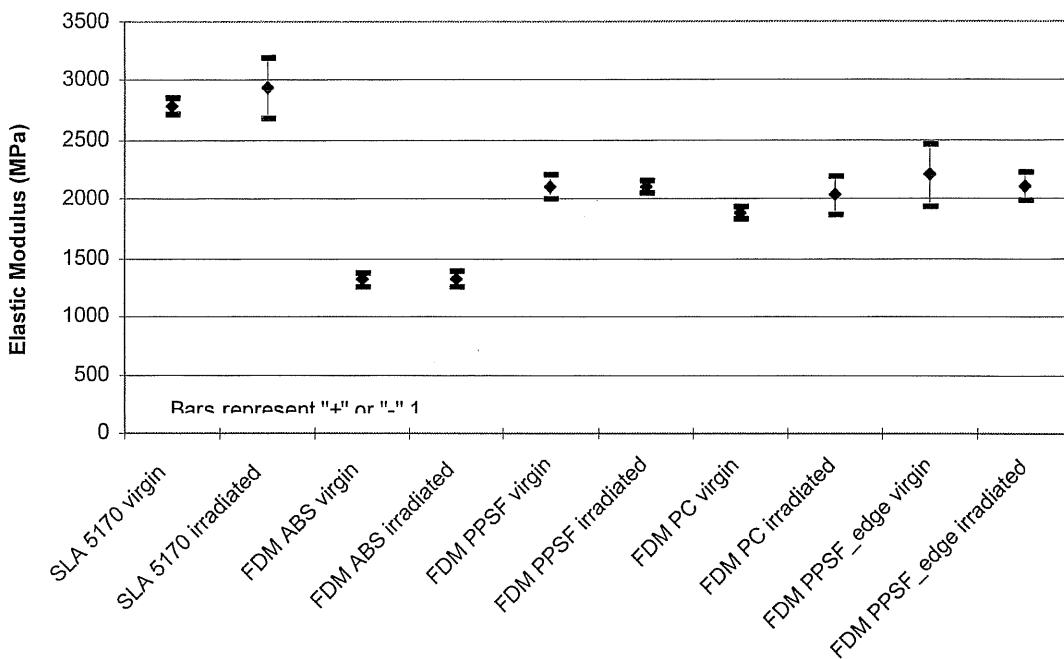


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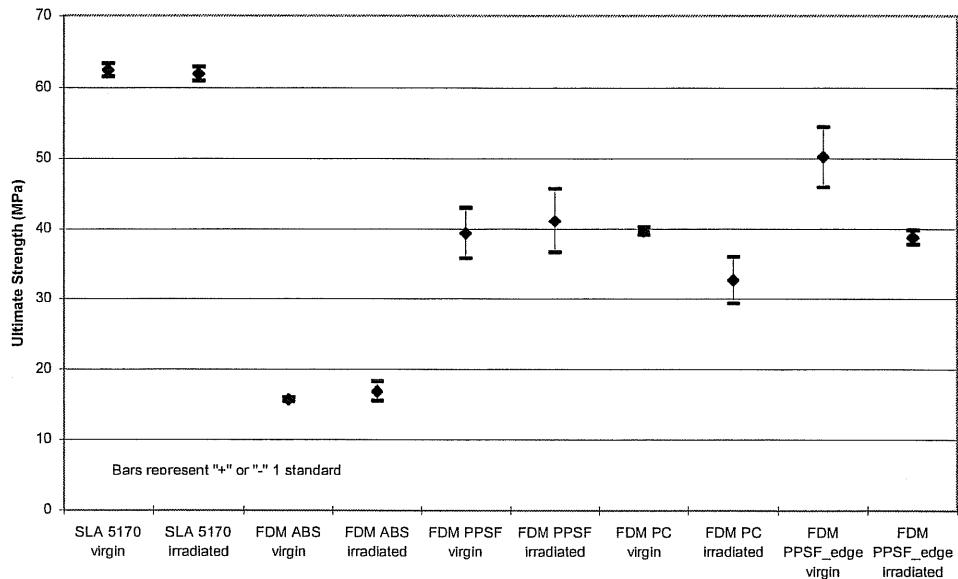
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Summary Chart: Elastic Modulus



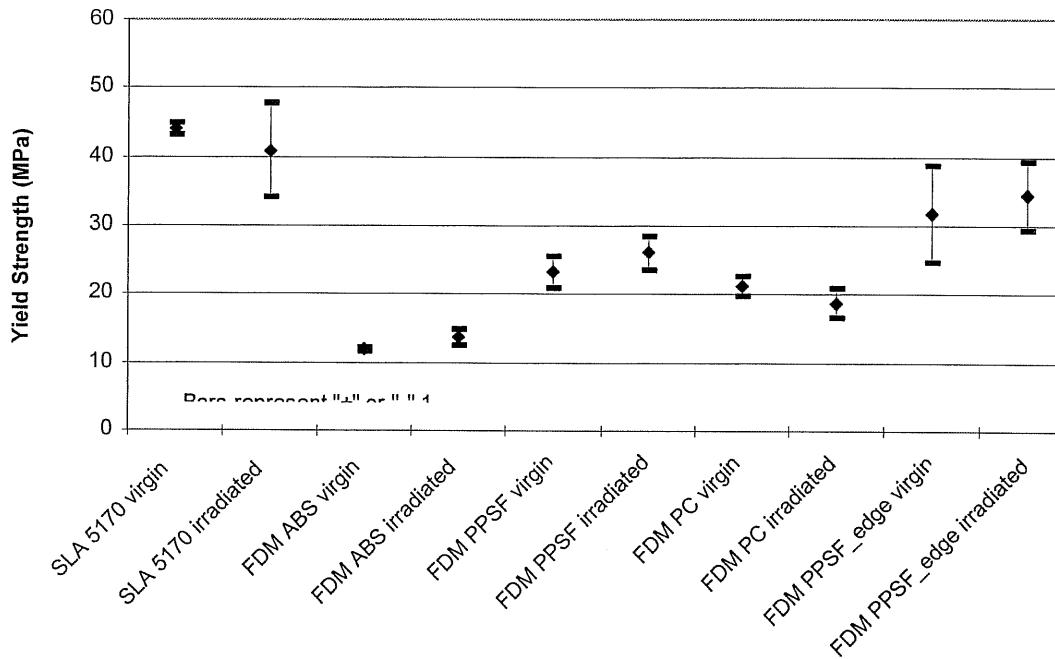
Summary Chart: Ultimate Strength



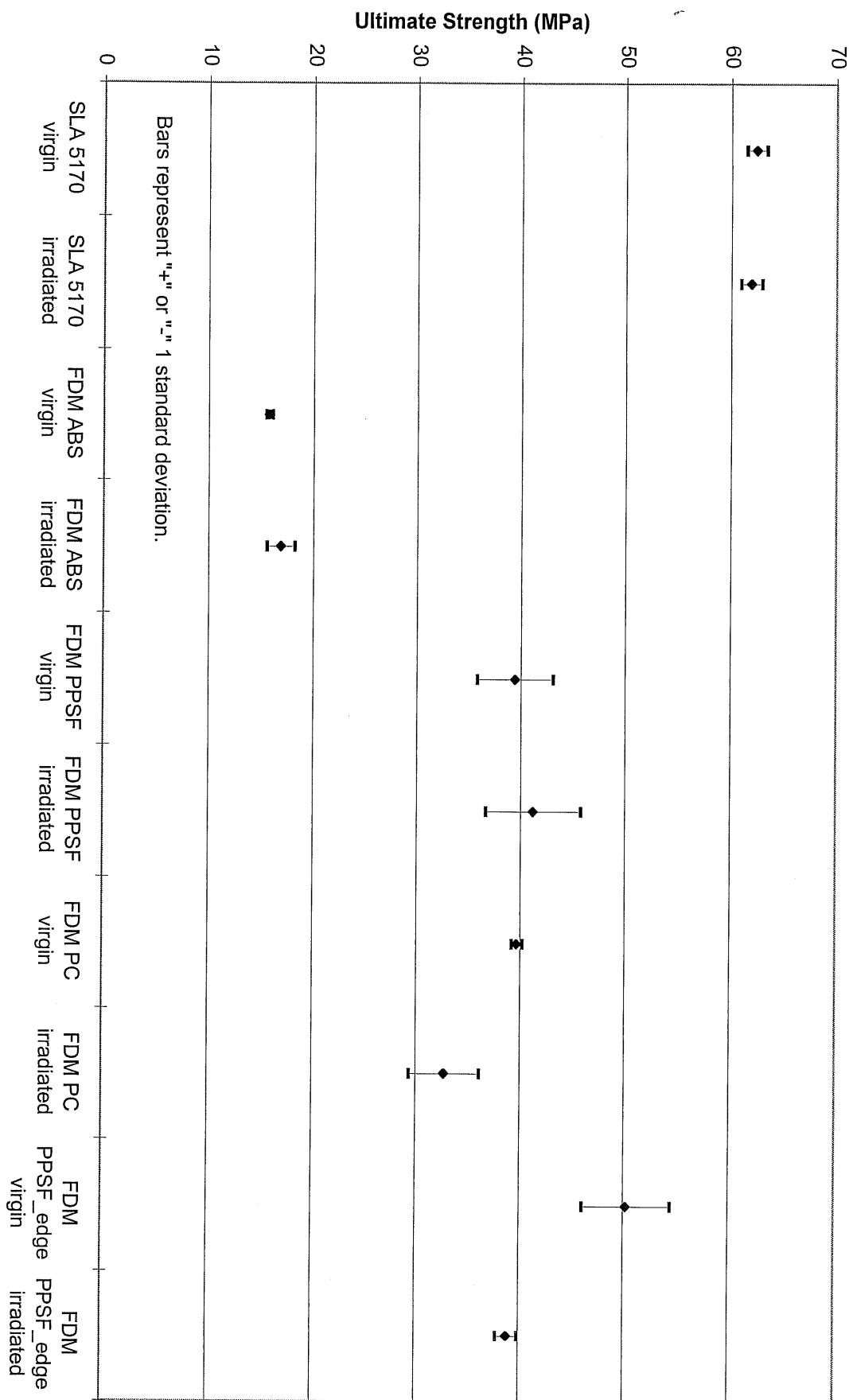
Author(s)
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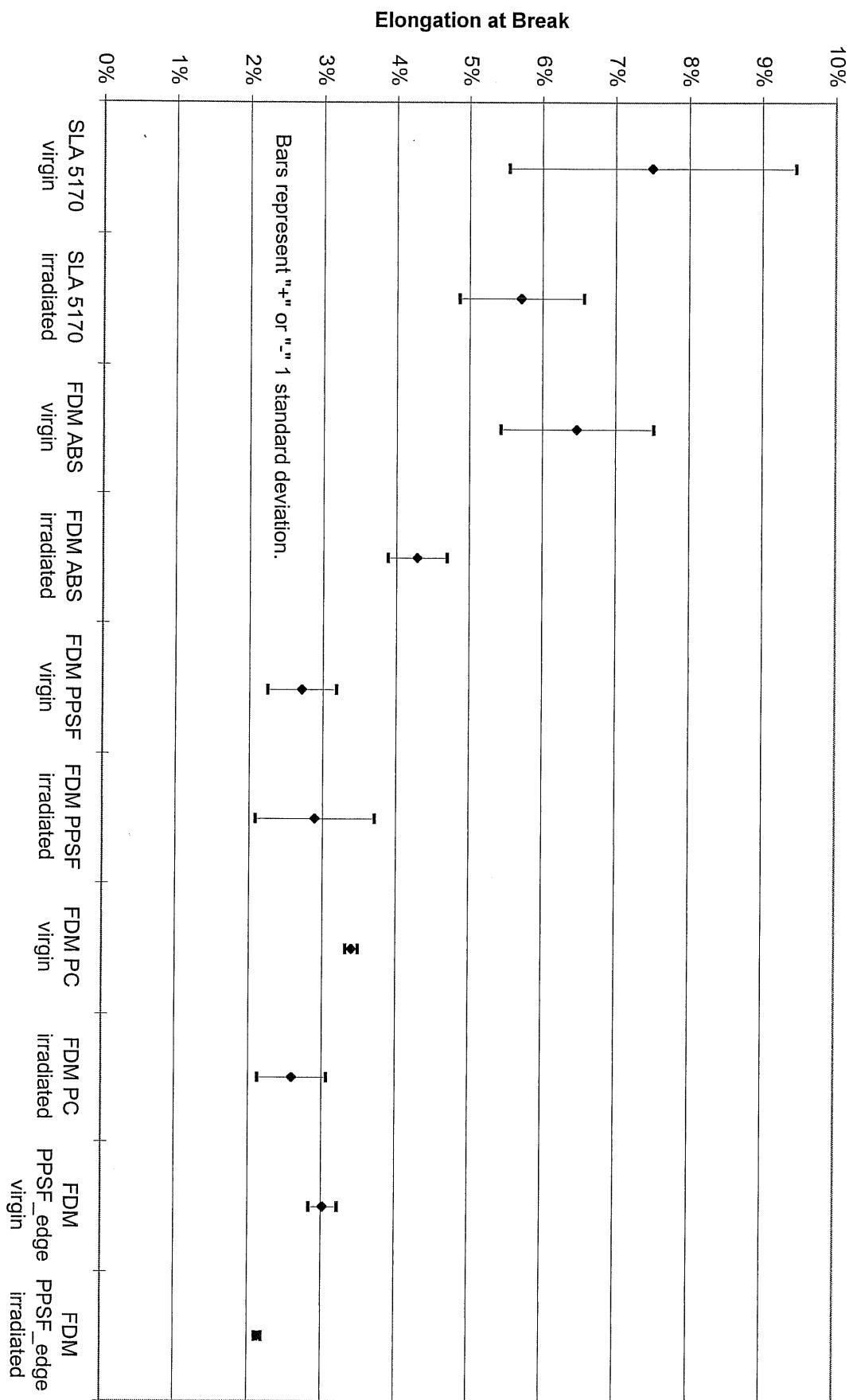
Summary Chart: Yield Strength



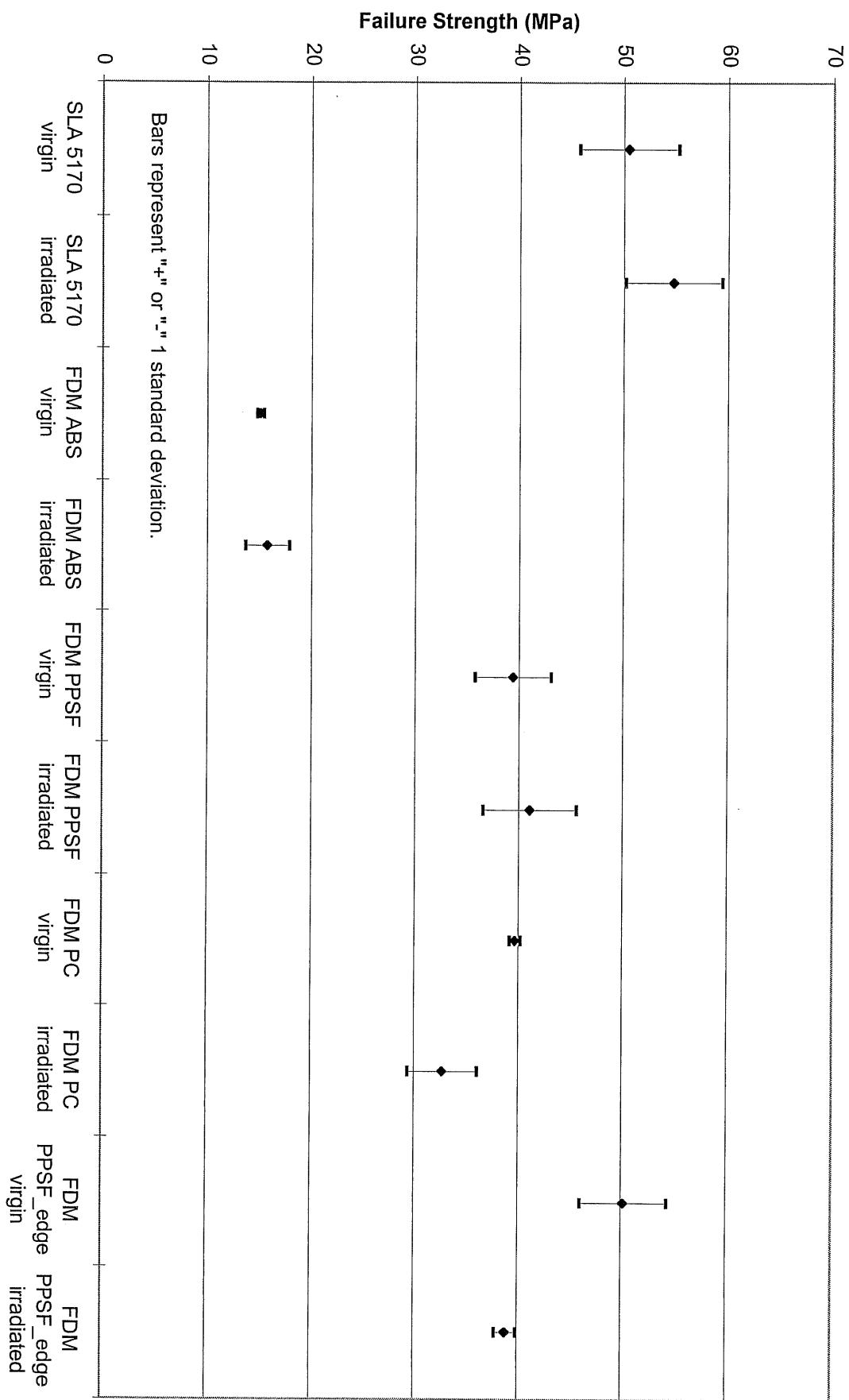
Summary Chart: Ultimate Strength



Summary Chart: Elongation at Break

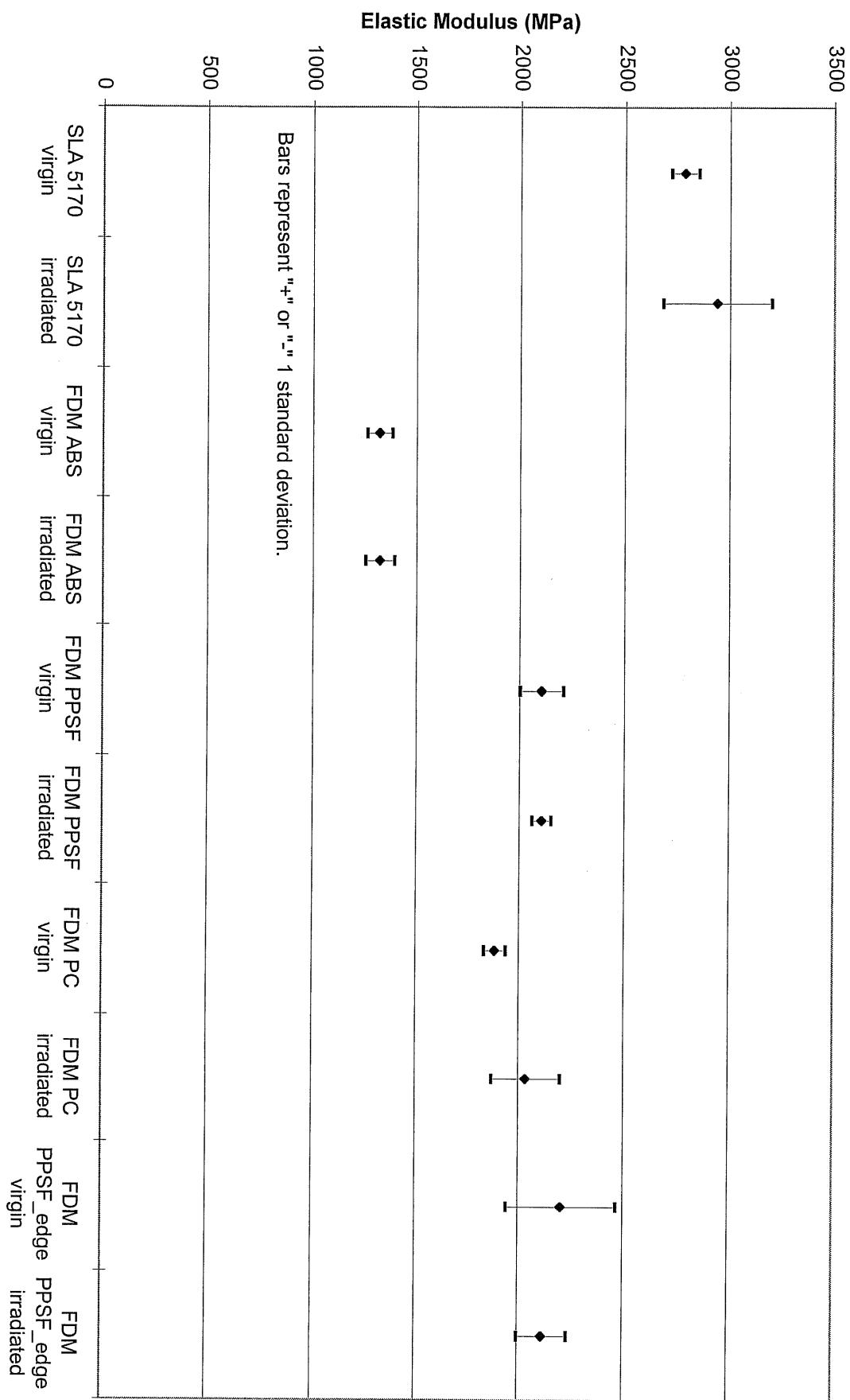


Summary Chart: Stress at Failure

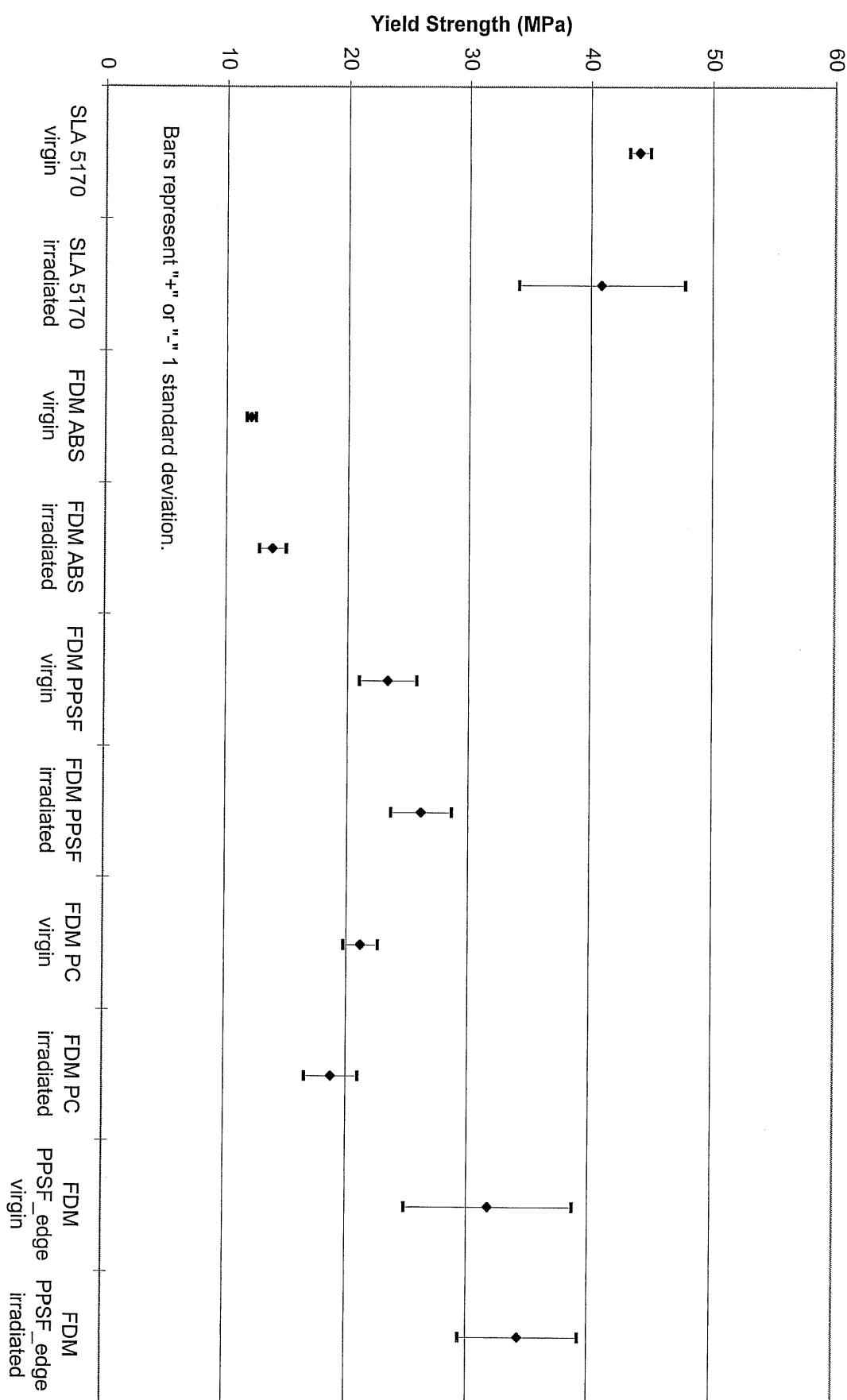


Bars represent "+" or "-" 1 standard deviation.

Summary Chart: Elastic Modulus

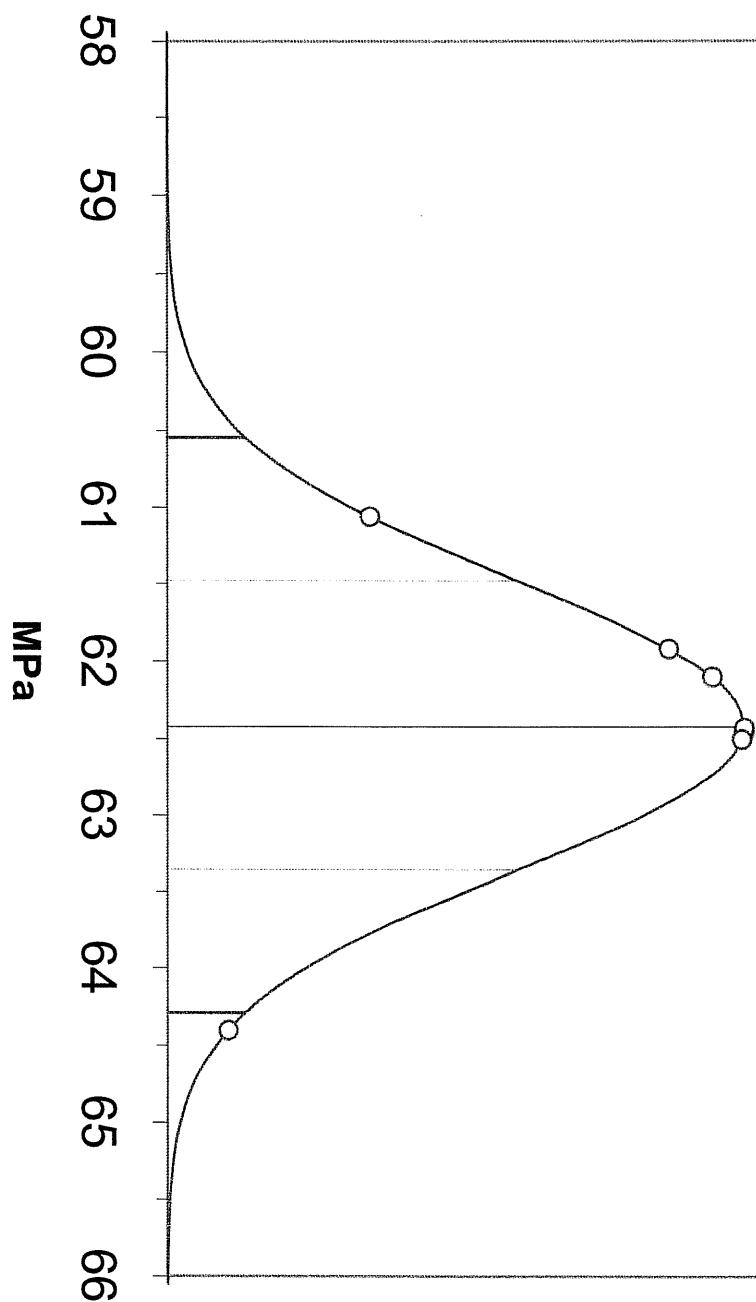


Summary Chart: Yield Strength



Ultimate Strength

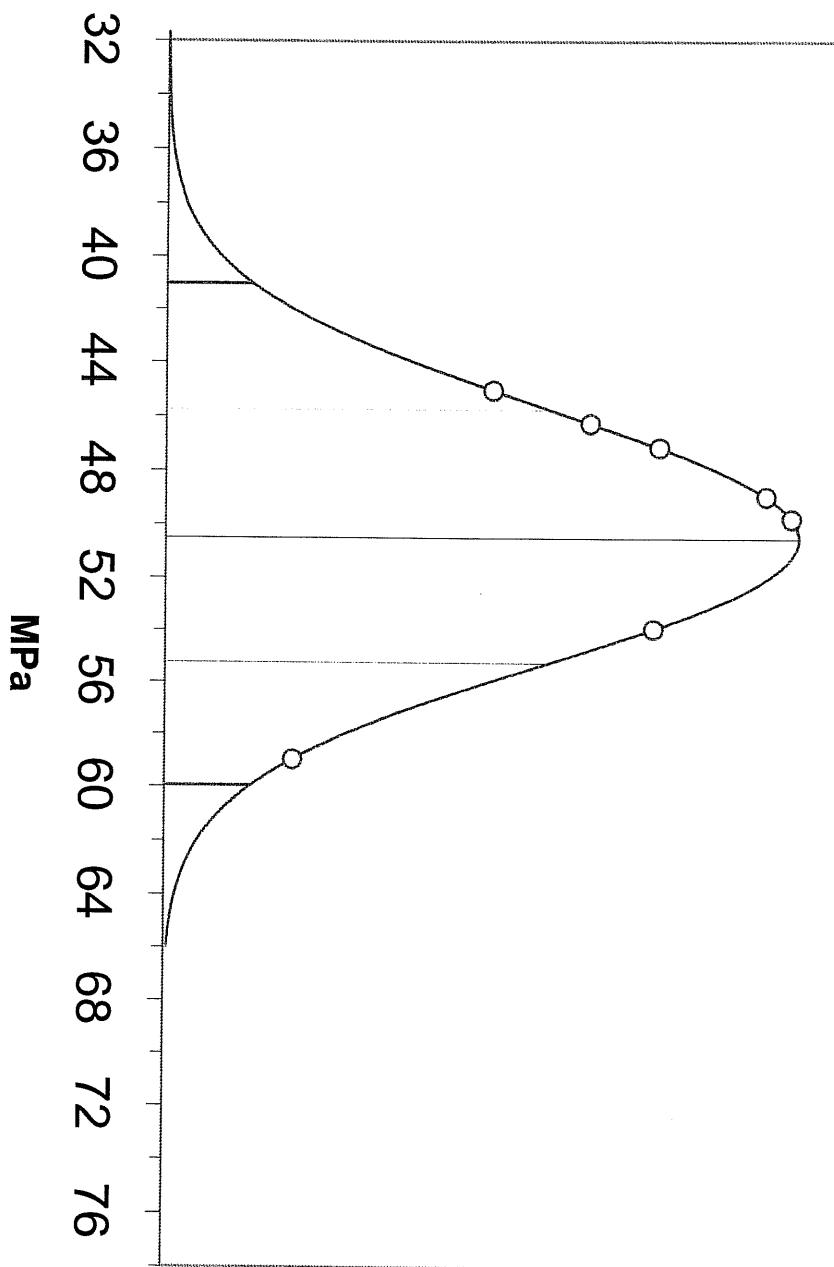
SLA_5170



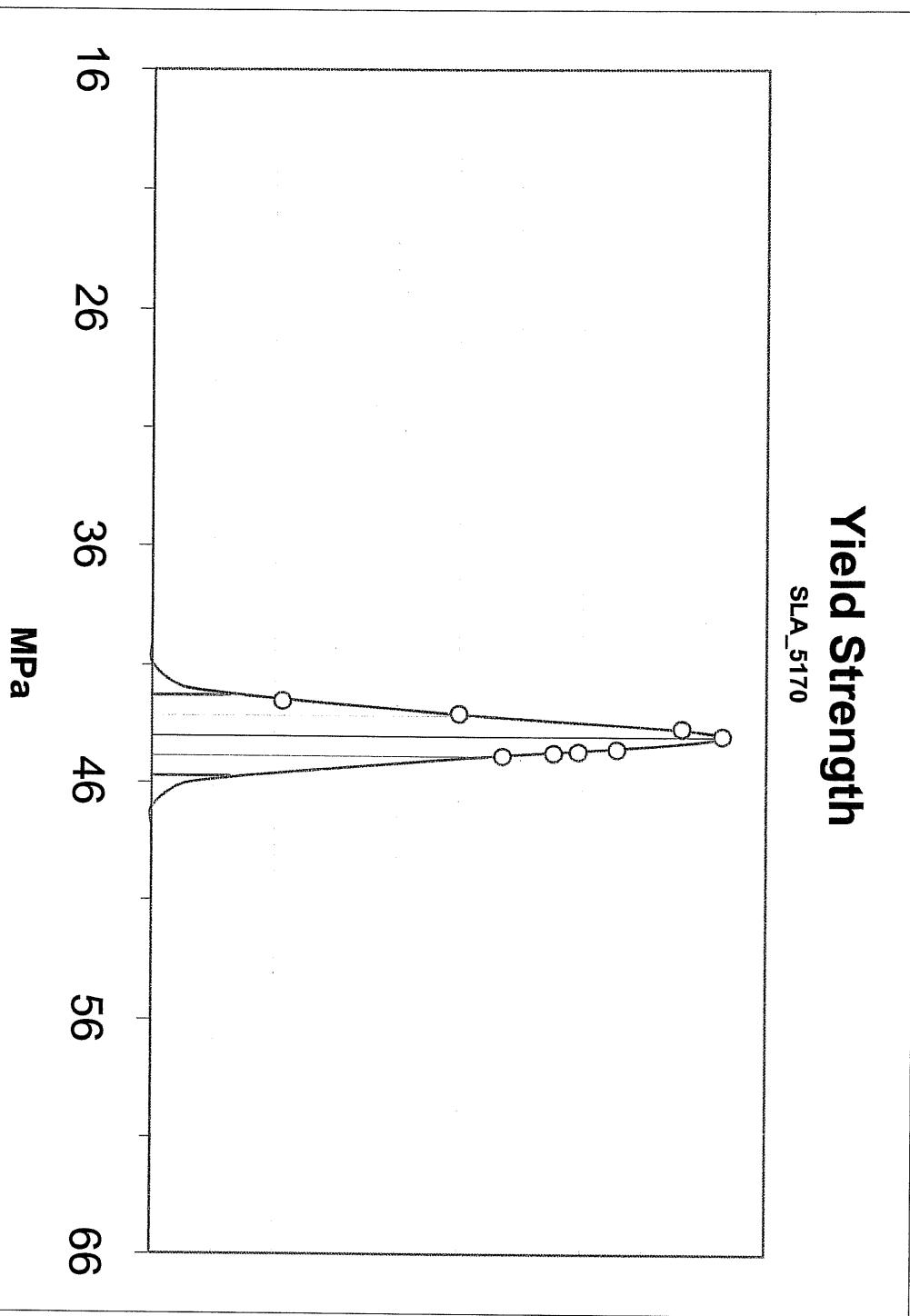
samples = 8.00
Average = 62.42
Minimum = 61.07
Maximum = 64.41
Std dev = 0.94

Stress at Failure

SLA_5170



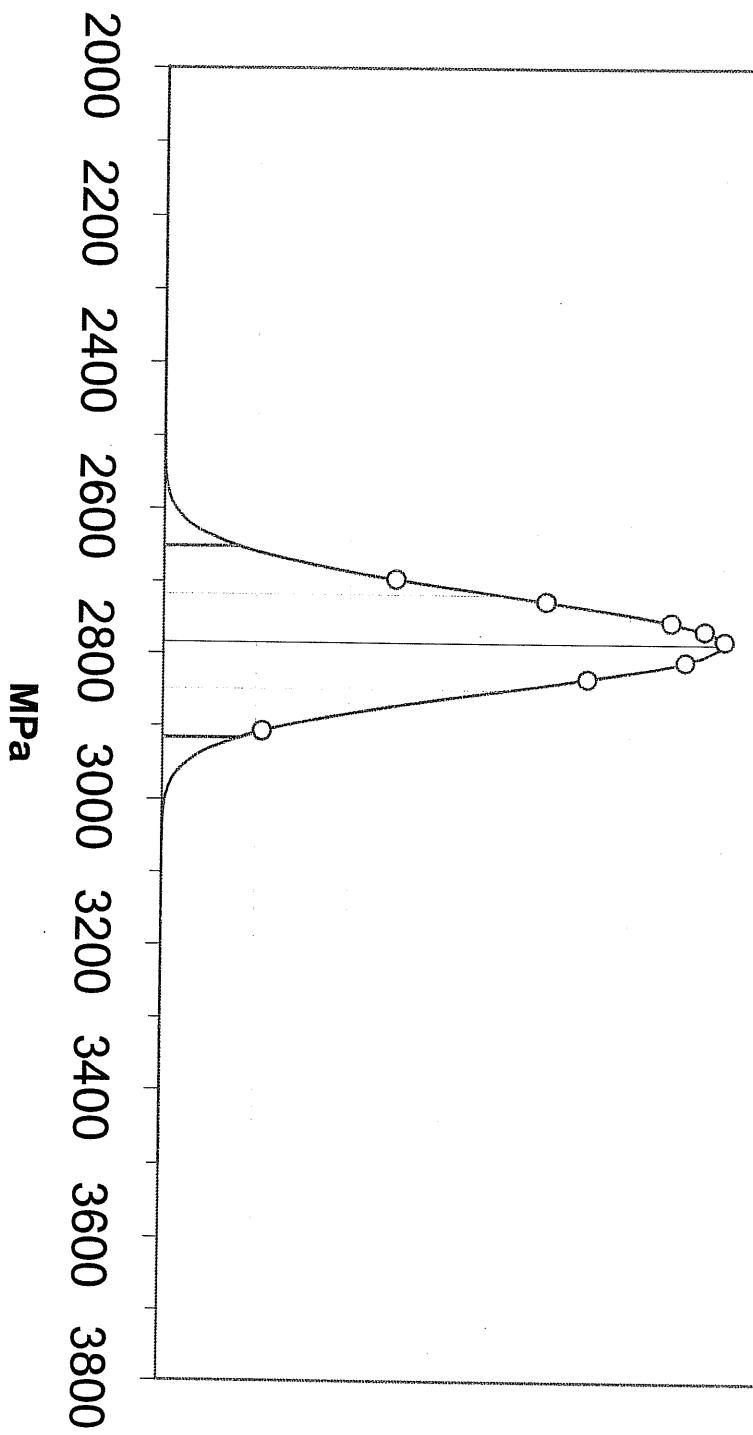
samples = 8.00
Average = 50.48
Minimum = 45.04
Maximum = 58.96
Std dev = 4.73



# samples =	8.00
Average =	44.01
Minimum =	42.54
Maximum =	44.86
Std dev =	0.86

Elastic Modulus

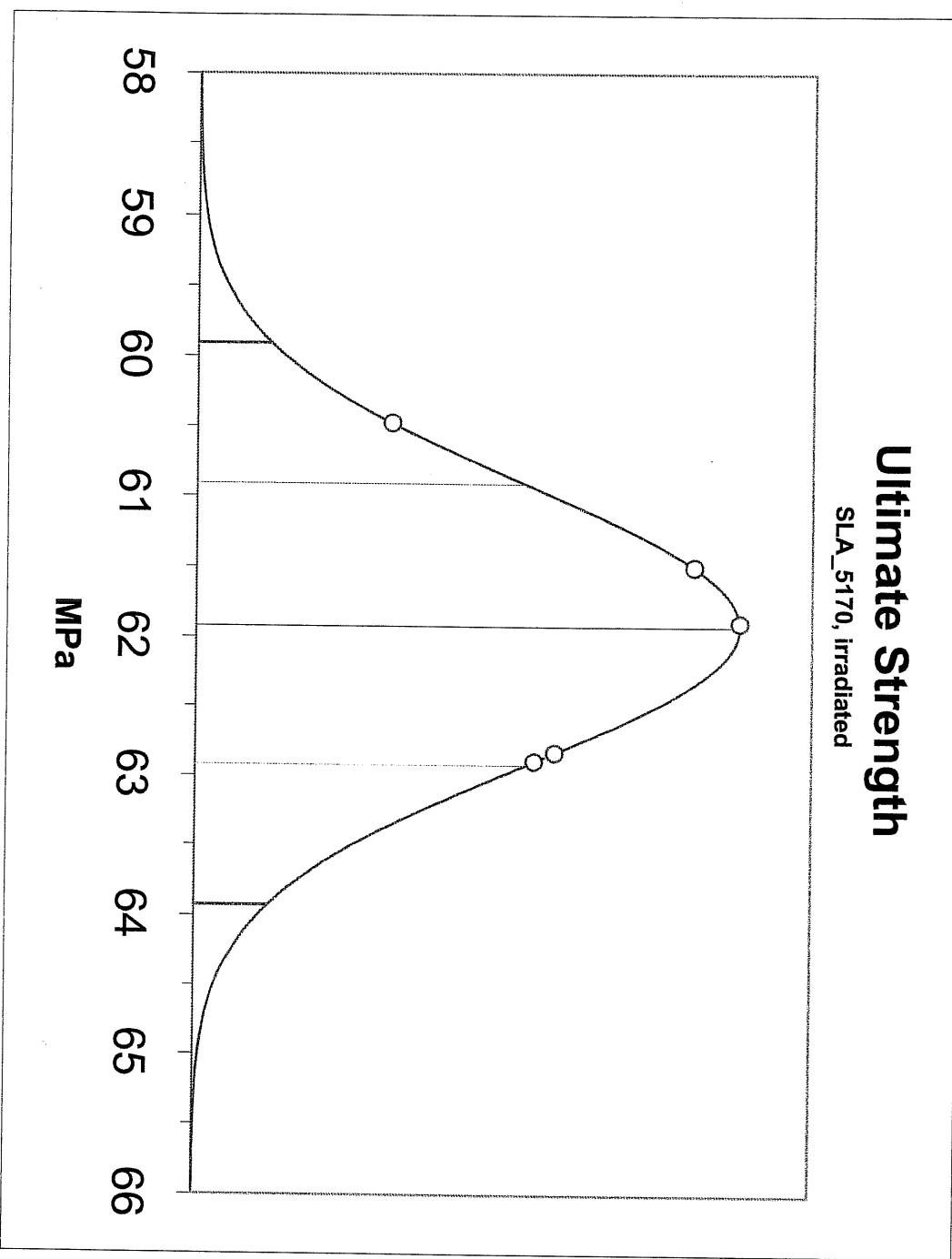
SLA_5170



samples = 8.00
Average = 2784.52
Minimum = 2696.64
Maximum = 2907.58
Std dev = 66.14

Ultimate Strength

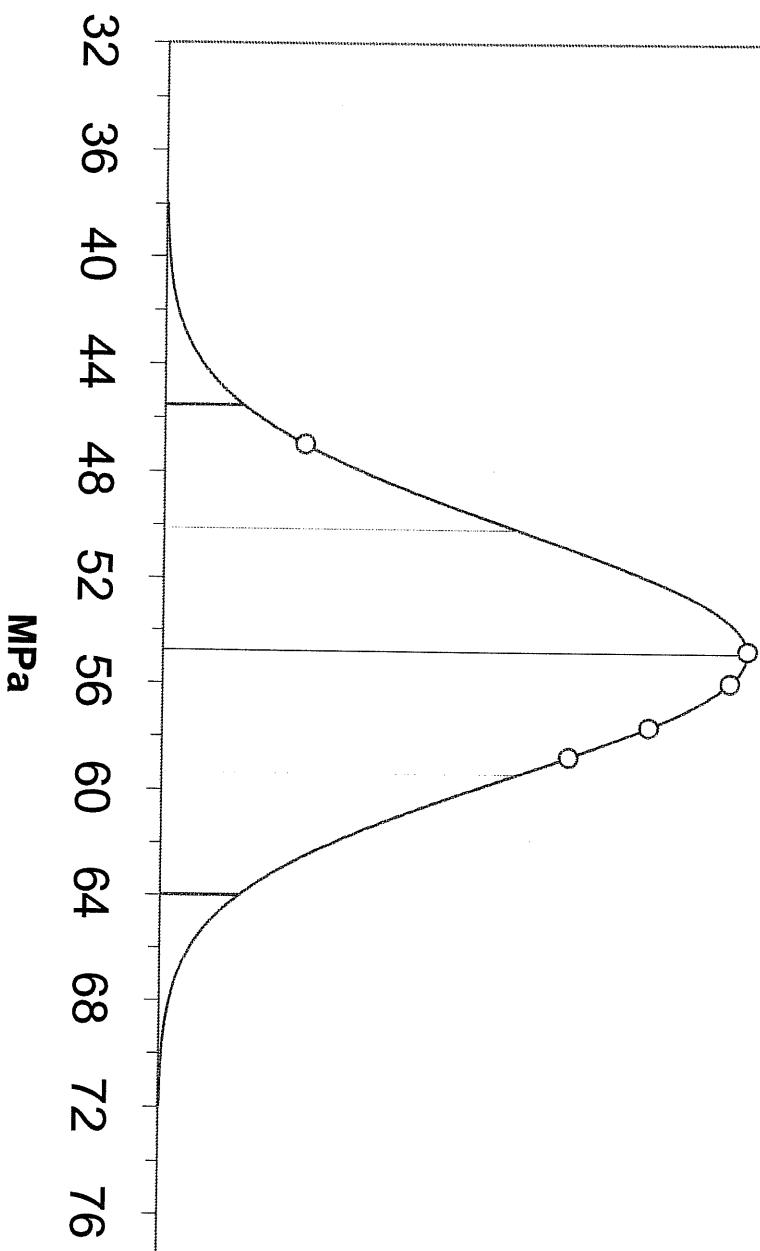
SLA_5170, irradiated



samples = 5.00
Average = 61.92
Minimum = 60.48
Maximum = 62.89
Std dev = 1.00

Stress at Failure

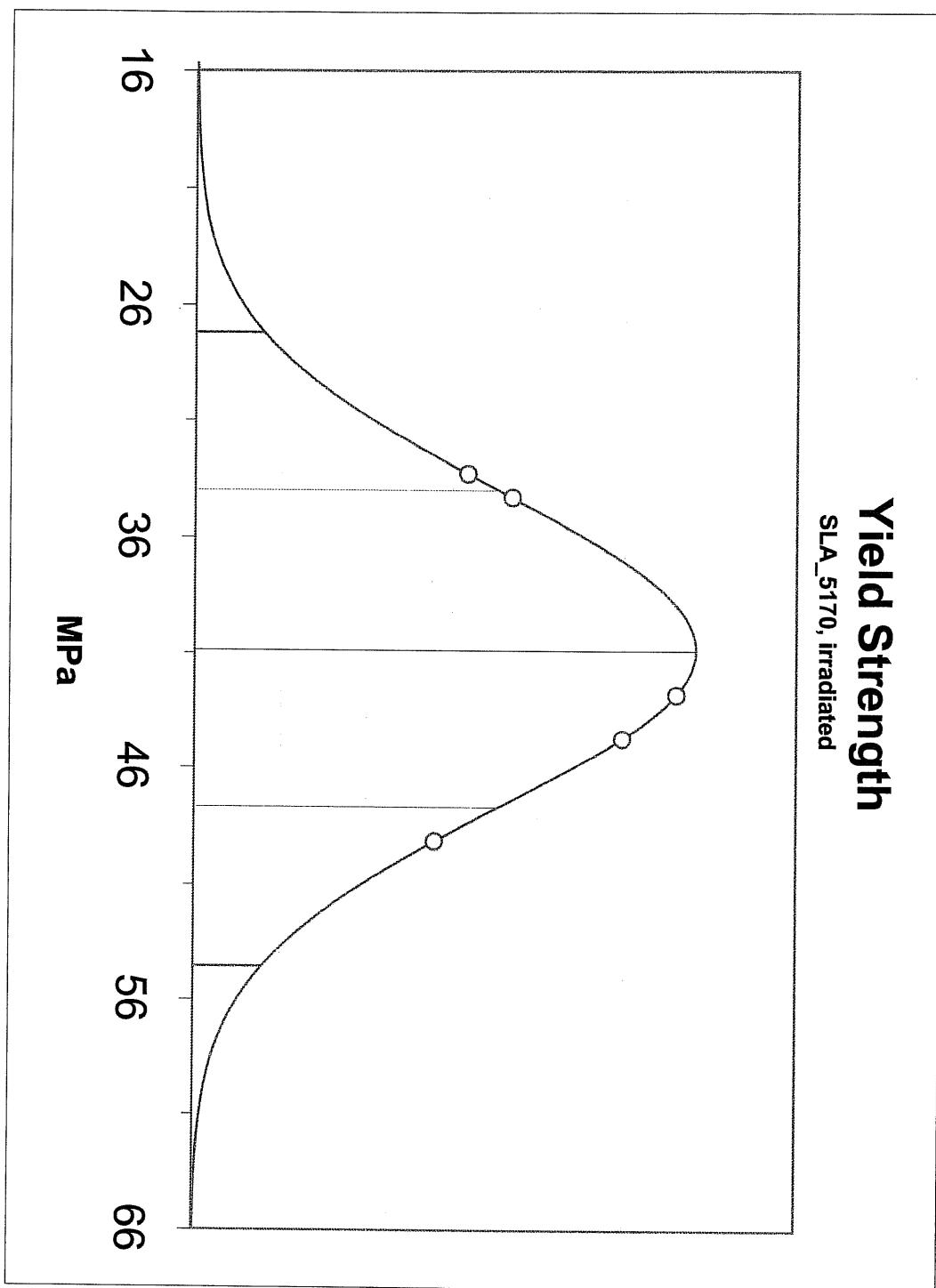
SLA_5170, irradiated



samples = 5.00
Average = 54.76
Minimum = 46.98
Maximum = 58.69
Std dev = 4.61

Yield Strength

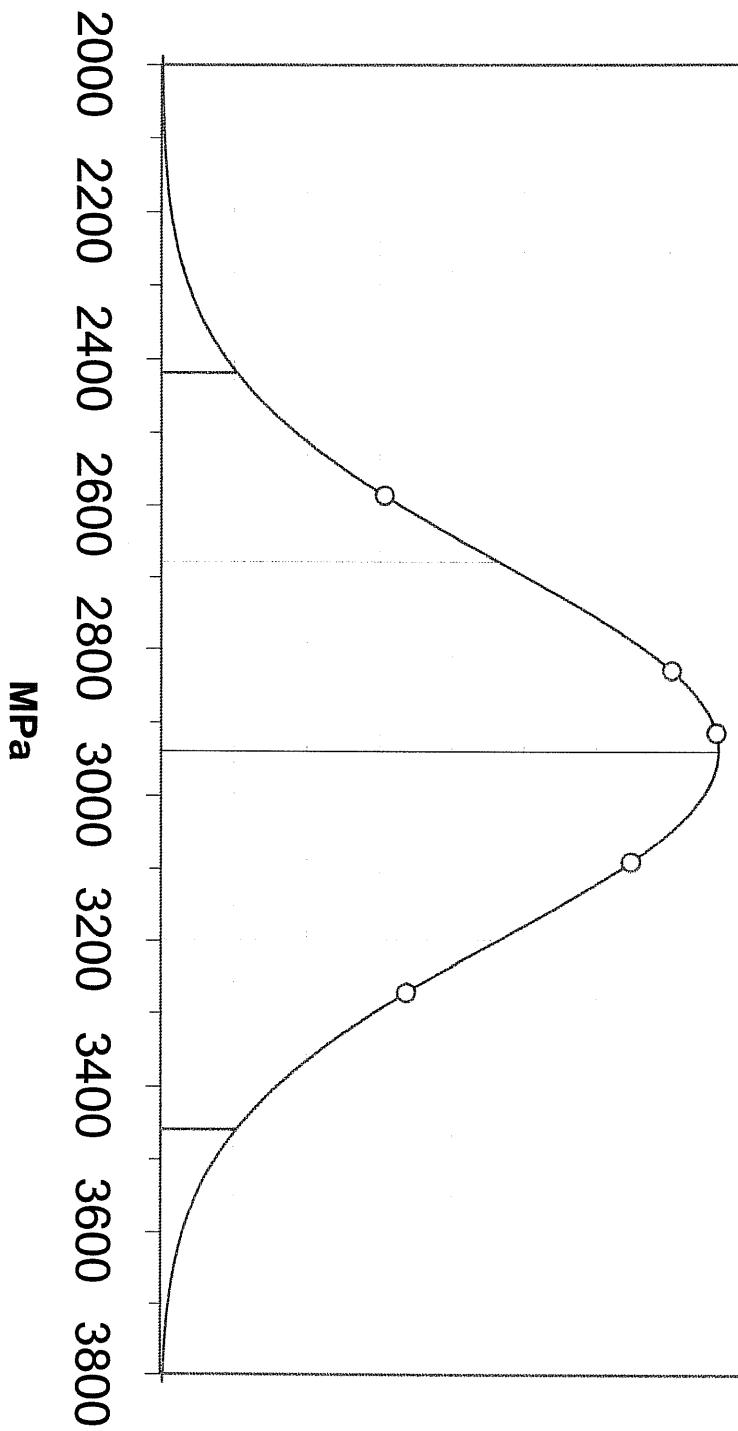
SLA_5170, irradiated



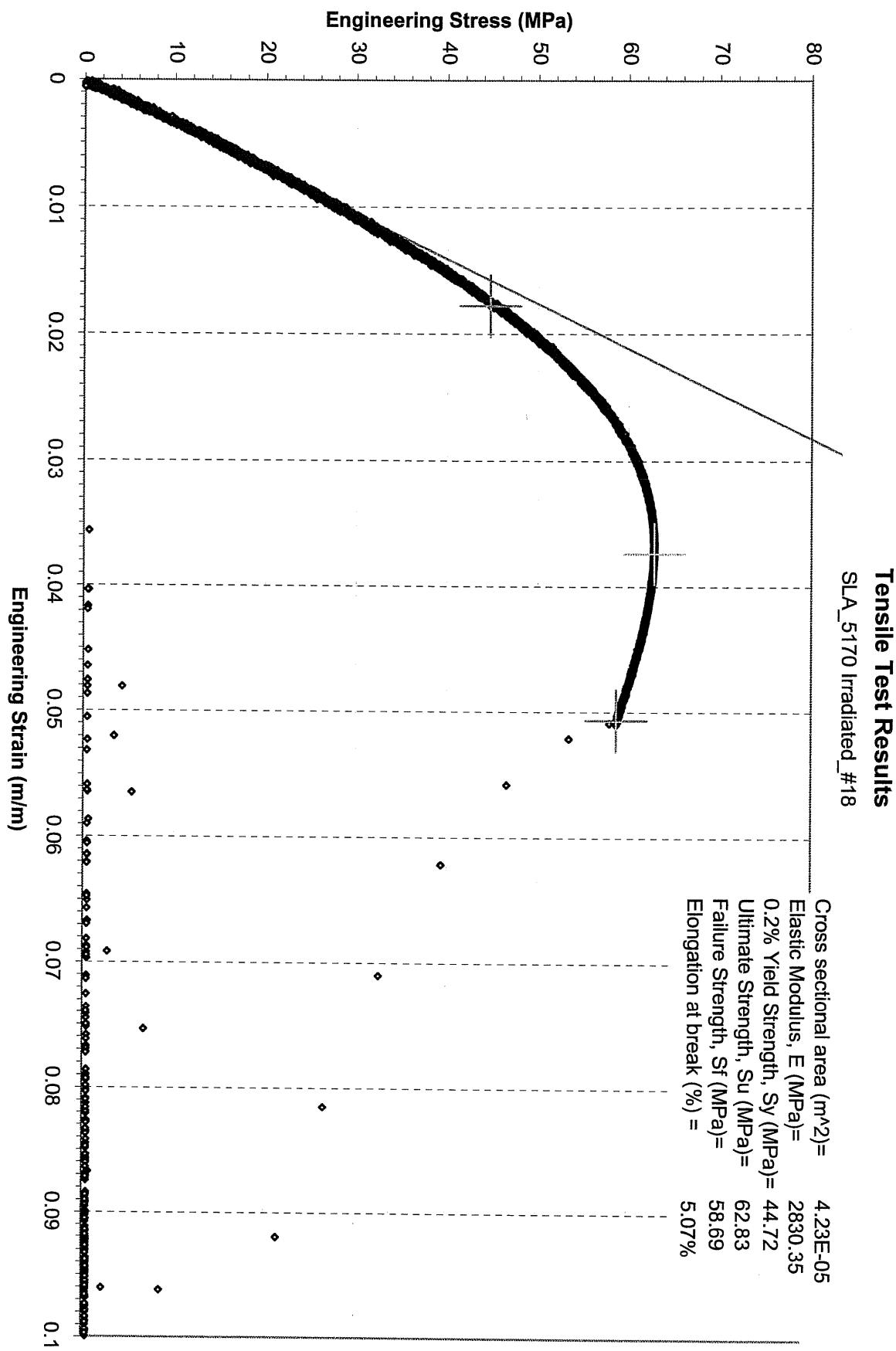
samples = 5.00
Average = 40.87
Minimum = 33.32
Maximum = 49.16
Std dev = 6.84

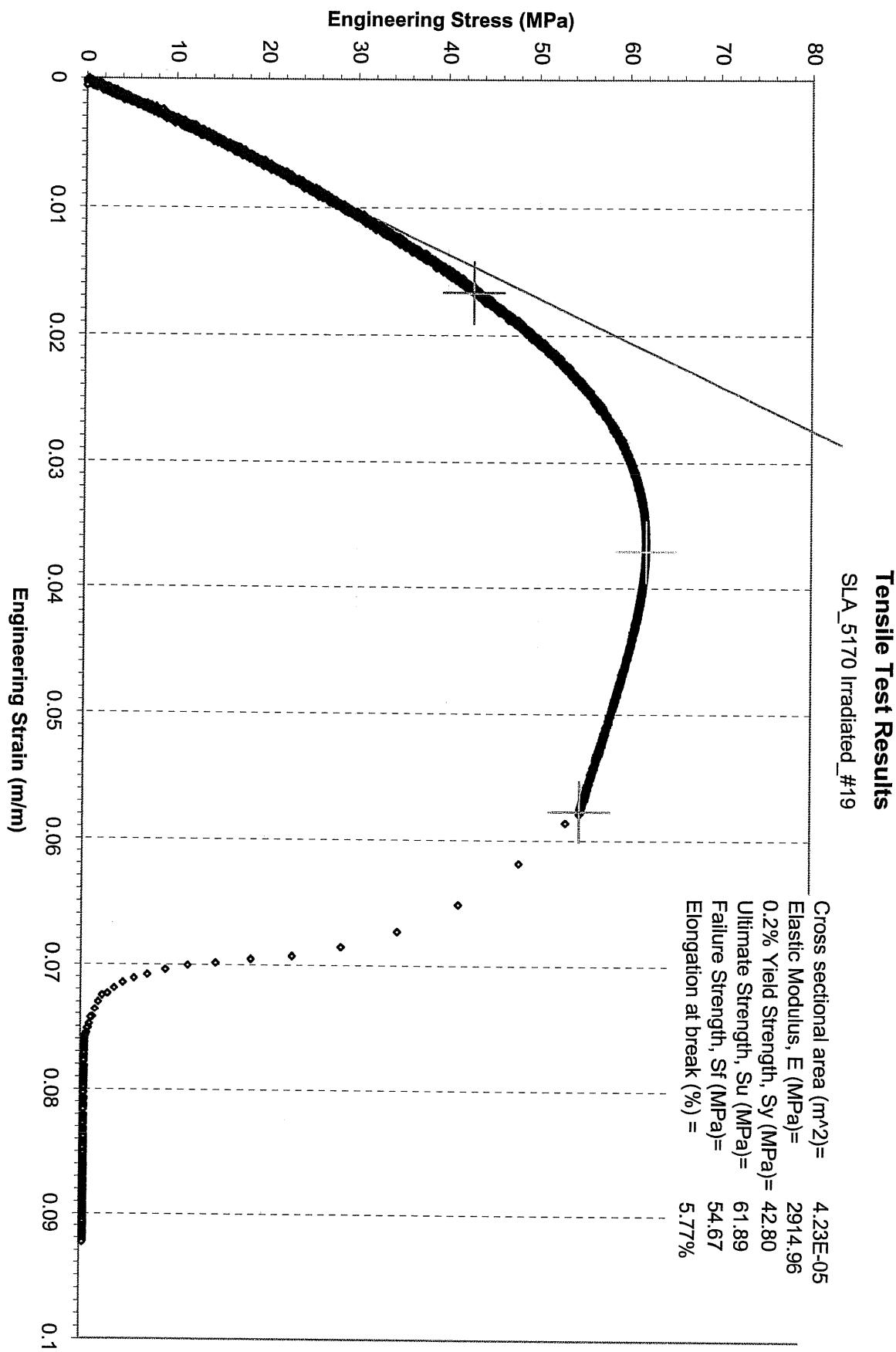
Elastic Modulus

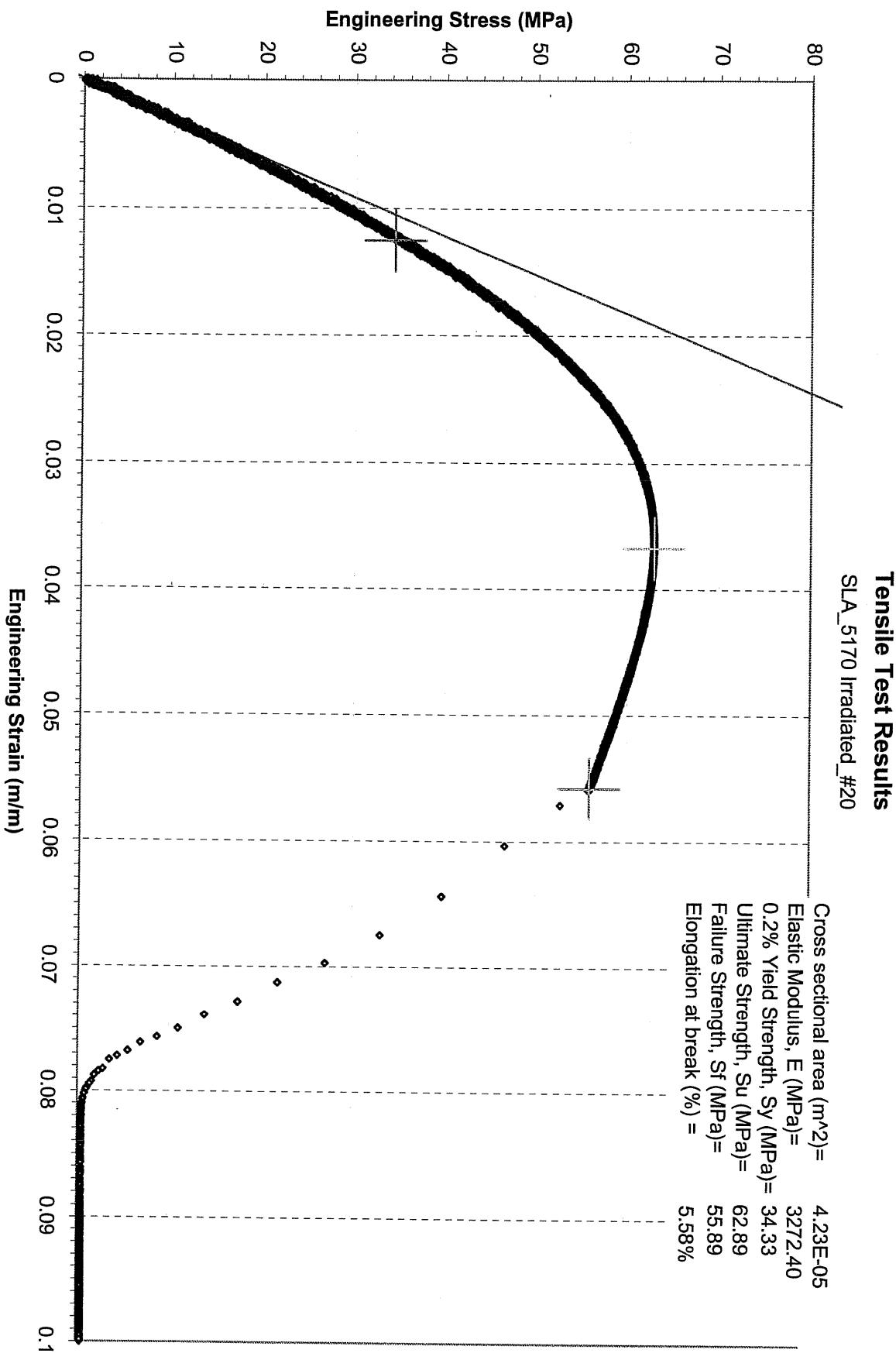
SLA_5170, irradiated

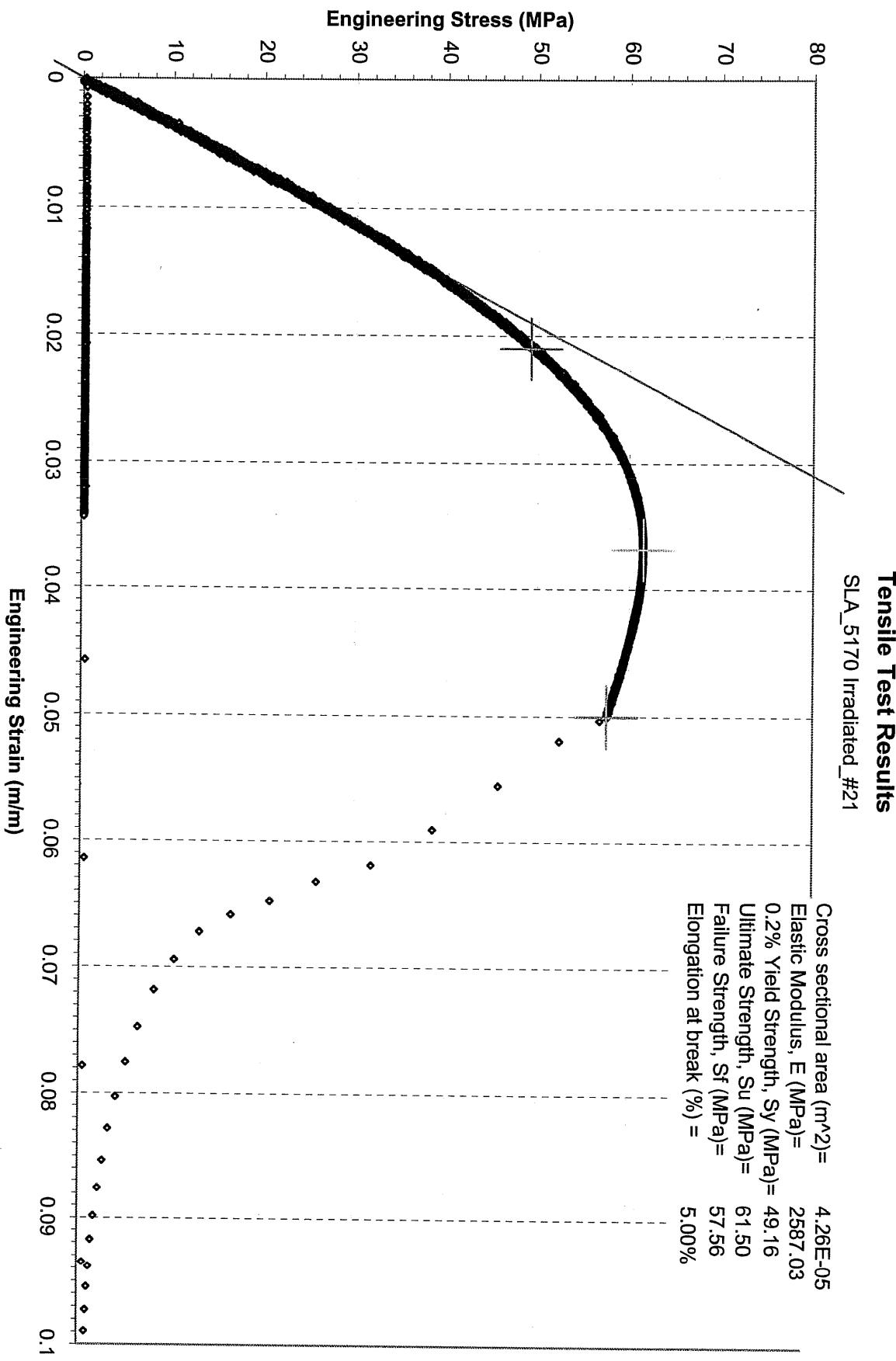


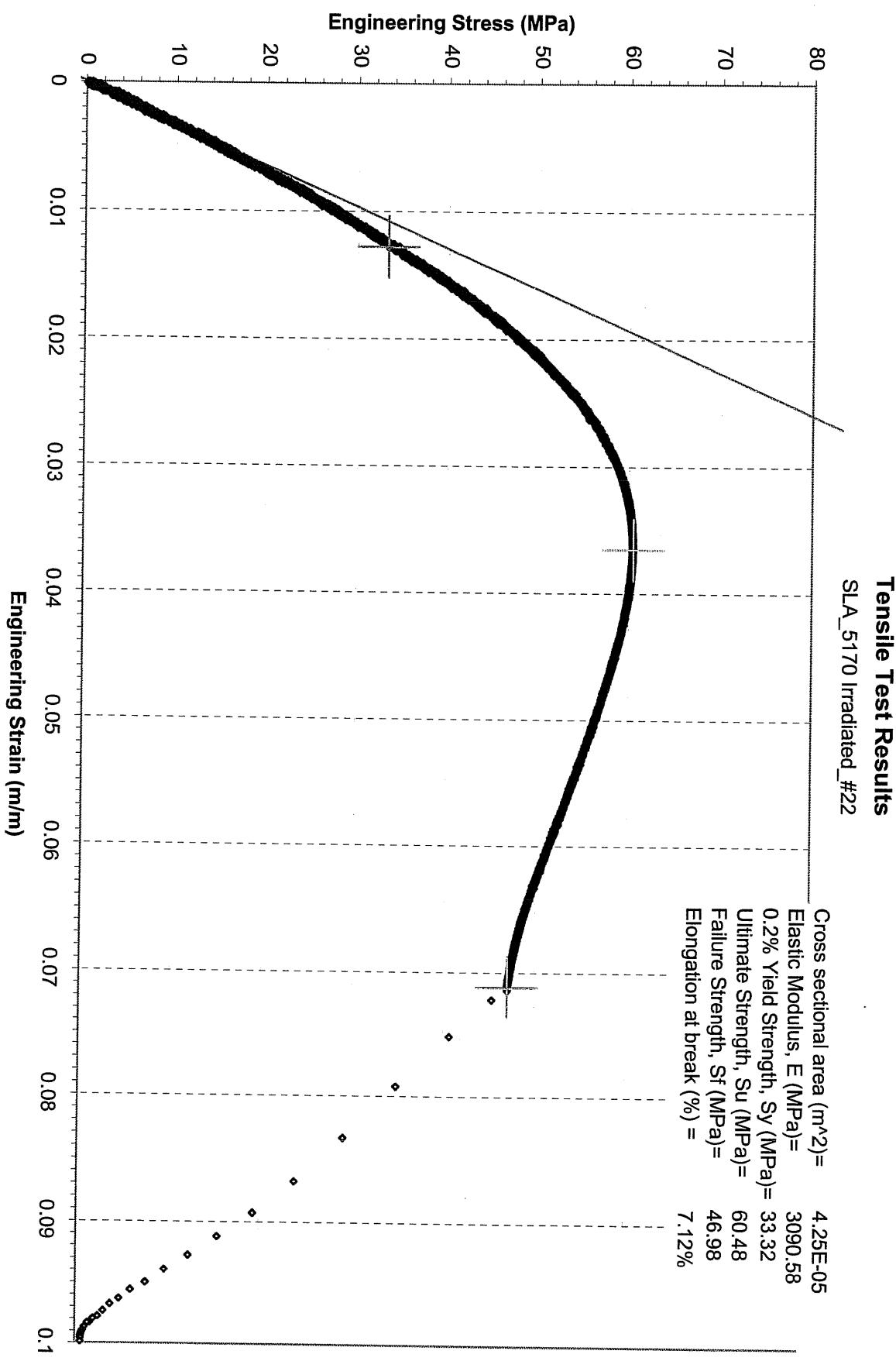
samples = 5.00
Average = 2939.06
Minimum = 2587.03
Maximum = 3272.40
Std dev = 260.00







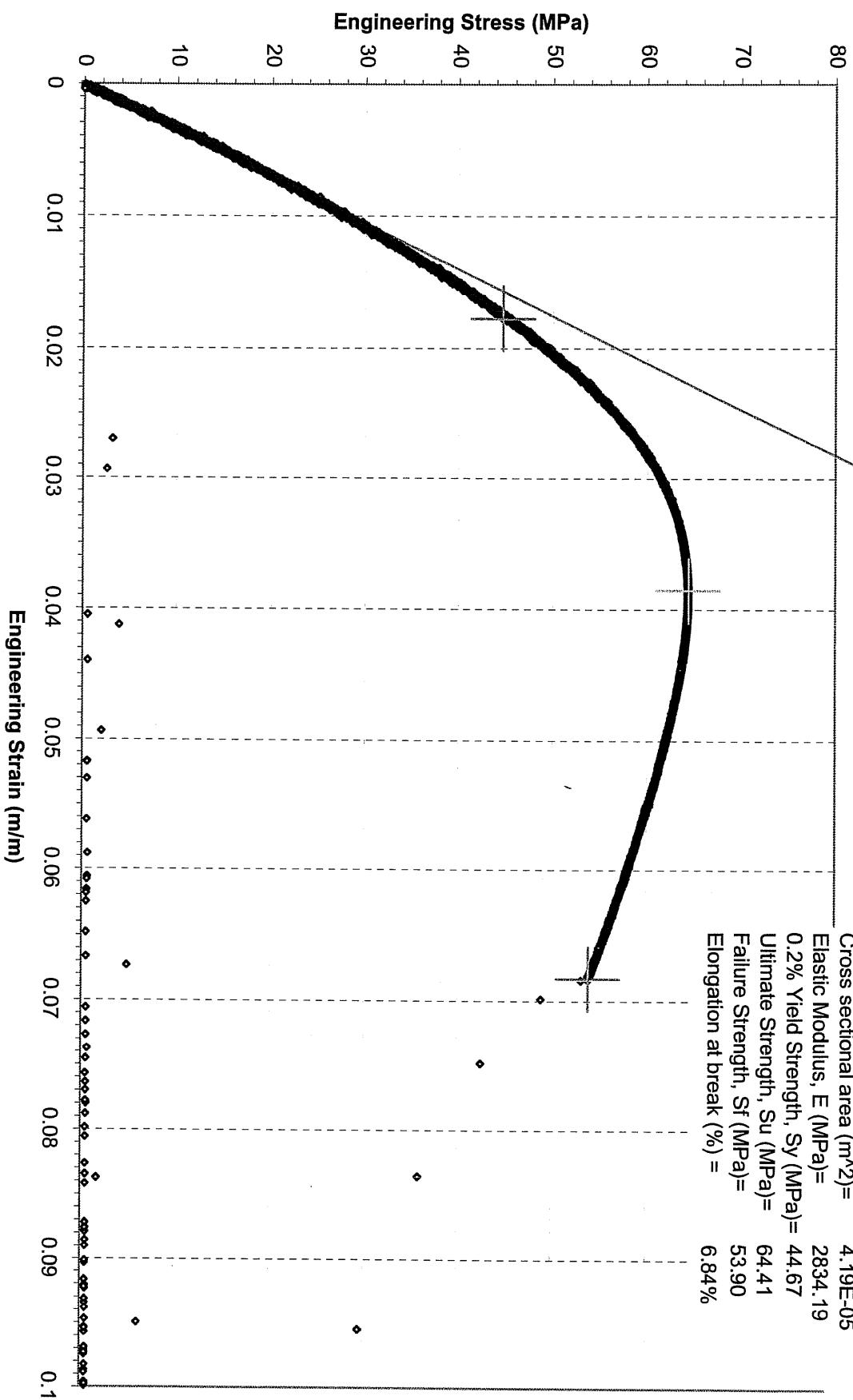




Tensile Test Results

SLA_5170_#2

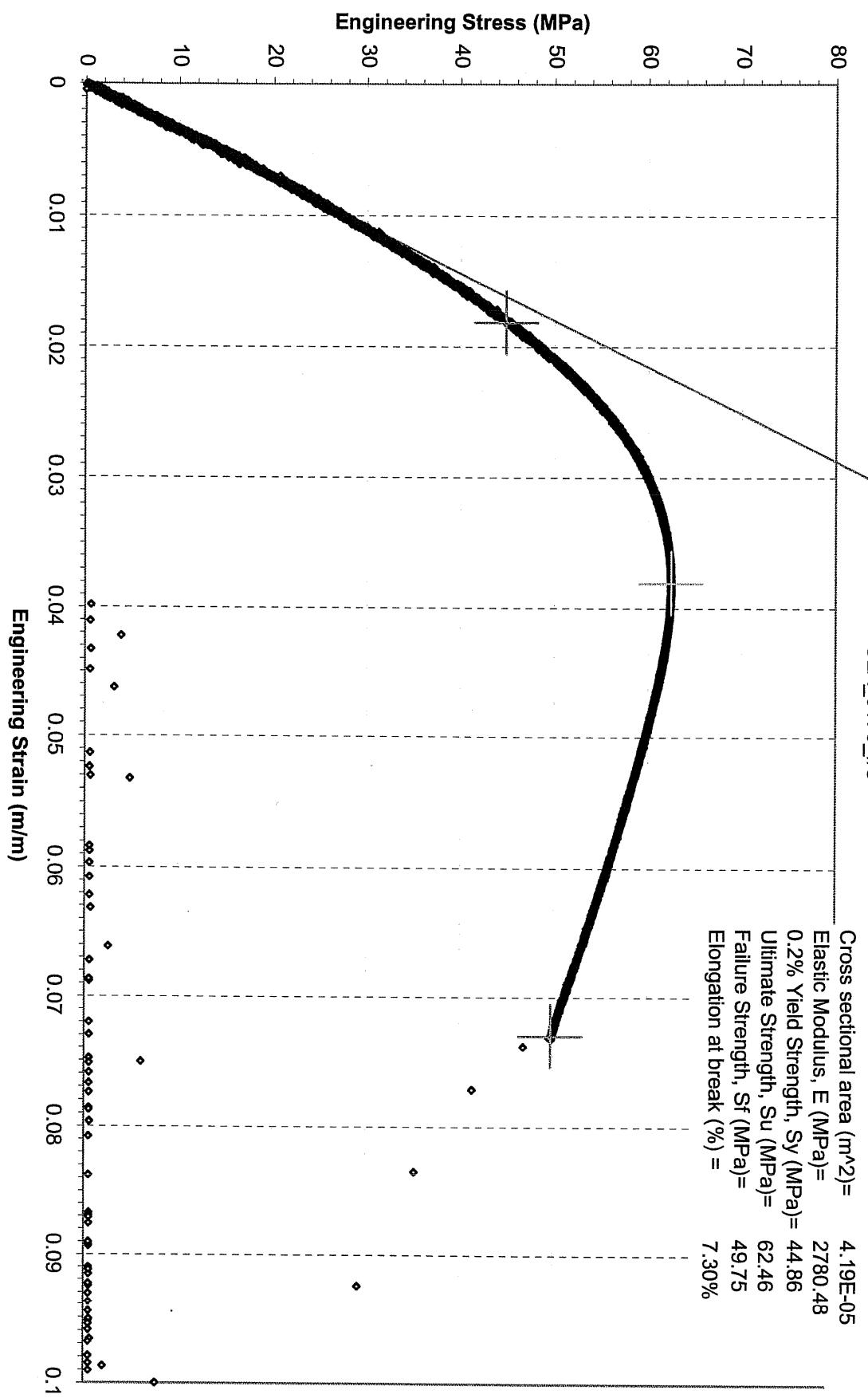
Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 2834.19
0.2% Yield Strength, S_y (MPa) = 44.67
Ultimate Strength, S_u (MPa) = 64.41
Failure Strength, S_f (MPa) = 53.90
Elongation at break (%) = 6.84%



Tensile Test Results

SLA_5170_#5

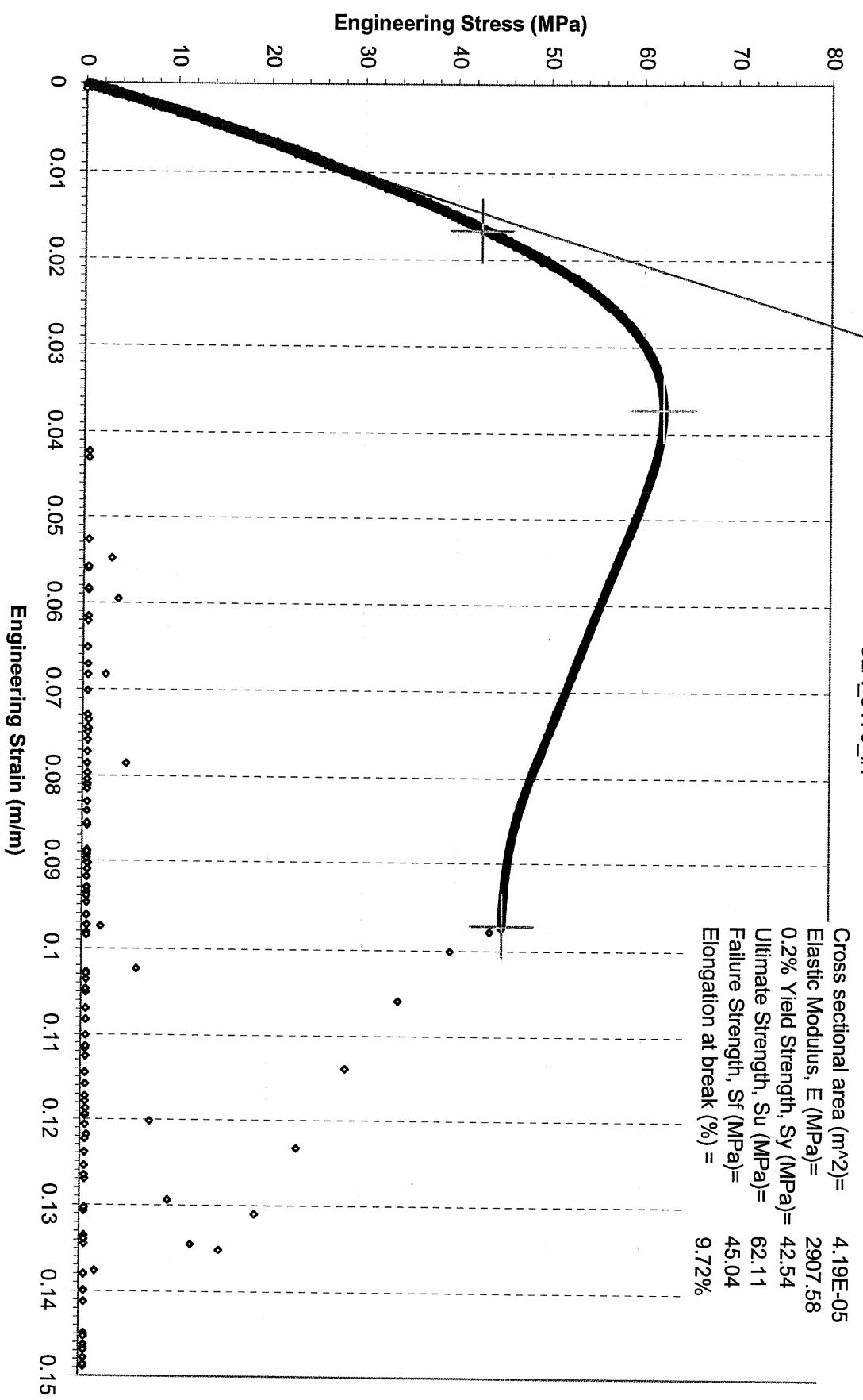
Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 2780.48
0.2% Yield Strength, S_y (MPa) = 44.86
Ultimate Strength, S_u (MPa) = 62.46
Failure Strength, S_f (MPa) = 49.75
Elongation at break (%) = 7.30%

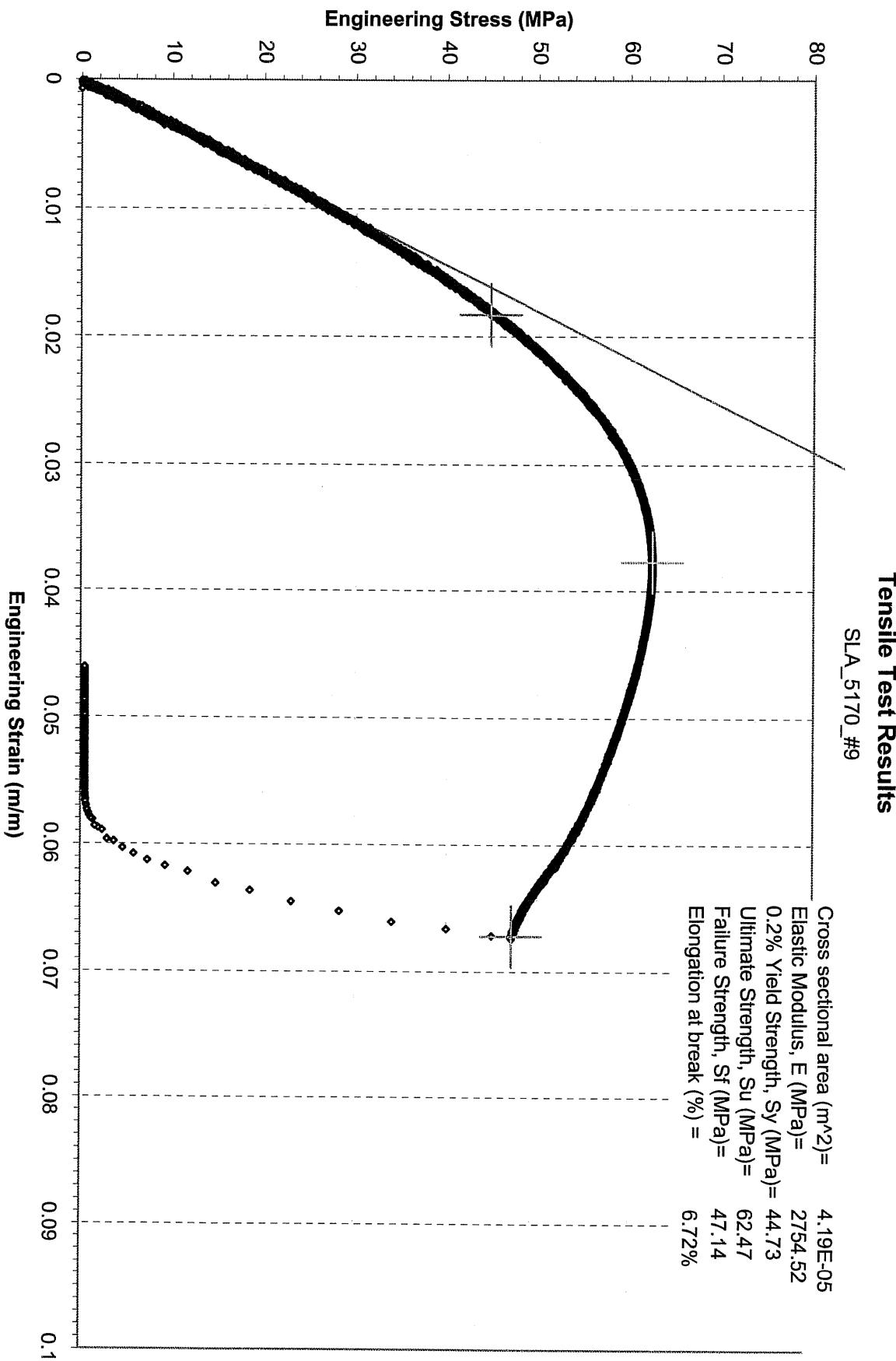


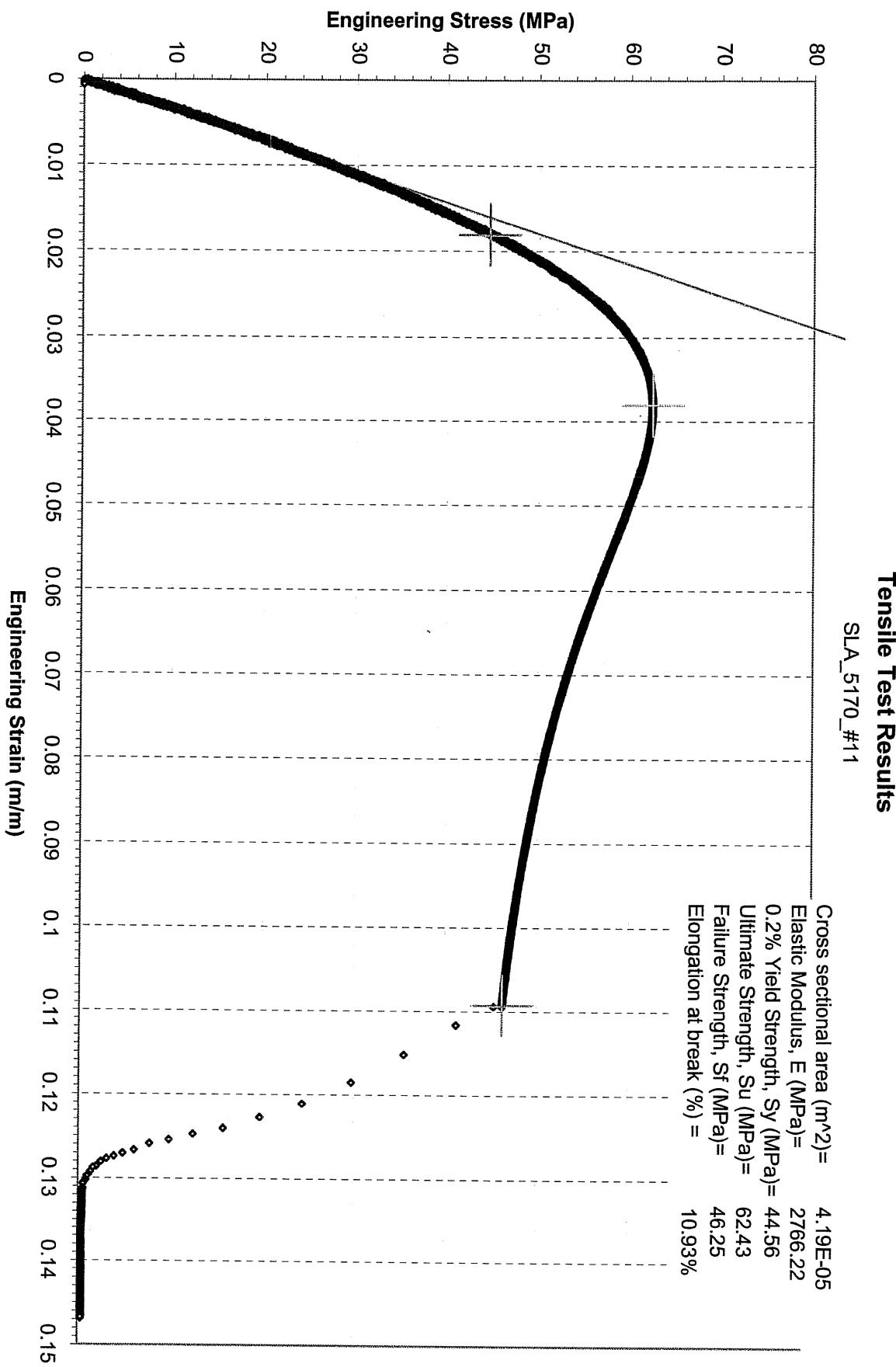
Tensile Test Results

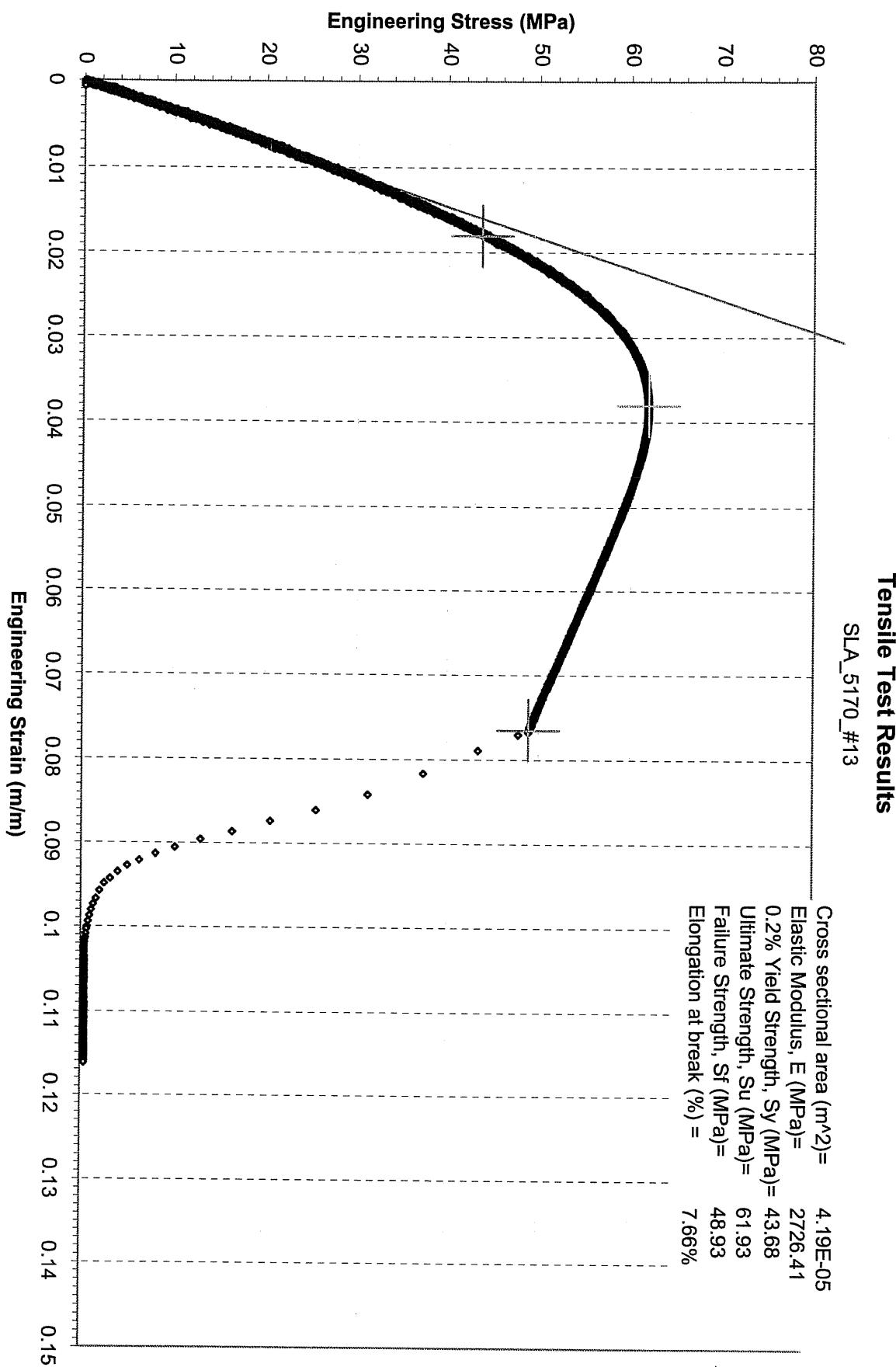
SLA_5170_#7

Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 2907.58
0.2% Yield Strength, S_y (MPa) = 42.54
Ultimate Strength, S_u (MPa) = 62.11
Failure Strength, S_f (MPa) = 45.04
Elongation at break (%) = 9.72%





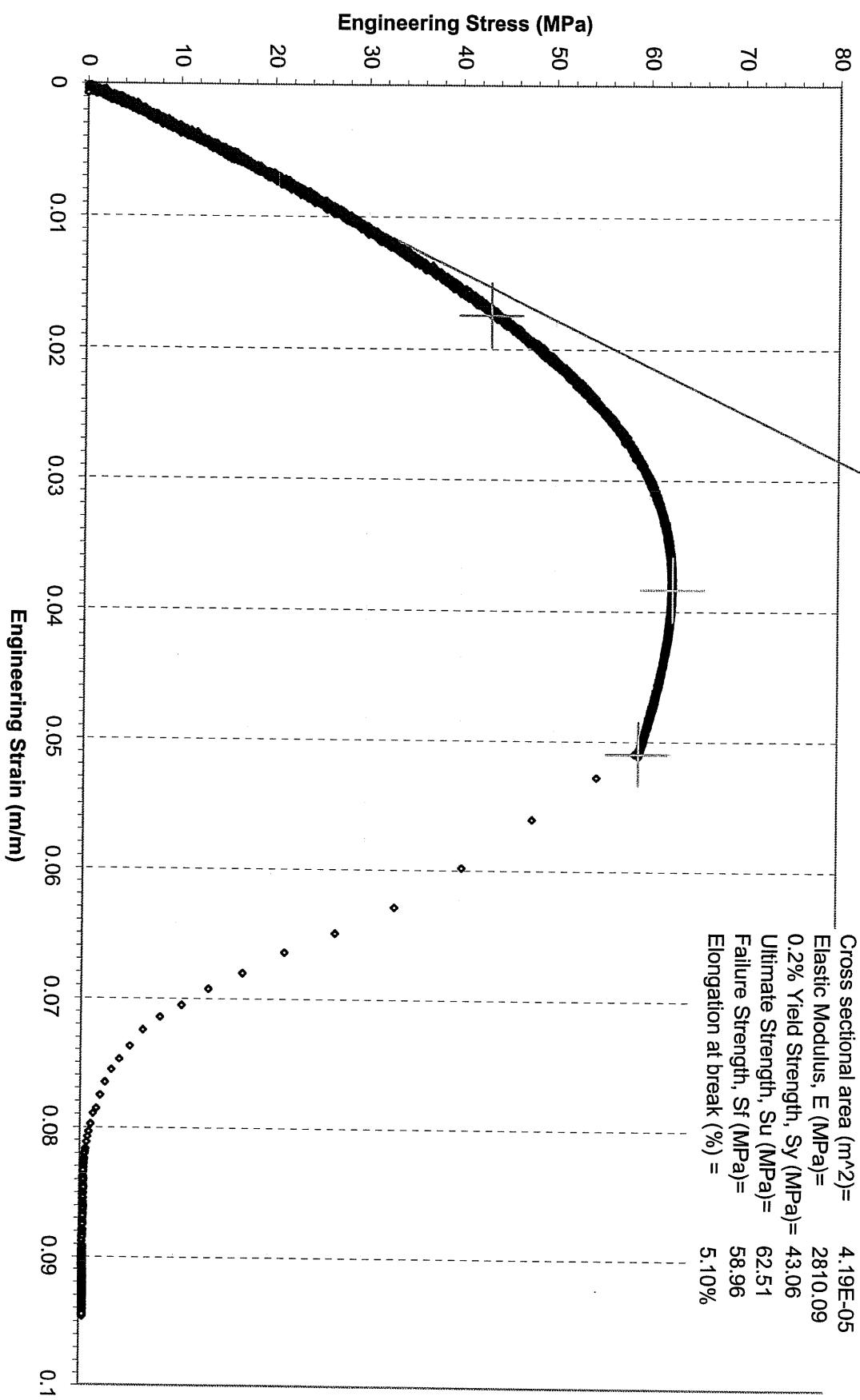




Tensile Test Results

SLA_5170_#15

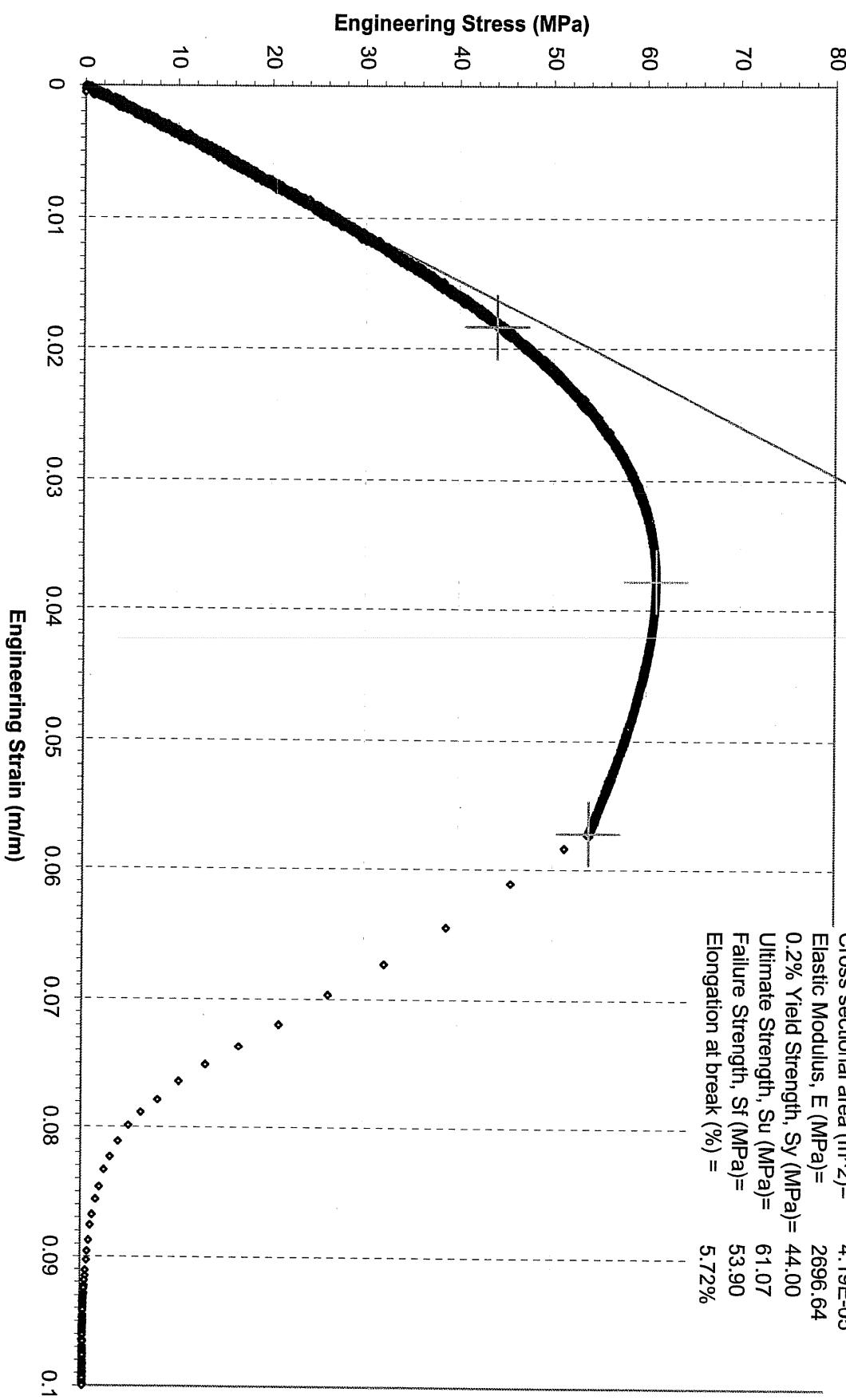
Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 2810.09
0.2% Yield Strength, S_y (MPa) = 43.06
Ultimate Strength, S_u (MPa) = 62.51
Failure Strength, S_f (MPa) = 58.96
Elongation at break (%) = 5.10%



Tensile Test Results

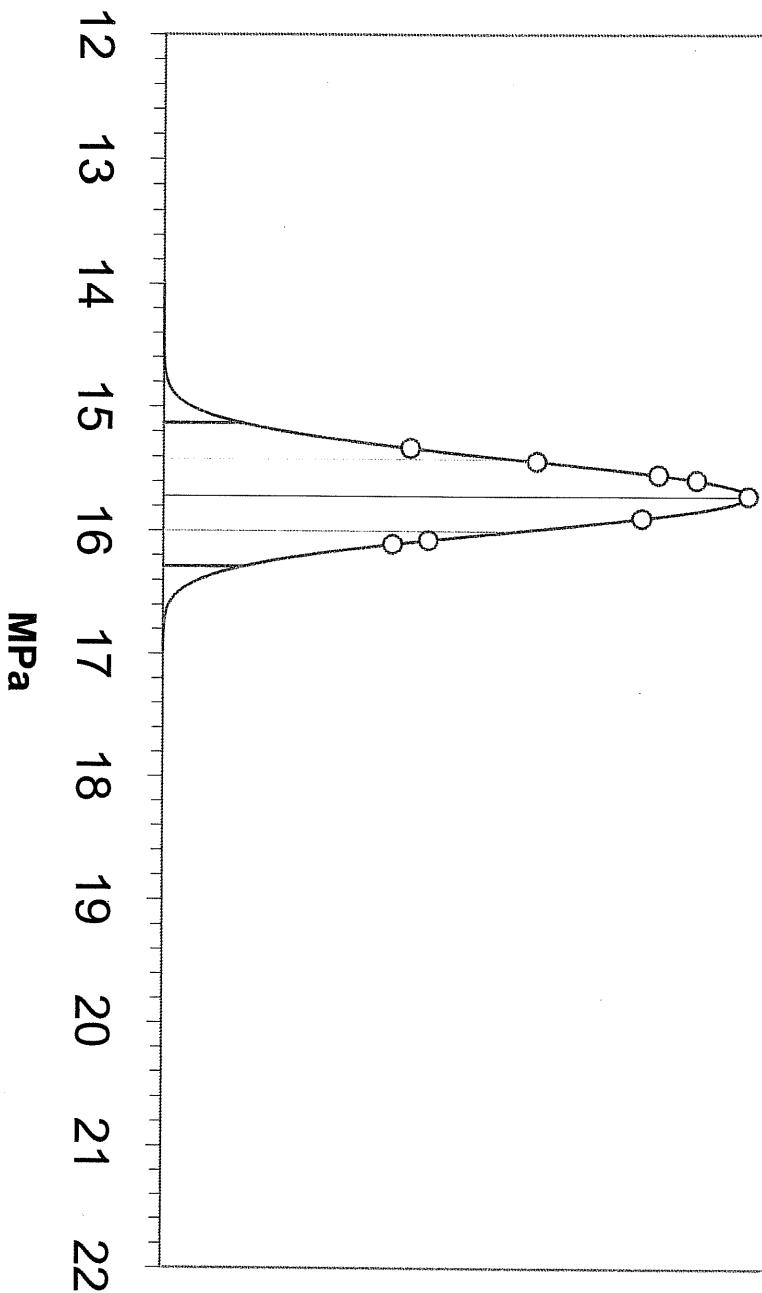
SLA_5170_#17

Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 2696.64
0.2% Yield Strength, S_y (MPa) = 44.00
Ultimate Strength, S_u (MPa) = 61.07
Failure Strength, S_f (MPa) = 53.90
Elongation at break (%) = 5.72%



Ultimate Strength

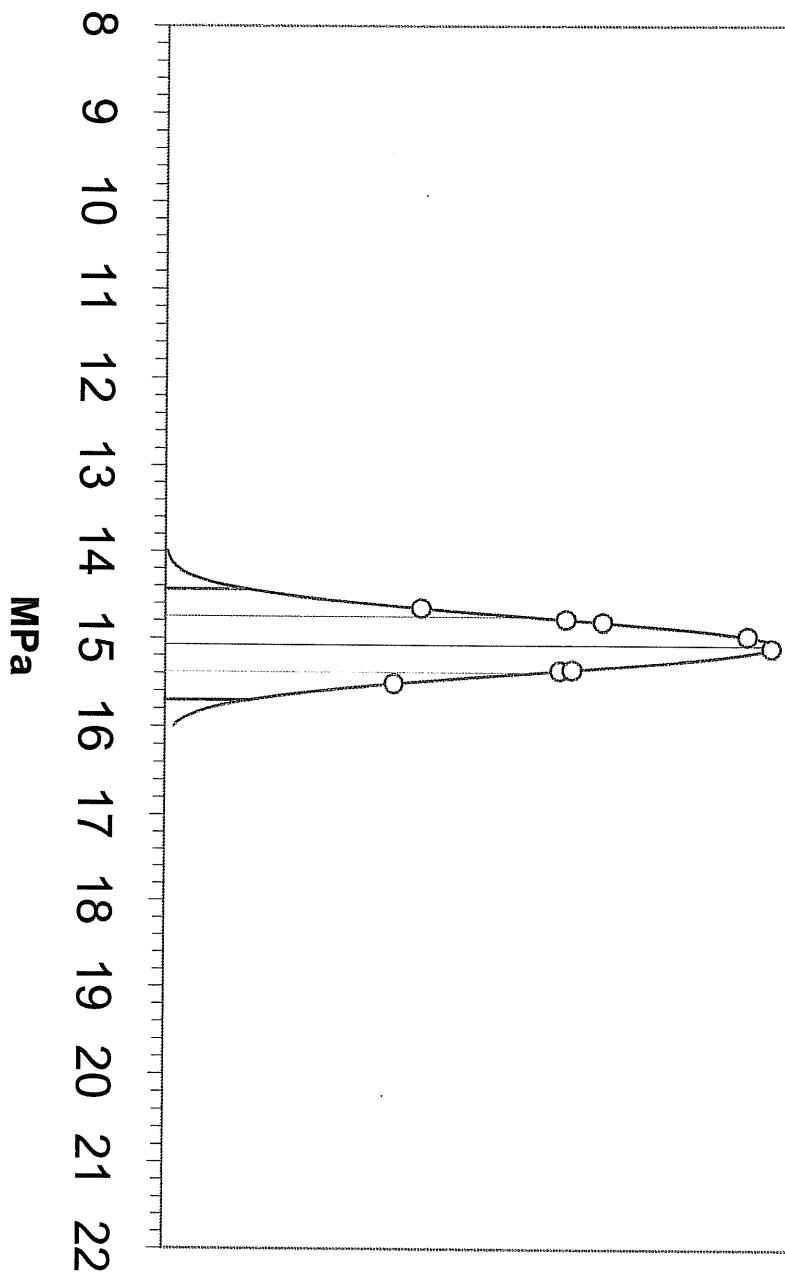
FDM ABS, not irradiated



samples = 8.00
Average = 15.72
Minimum = 15.34
Maximum = 16.11
Std dev = 0.29

Stress at Failure

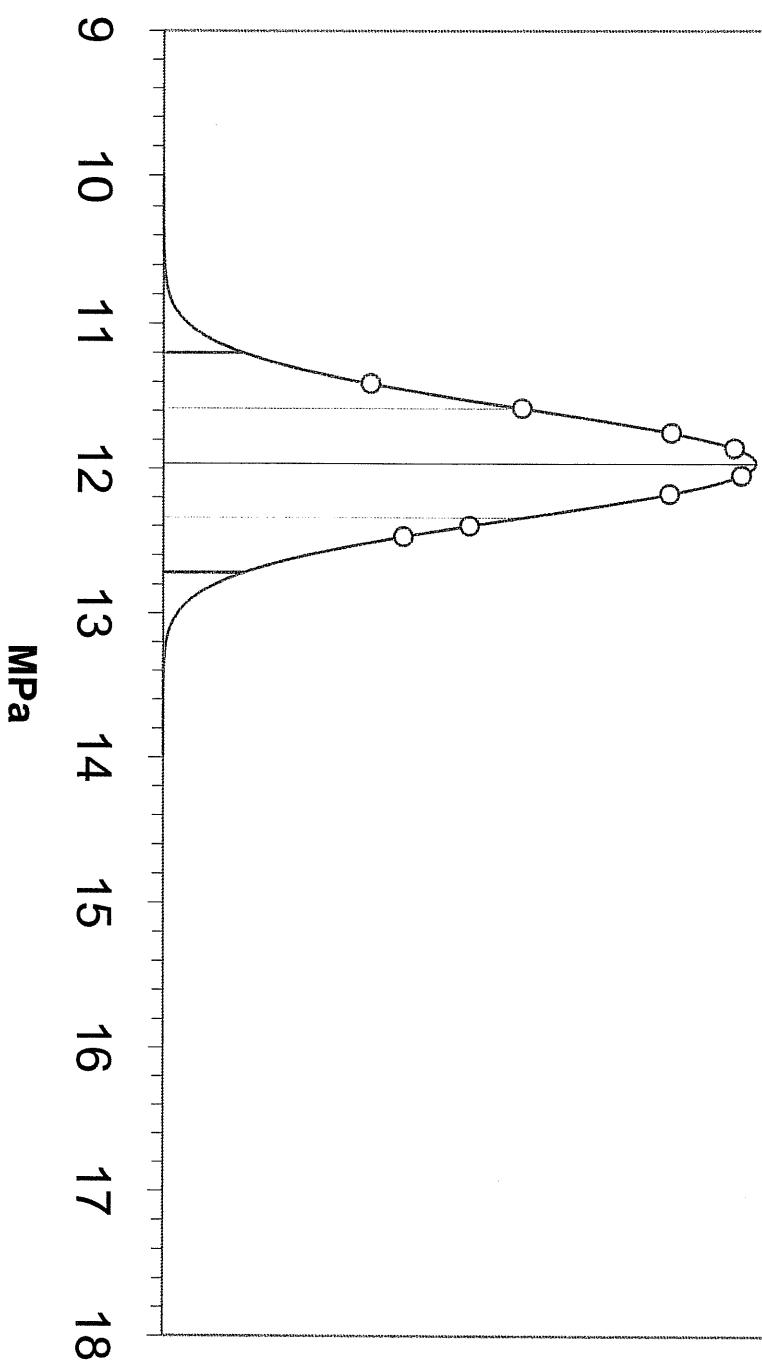
FDM ABS, not irradiated



samples = 8.00
Average = 15.08
Minimum = 14.66
Maximum = 15.52
Std dev = 0.32

Yield Strength

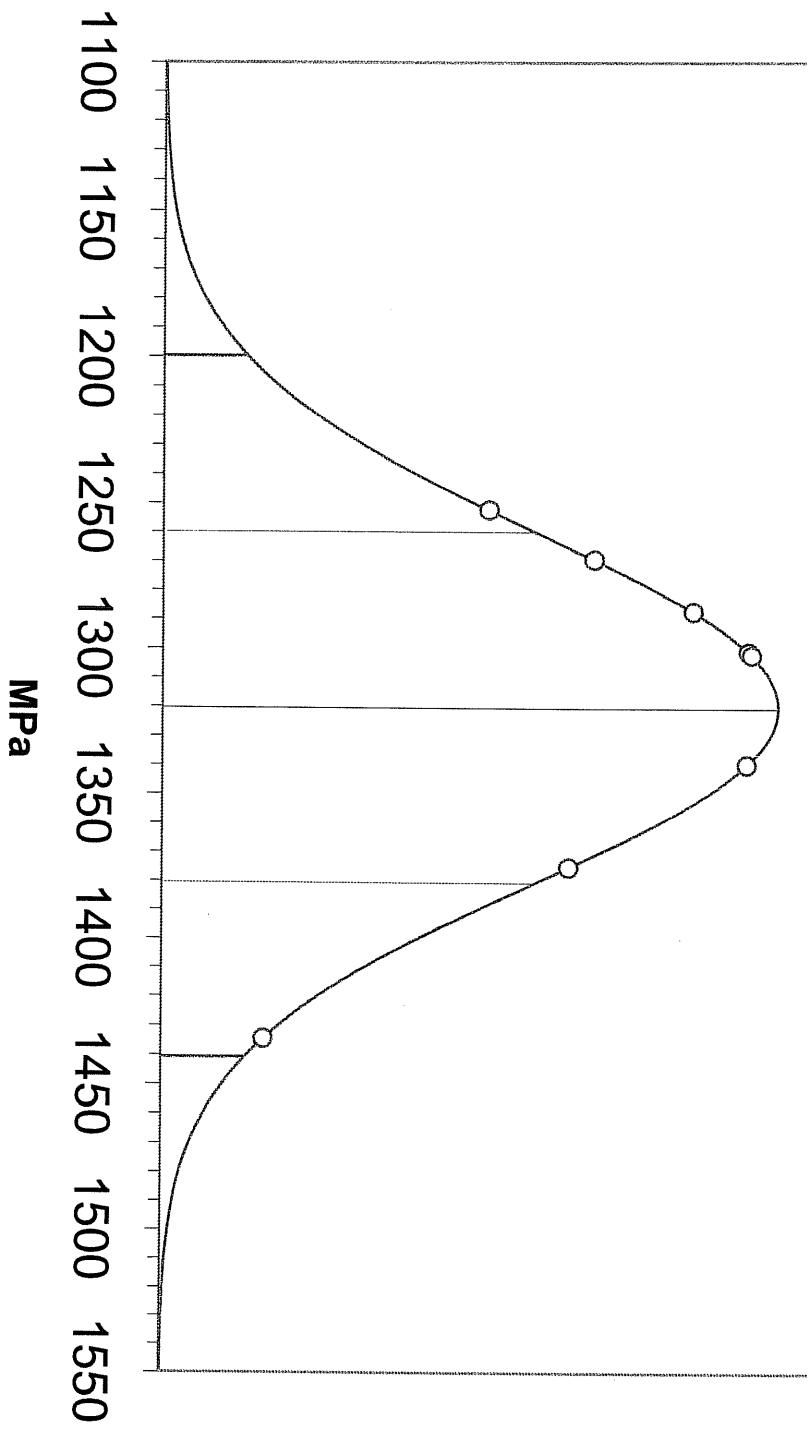
FDM ABS, not irradiated



samples = 8.00
Average = 11.96
Minimum = 11.41
Maximum = 12.47
Std dev = 0.38

Elastic Modulus

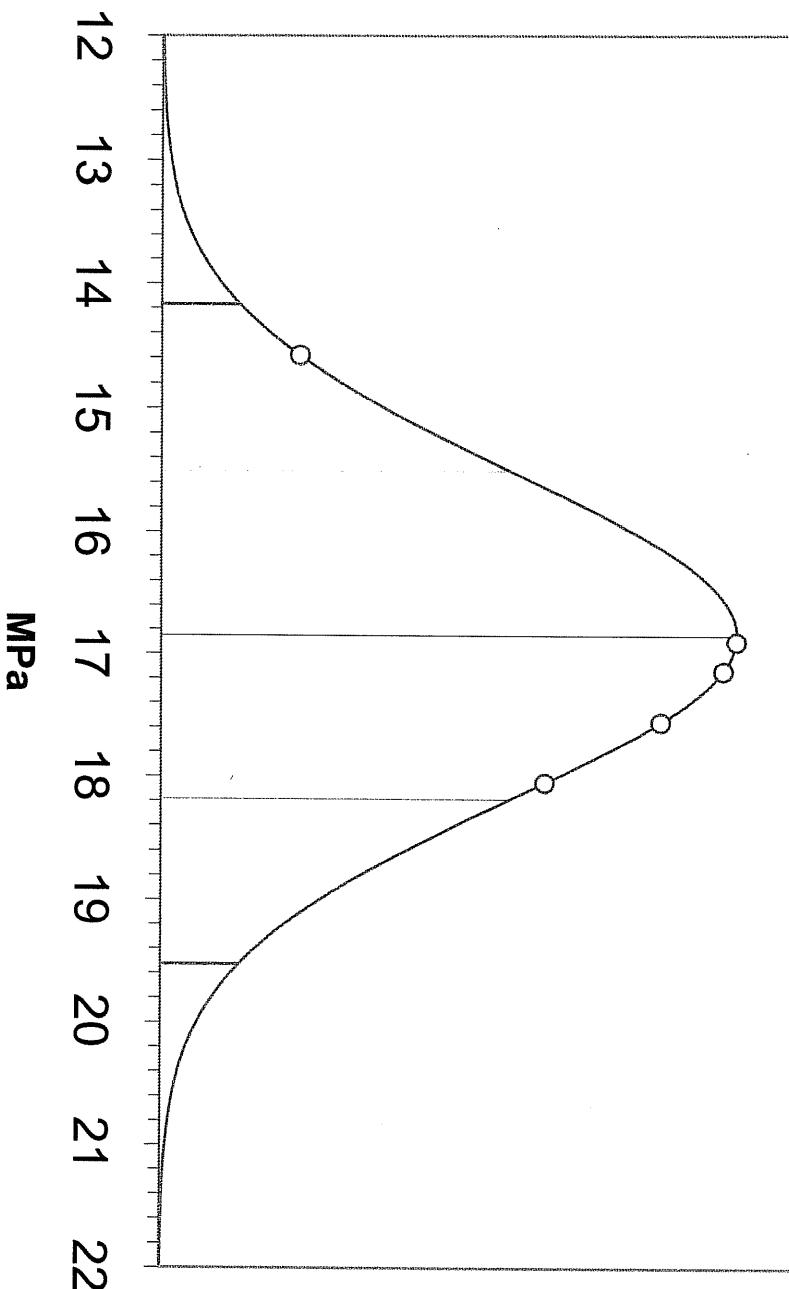
FDM ABS, not irradiated



samples = 8.00
Average = 1320.37
Minimum = 1252.49
Maximum = 1434.71
Std dev = 60.26

Ultimate Strength

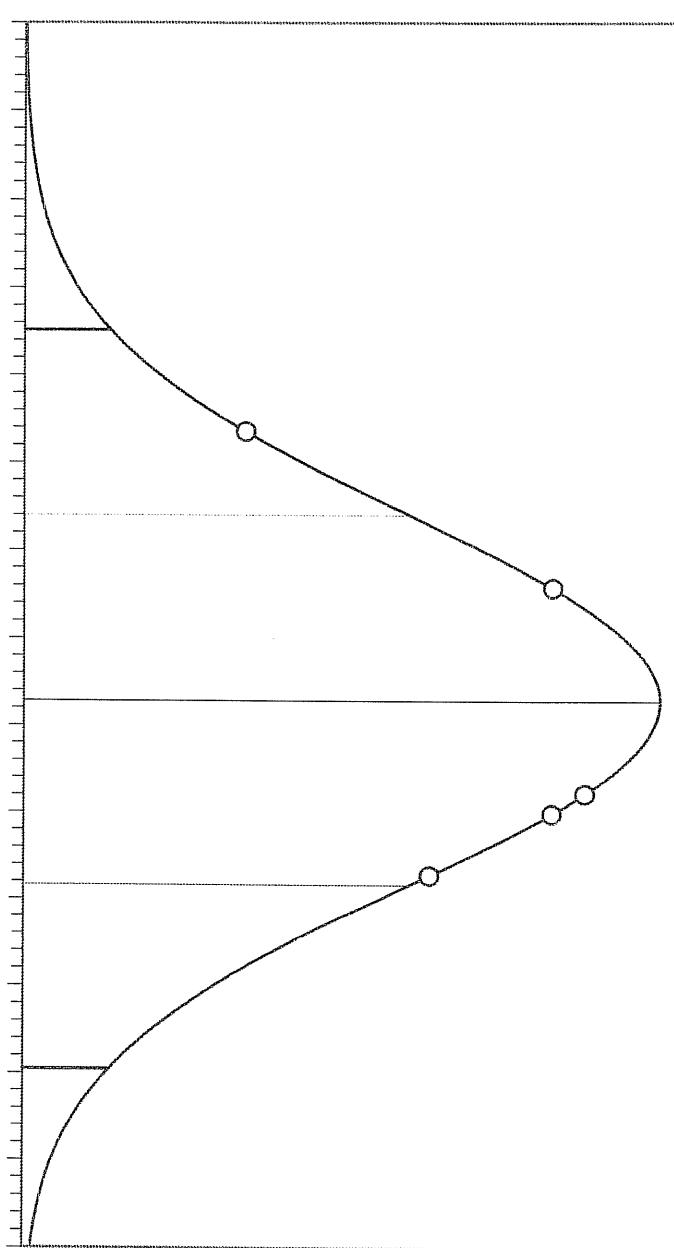
FDM ABS, irradiated



samples = 5.00
Average = 16.85
Minimum = 14.59
Maximum = 18.05
Std dev = 1.34

Stress at Failure

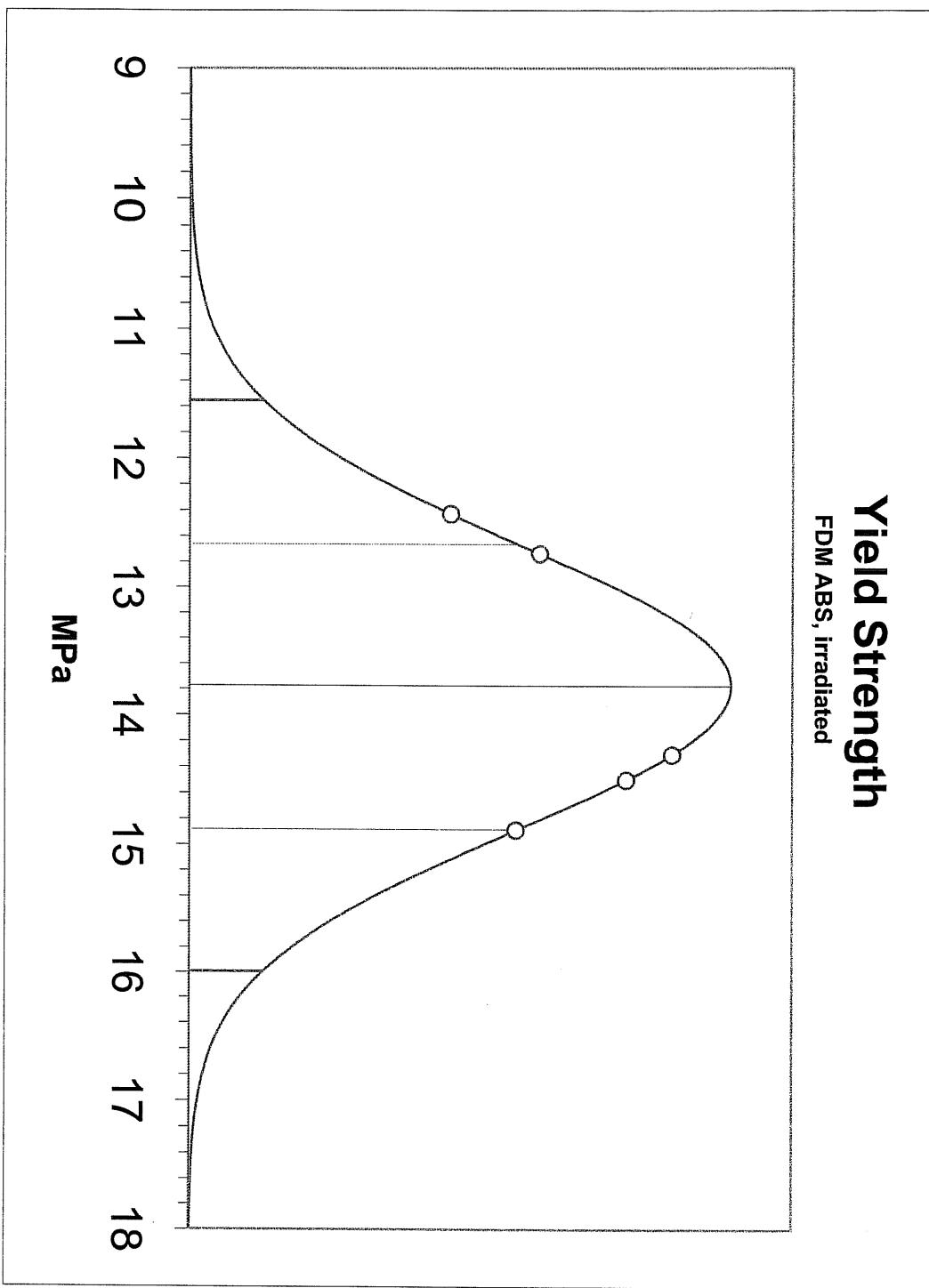
FDM ABS, irradiated



samples = 5.00
Average = 15.72
Minimum = 12.65
Maximum = 17.73
Std dev = 2.12

Yield Strength

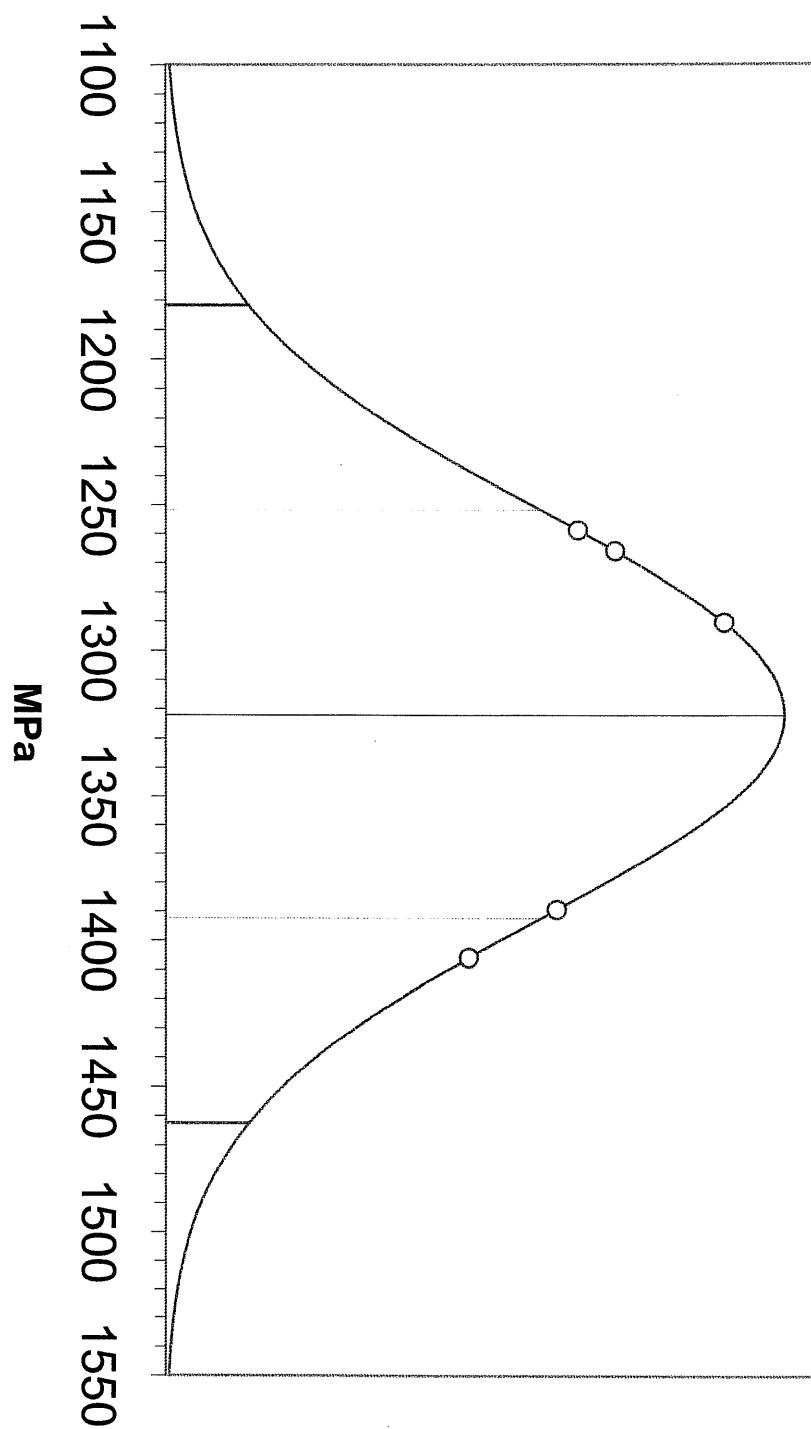
FDM ABS, irradiated



samples = 5.00
Average = 13.77
Minimum = 12.43
Maximum = 14.89
Std dev = 1.11

Elastic Modulus

FDM ABS, irradiated

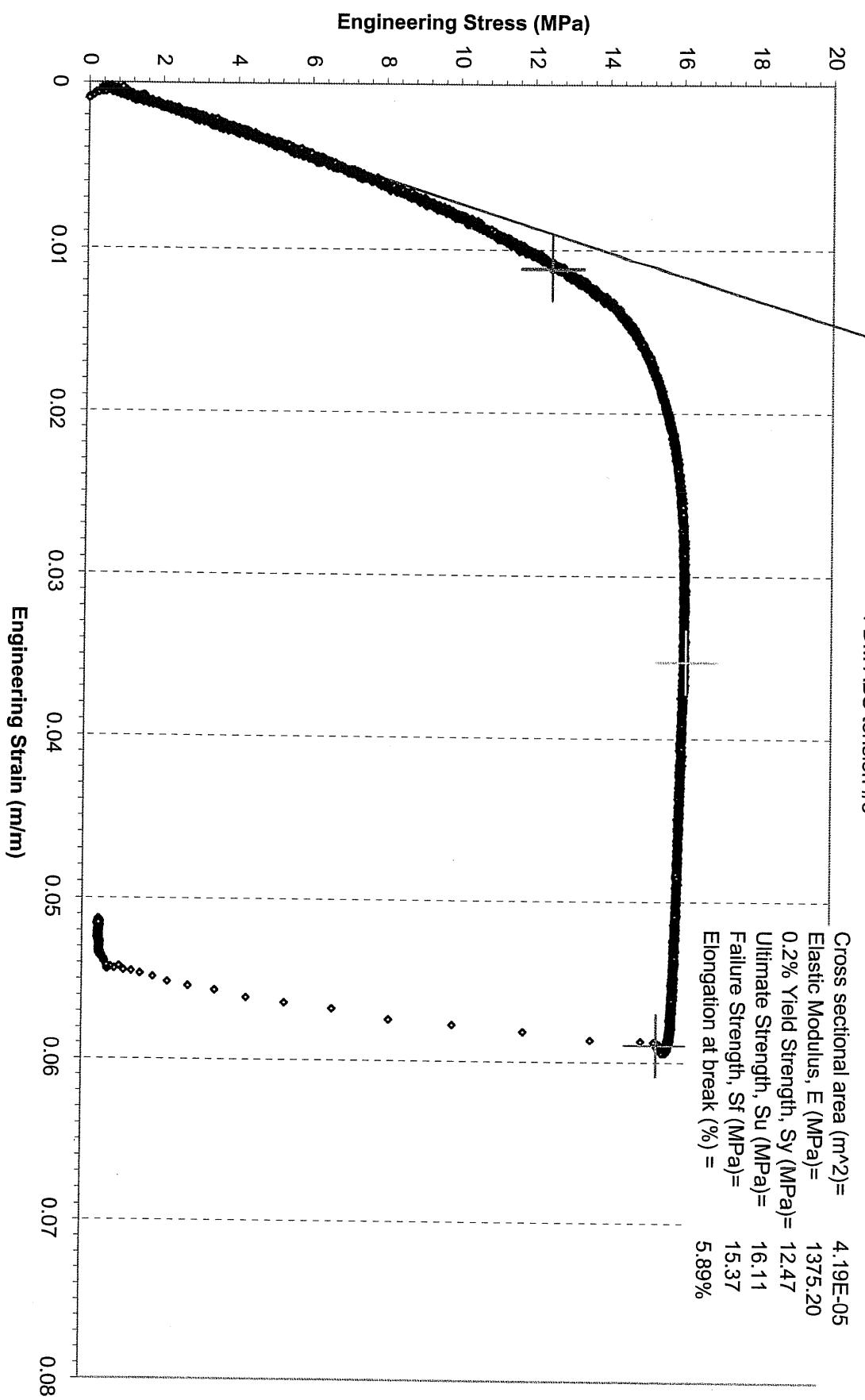


samples = 5.00
Average = 1322.10
Minimum = 1258.82
Maximum = 1405.95
Std dev = 70.19

Tensile Test Results

FDM ABS tension #3

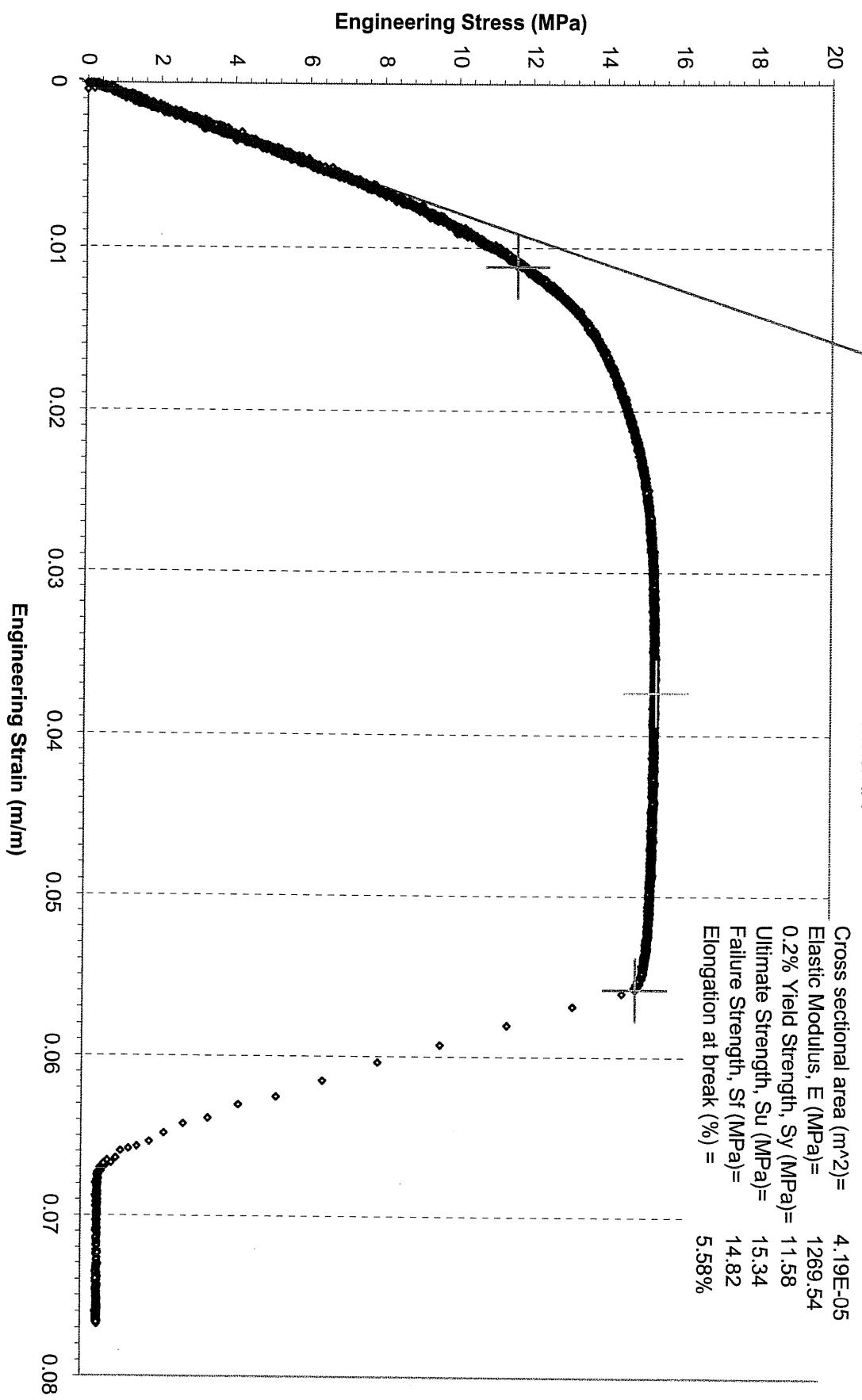
Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 1375.20
0.2% Yield Strength, S_y (MPa) = 12.47
Ultimate Strength, S_u (MPa) = 16.11
Failure Strength, S_f (MPa) = 15.37
Elongation at break (%) = 5.89%



Tensile Test Results

FDM ABS tension #4

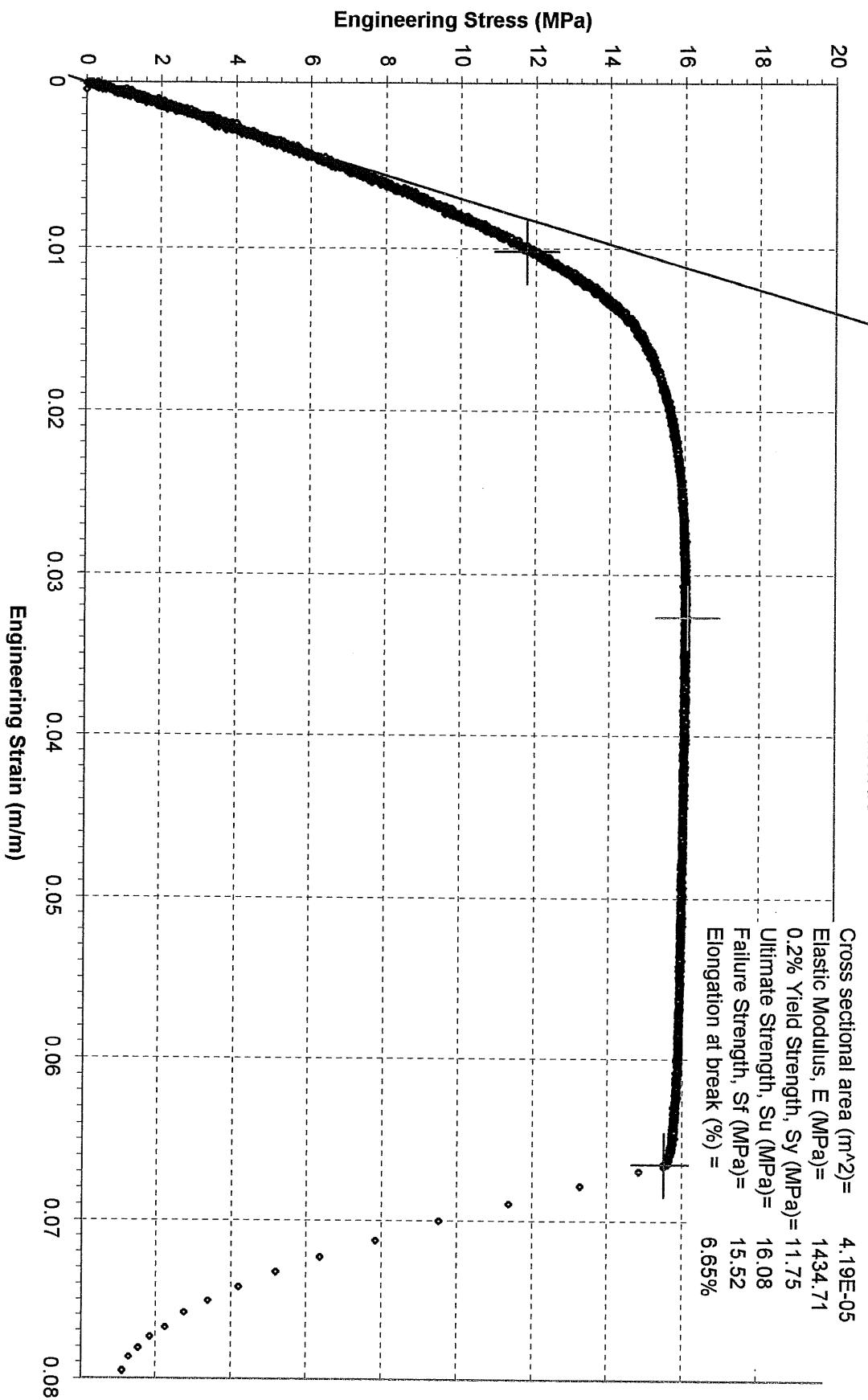
Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 1269.54
0.2% Yield Strength, S_y (MPa) = 11.58
Ultimate Strength, S_u (MPa) = 15.34
Failure Strength, S_f (MPa) = 14.82
Elongation at break (%) = 5.58%



Tensile Test Results

FDM ABS tension #6

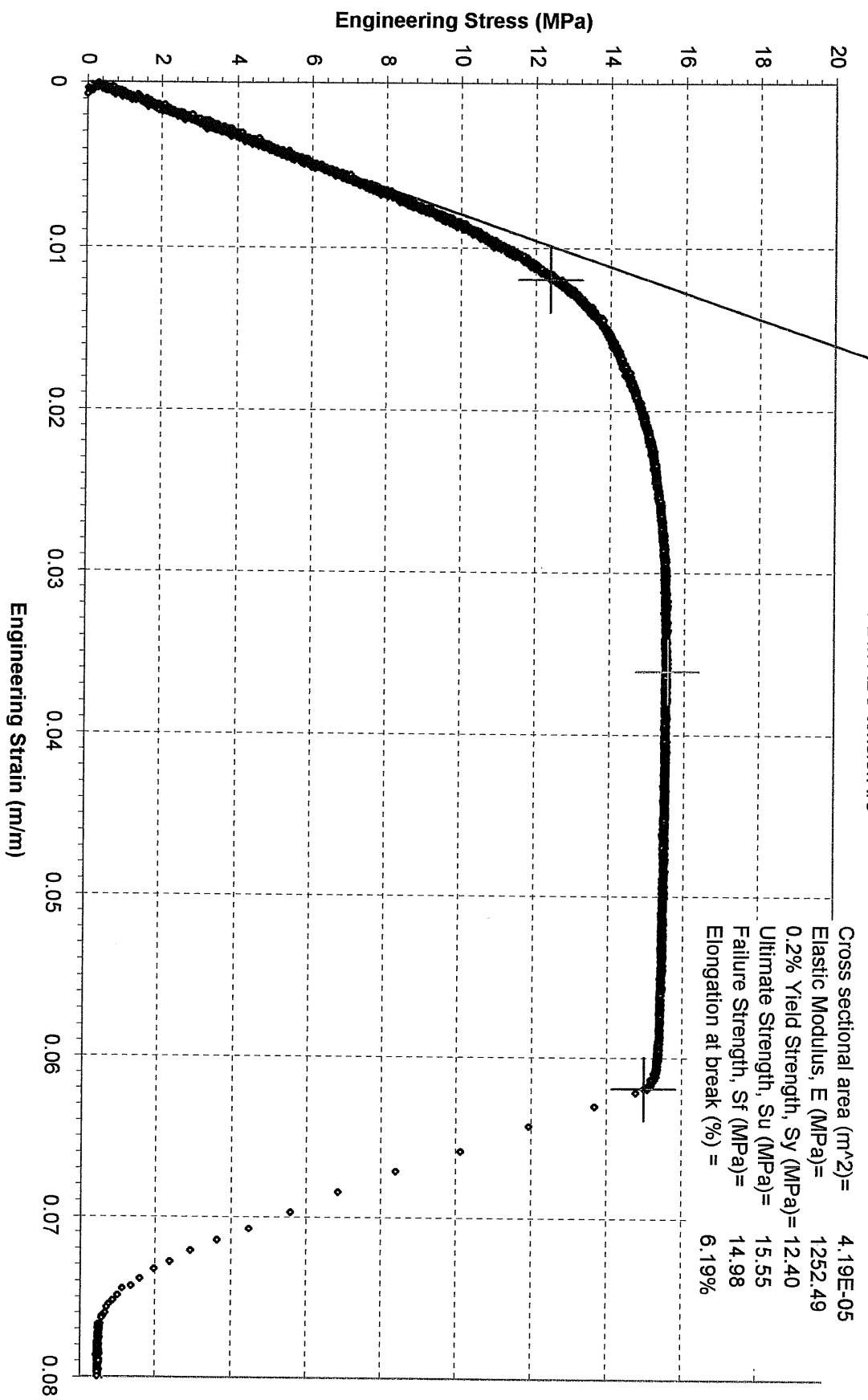
Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 1434.71
0.2% Yield Strength, S_y (MPa) = 11.75
Ultimate Strength, S_u (MPa) = 16.08
Failure Strength, S_f (MPa) = 15.52
Elongation at break (%) = 6.65%



Tensile Test Results

FDM ABS tension #8

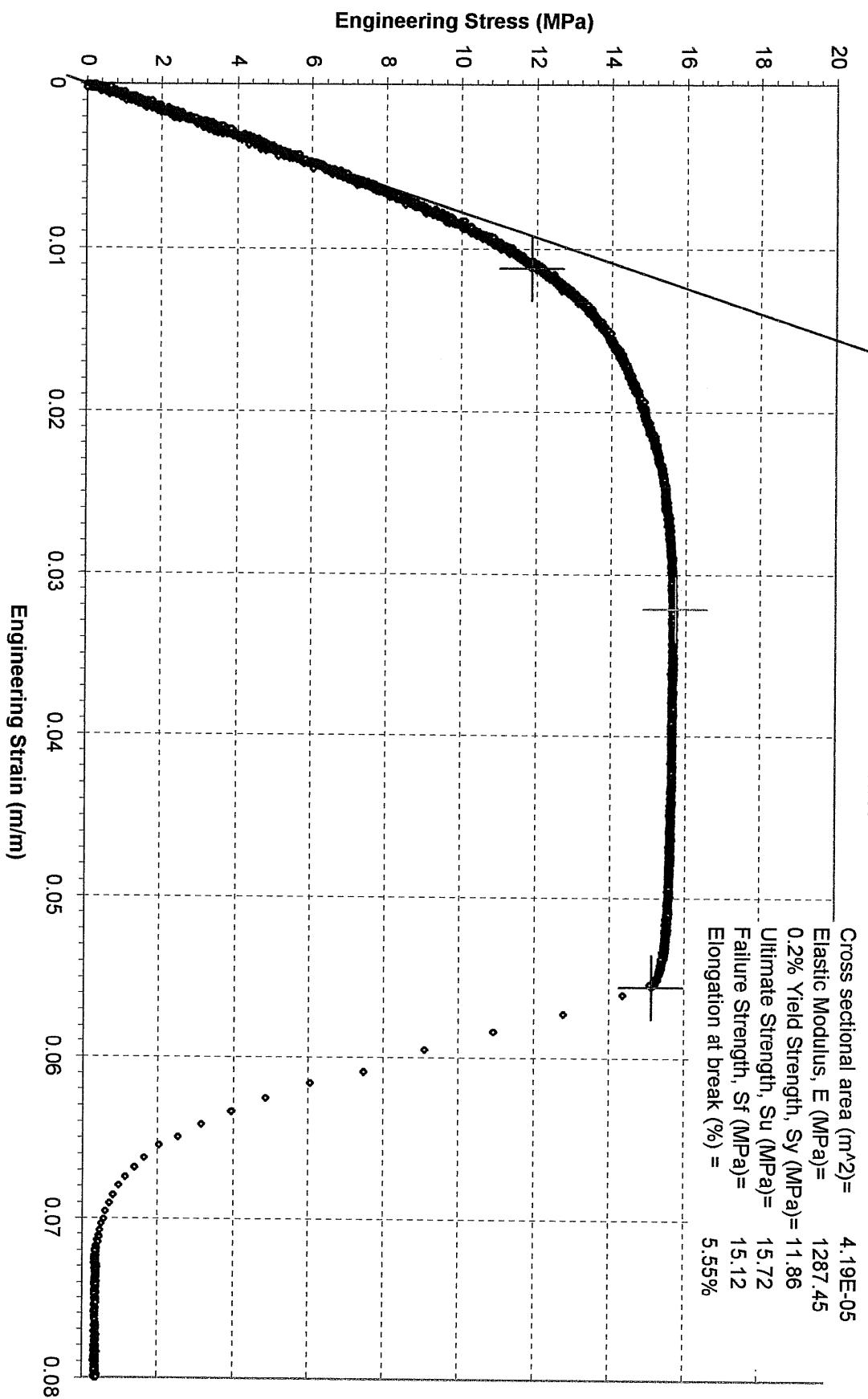
Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 1252.49
0.2% Yield Strength, S_y (MPa) = 12.40
Ultimate Strength, S_u (MPa) = 15.55
Failure Strength, S_f (MPa) = 14.98
Elongation at break (%) = 6.19%



Tensile Test Results

FDM ABS tension #10

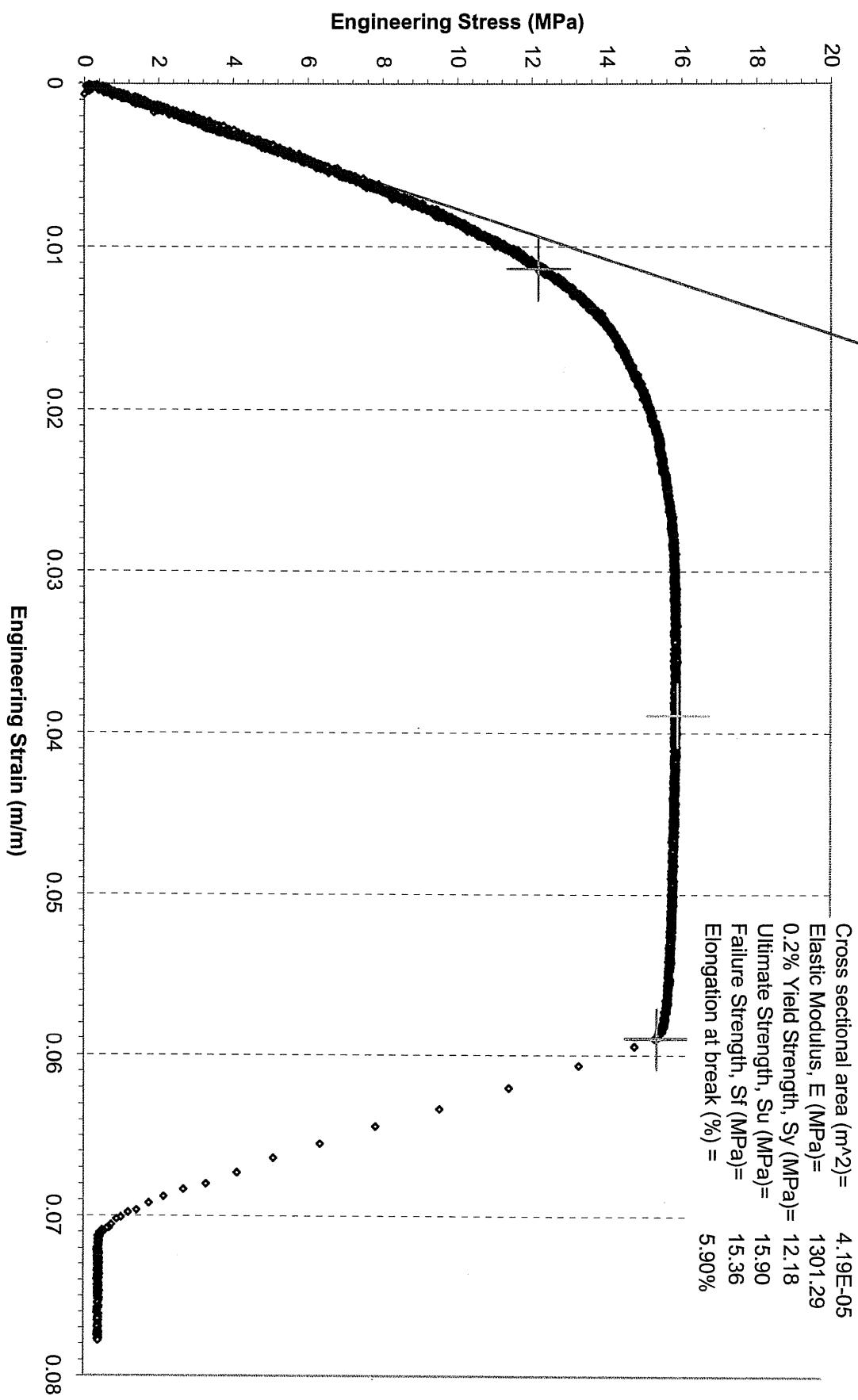
Cross sectional area (m^2)= 4.19E-05
Elastic Modulus, E (MPa)= 1287.45
0.2% Yield Strength, S_y (MPa)= 11.86
Ultimate Strength, S_u (MPa)= 15.72
Failure Strength, S_f (MPa)= 15.12
Elongation at break (%)= 5.55%



Tensile Test Results

FDM ABS tension #12

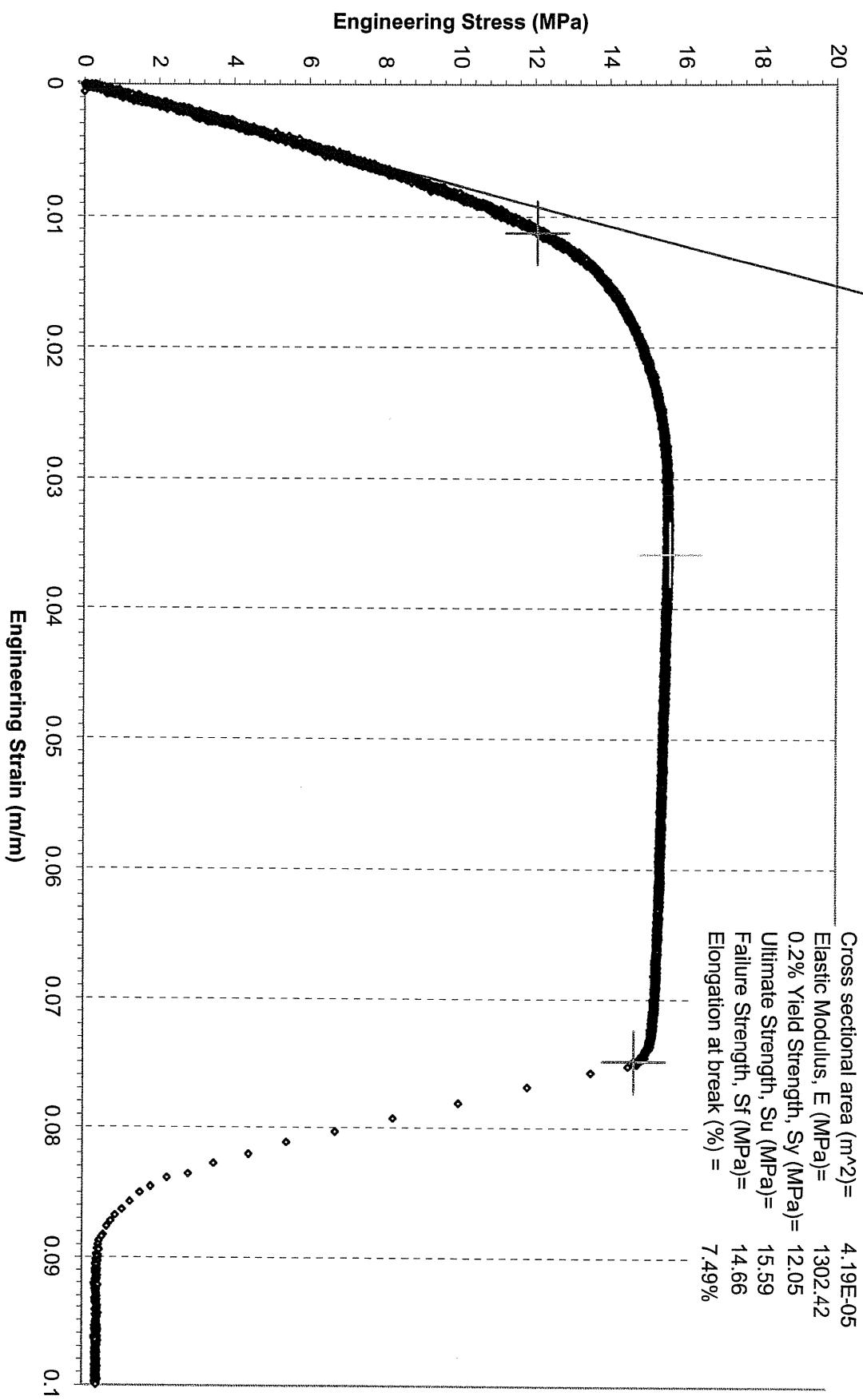
Cross sectional area (m^2)= 4.19E-05
Elastic Modulus, E (MPa)= 1301.29
0.2% Yield Strength, S_y (MPa)= 12.18
Ultimate Strength, S_u (MPa)= 15.90
Failure Strength, S_f (MPa)= 15.36
Elongation at break (%)= 5.90%



Tensile Test Results

FDM ABS tension #14

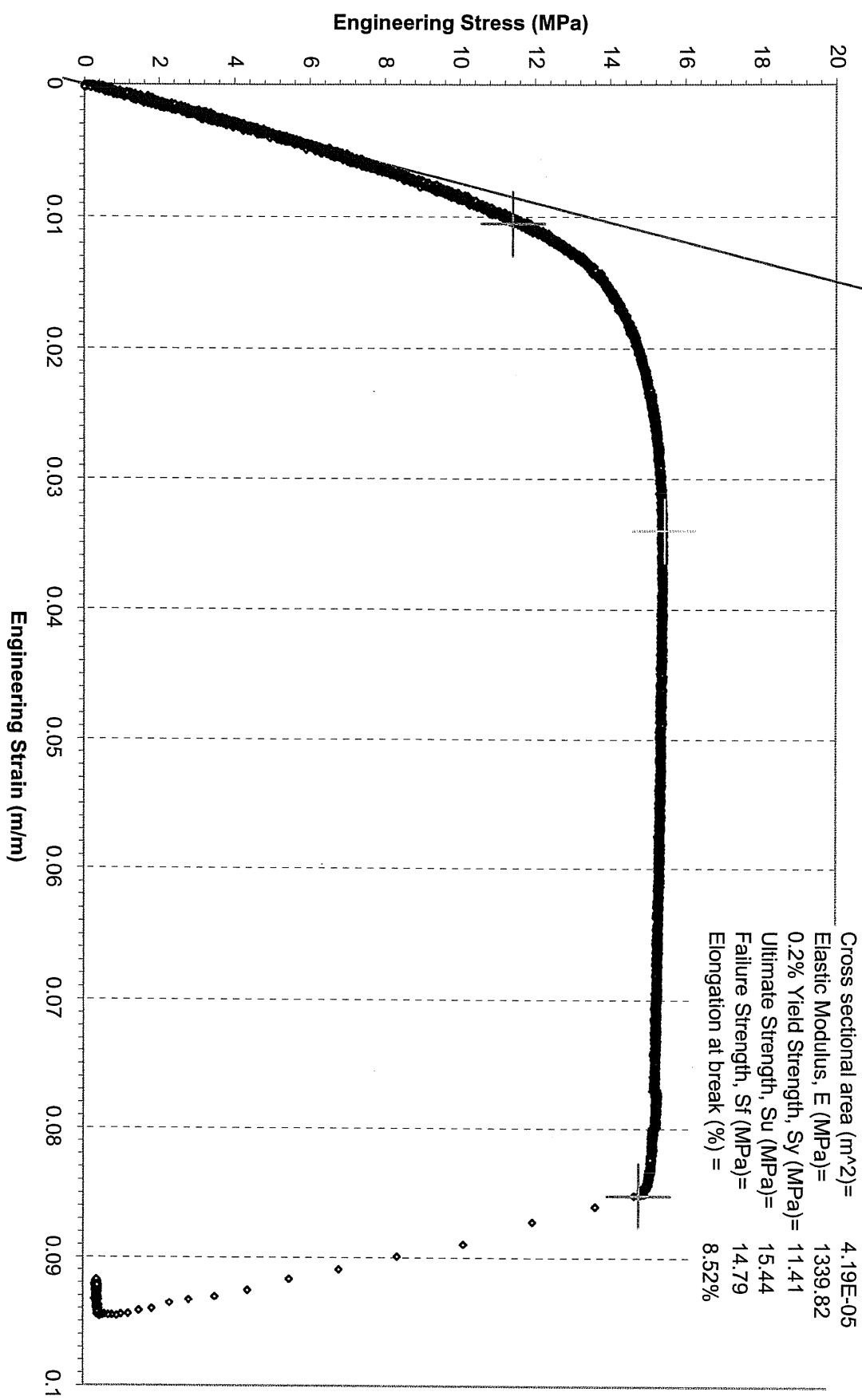
Cross sectional area (m^2)= 4.19E-05
Elastic Modulus, E (MPa)= 1302.42
0.2% Yield Strength, S_y (MPa)= 12.05
Ultimate Strength, S_u (MPa)= 15.59
Failure Strength, S_f (MPa)= 14.66
Elongation at break (%)= 7.49%

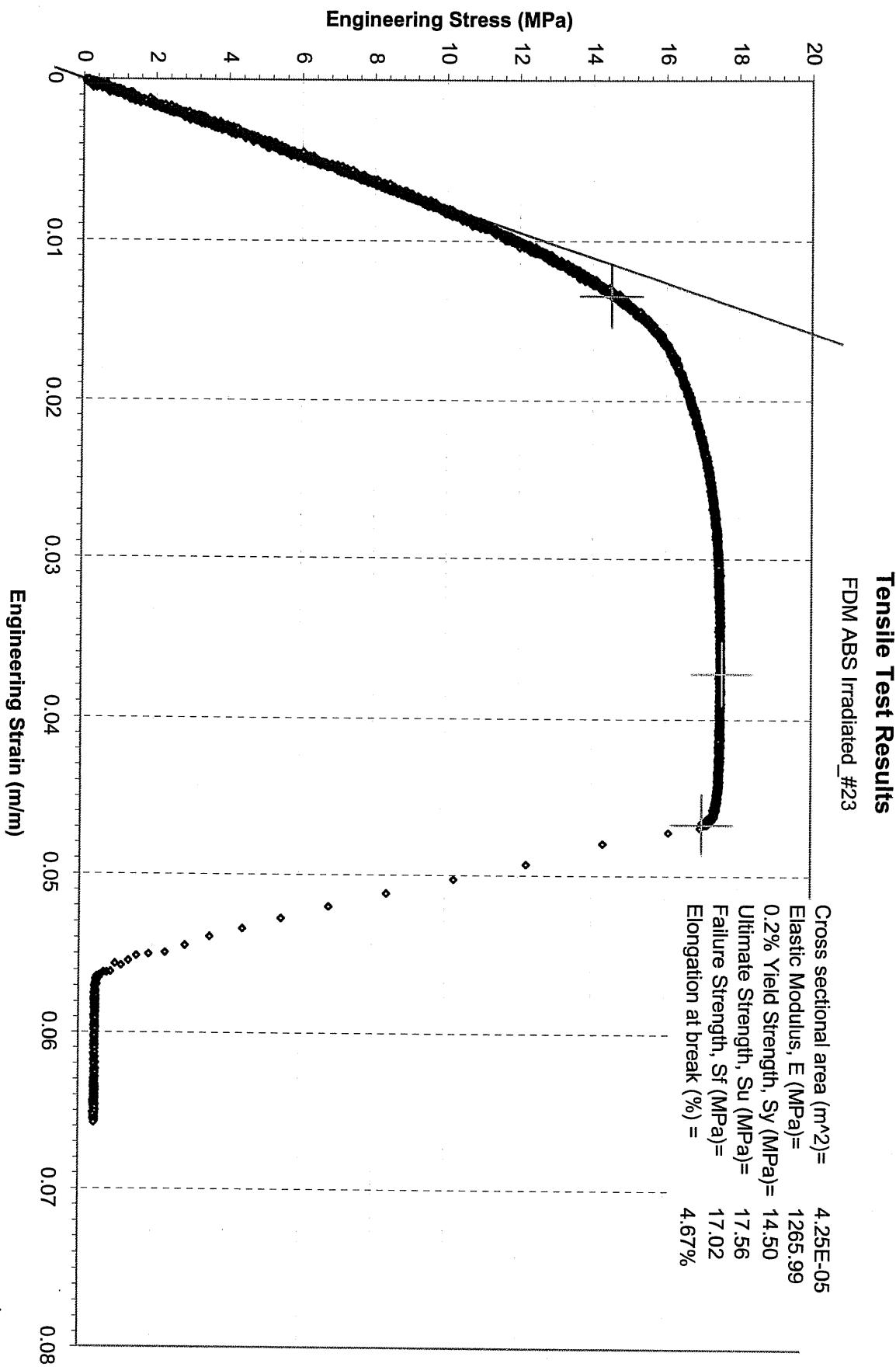


Tensile Test Results

FDM ABS tension #16

Cross sectional area (m^2) = 4.19E-05
Elastic Modulus, E (MPa) = 1339.82
0.2% Yield Strength, S_y (MPa) = 11.41
Ultimate Strength, S_u (MPa) = 15.44
Failure Strength, S_f (MPa) = 14.79
Elongation at break (%) = 8.52%

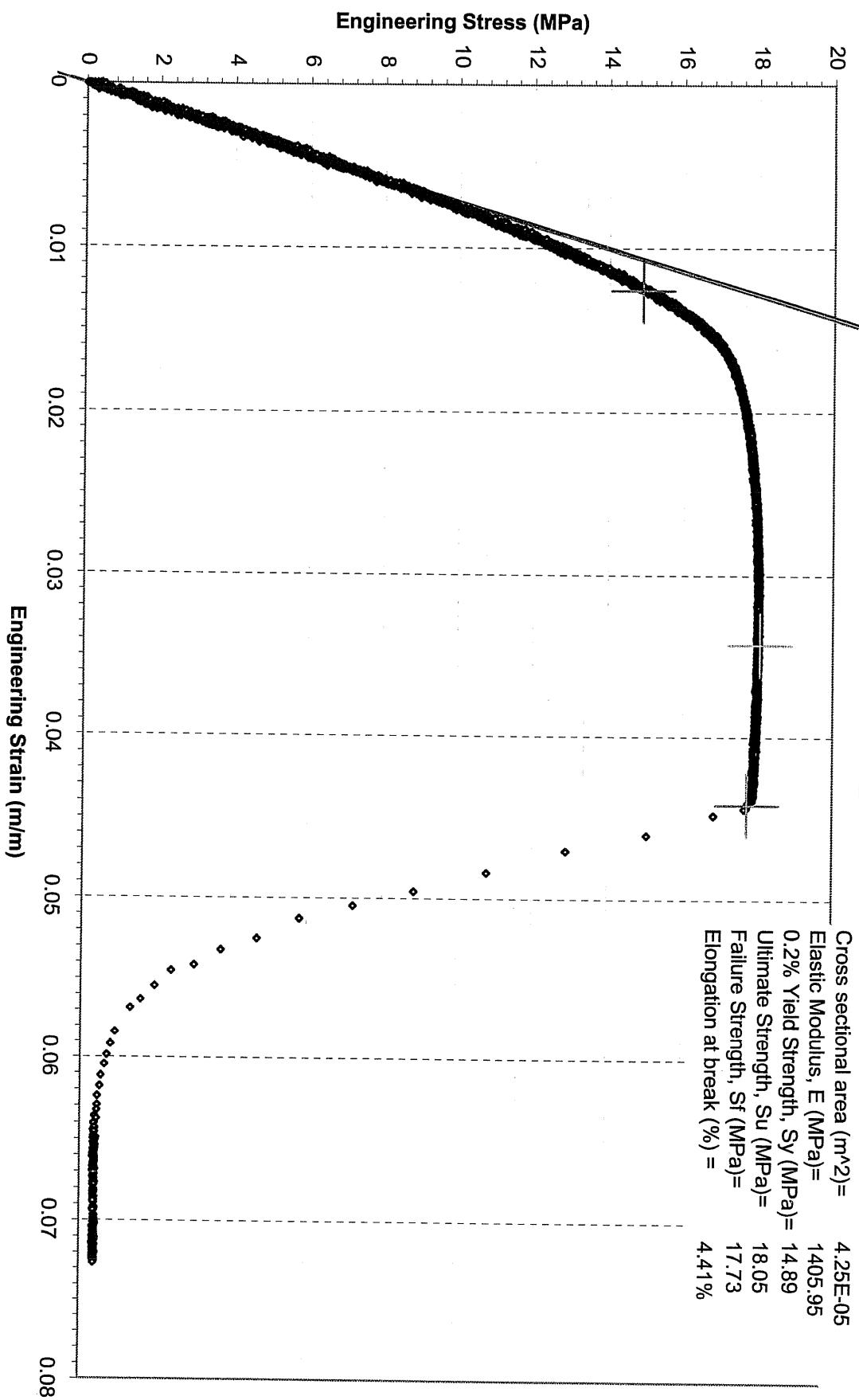




Tensile Test Results

FDM ABS Irradiated #24

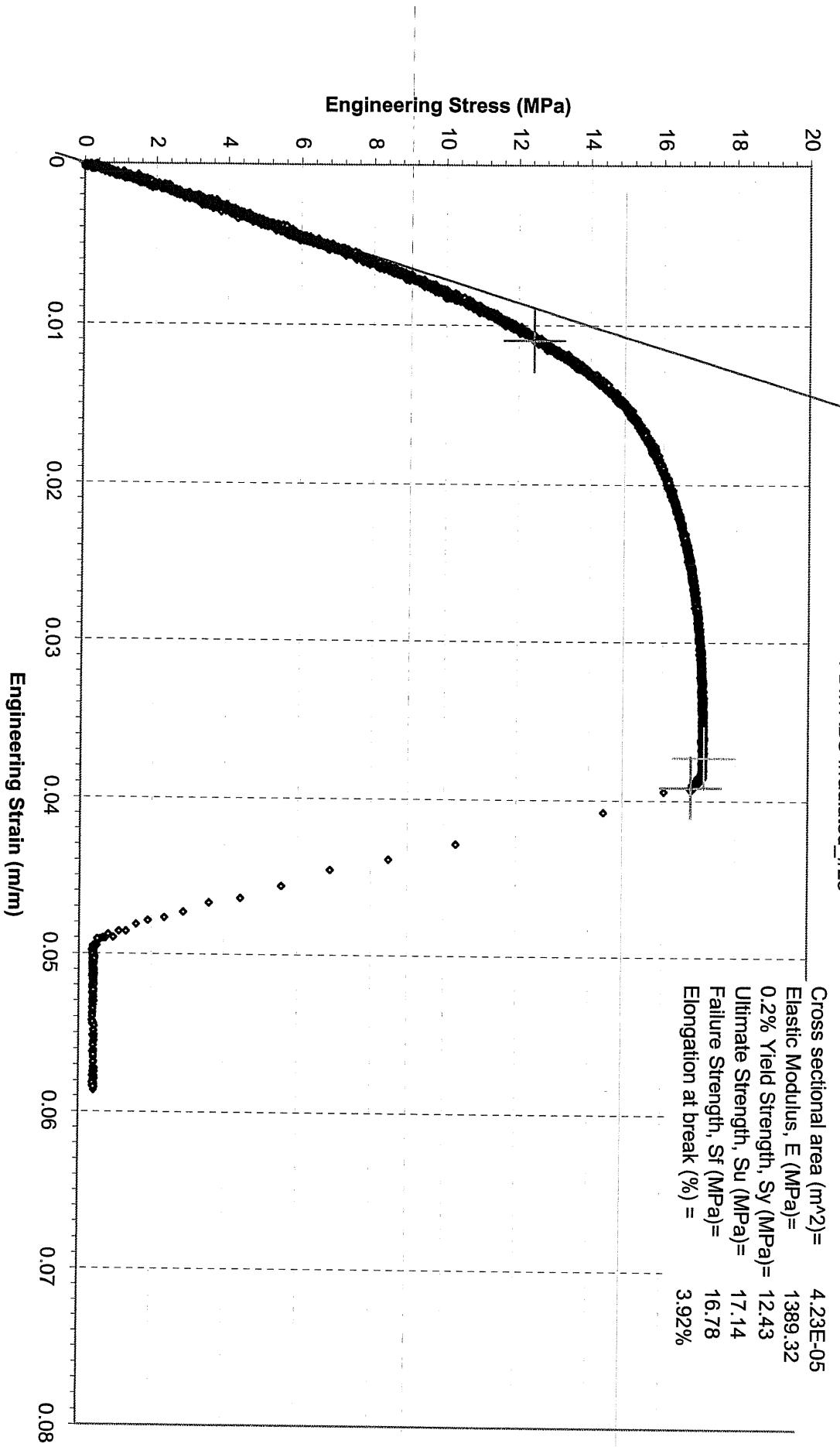
Cross sectional area (m^2) = 4.25E-05
Elastic Modulus, E (MPa) = 1405.95
0.2% Yield Strength, S_y (MPa) = 14.89
Ultimate Strength, S_u (MPa) = 18.05
Failure Strength, S_f (MPa) = 17.73
Elongation at break (%) = 4.41%

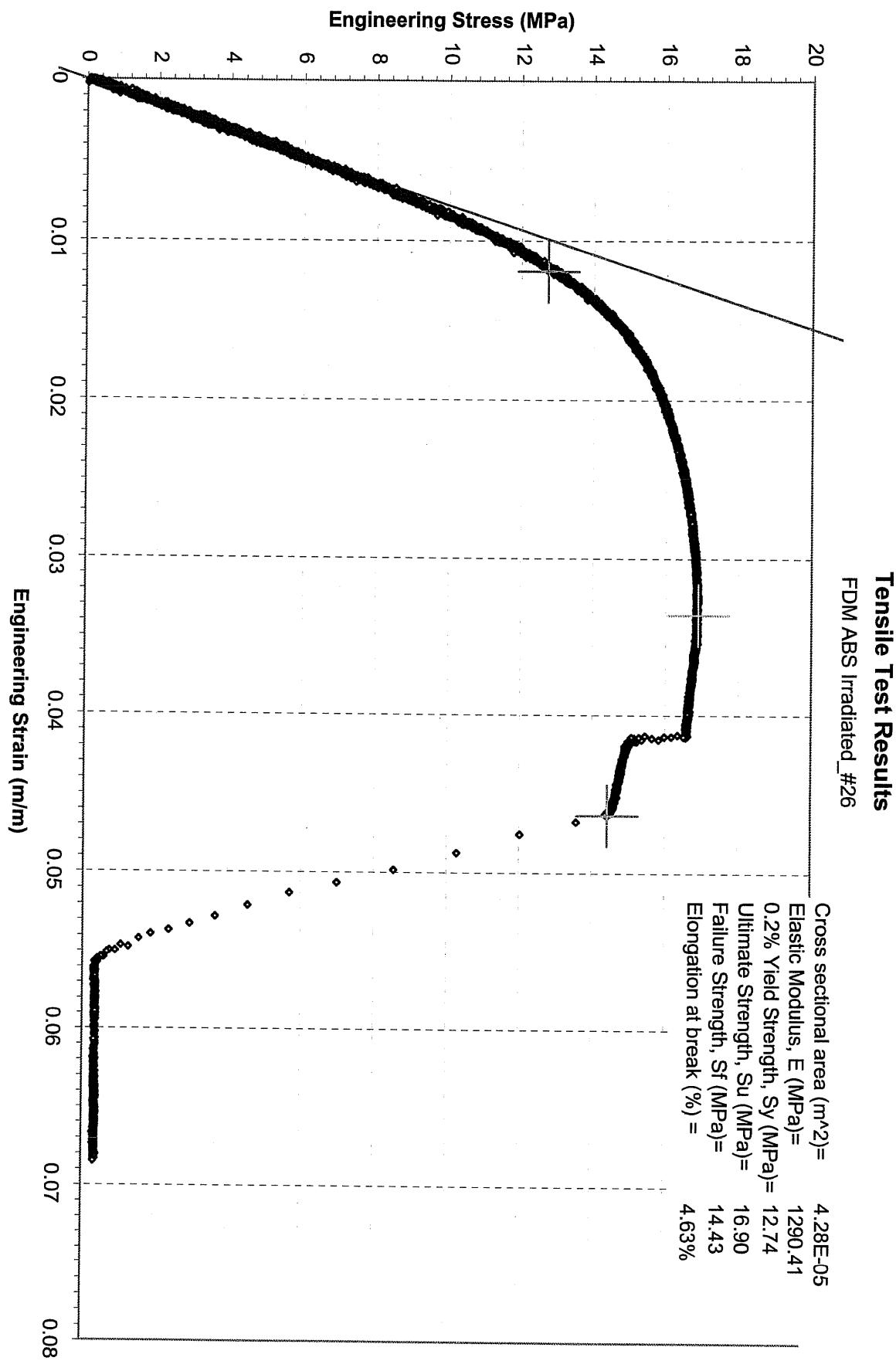


Tensile Test Results

FDM ABS Irradiated _#25

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

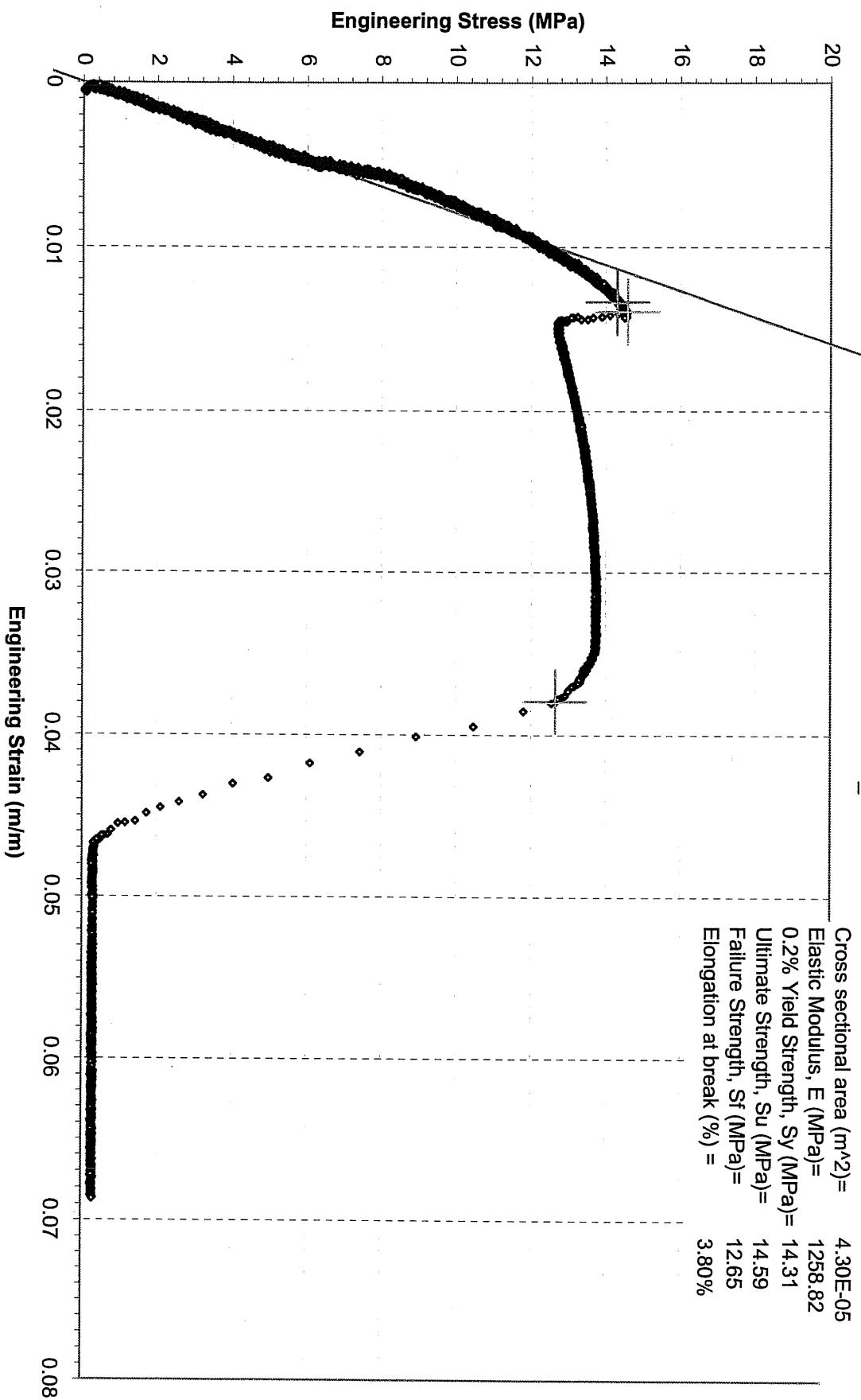




Tensile Test Results

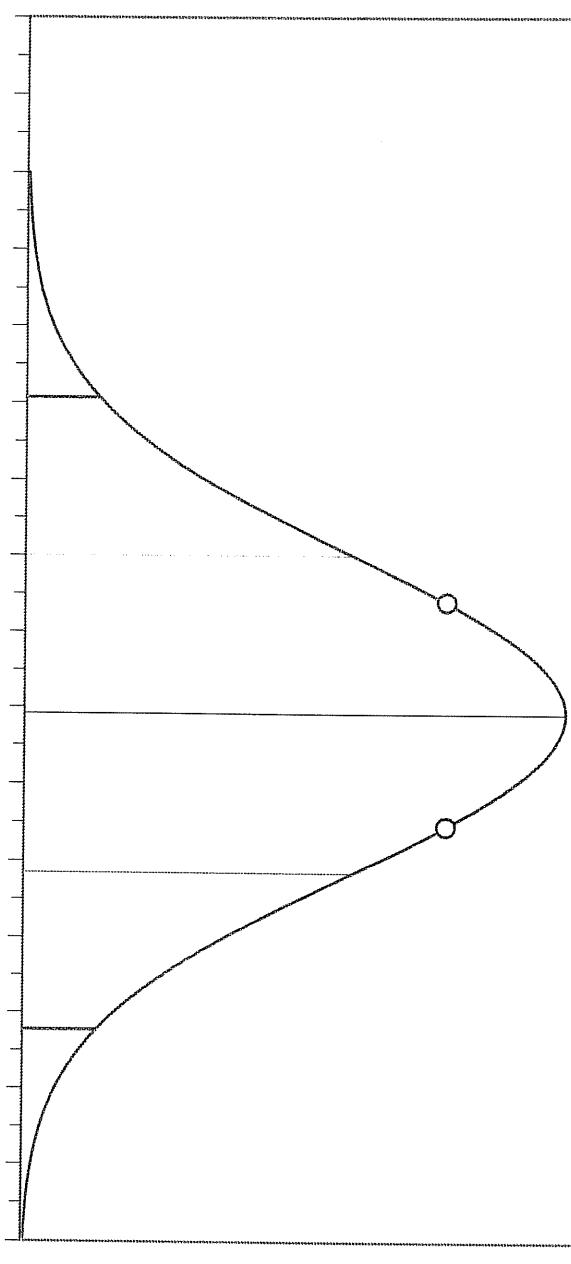
FDM ABS Irradiated #27

Cross sectional area (m^2) = 4.30E-05
Elastic Modulus, E (MPa) = 1258.82
0.2% Yield Strength, S_y (MPa) = 14.31
Ultimate Strength, S_u (MPa) = 14.59
Failure Strength, S_f (MPa) = 12.65
Elongation at break (%) = 3.80%



Stress at Failure

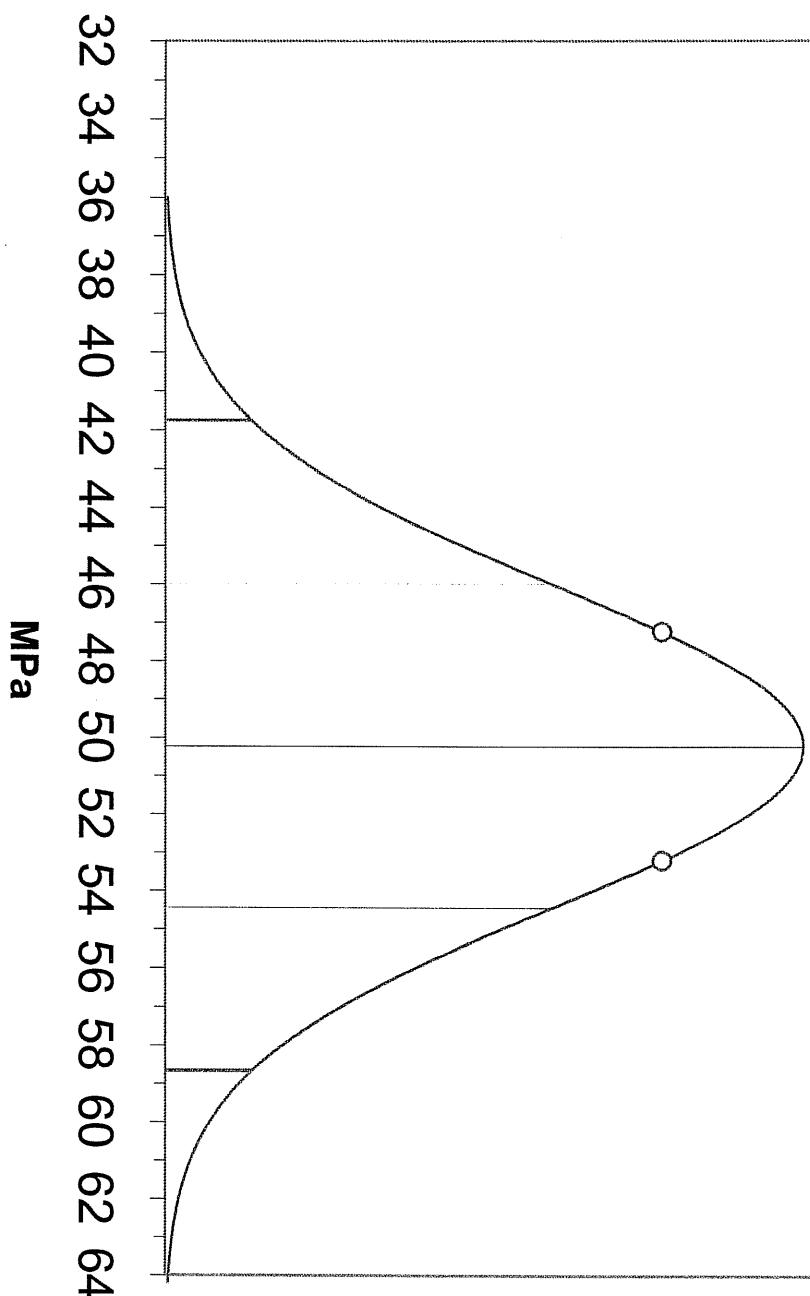
FDM PPSF Edge



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

Ultimate Strength

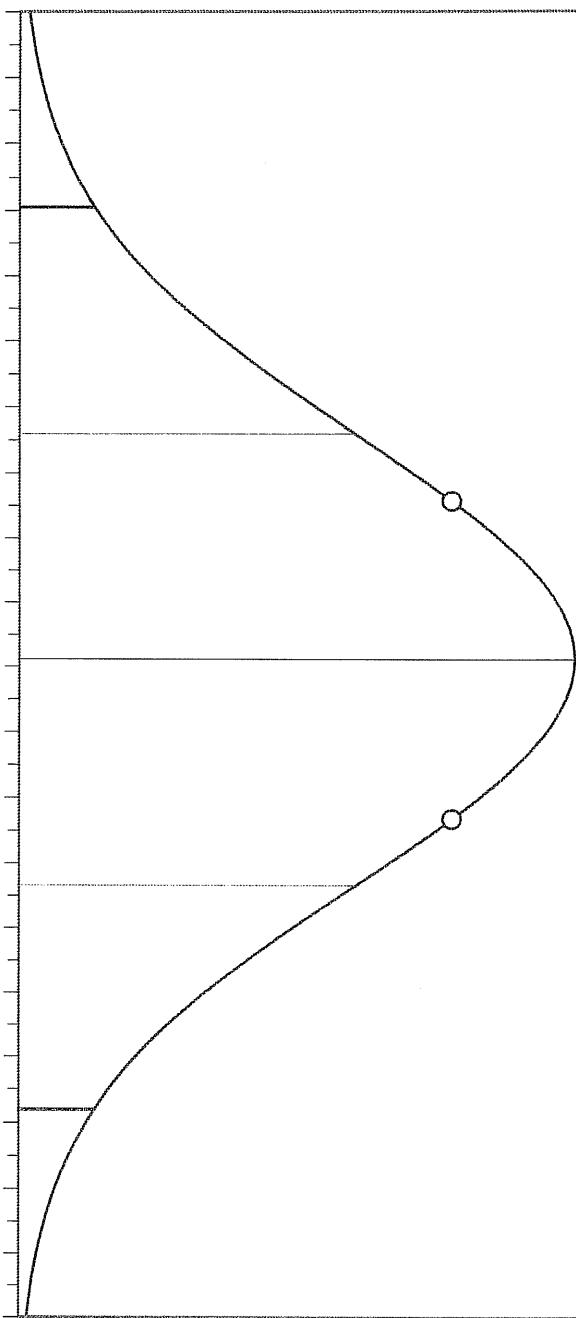
FDM PPSF Edge



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

Yield Strength

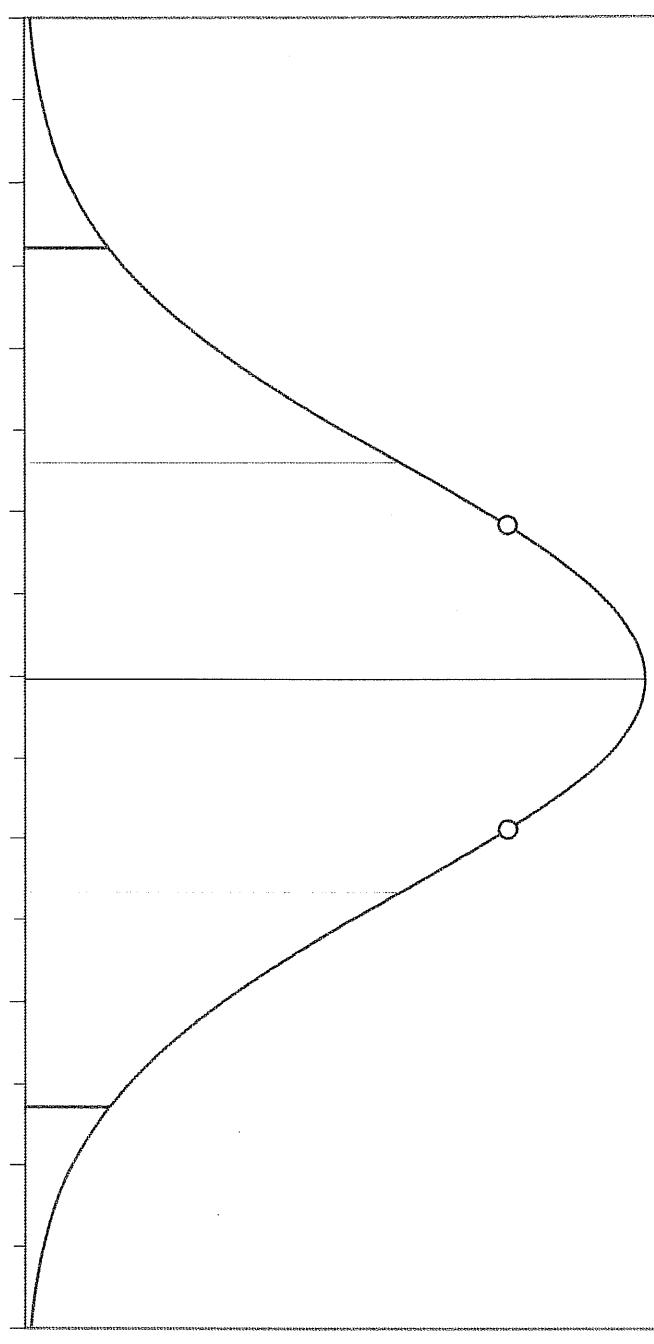
FDM PPSF Edge



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

Elastic Modulus

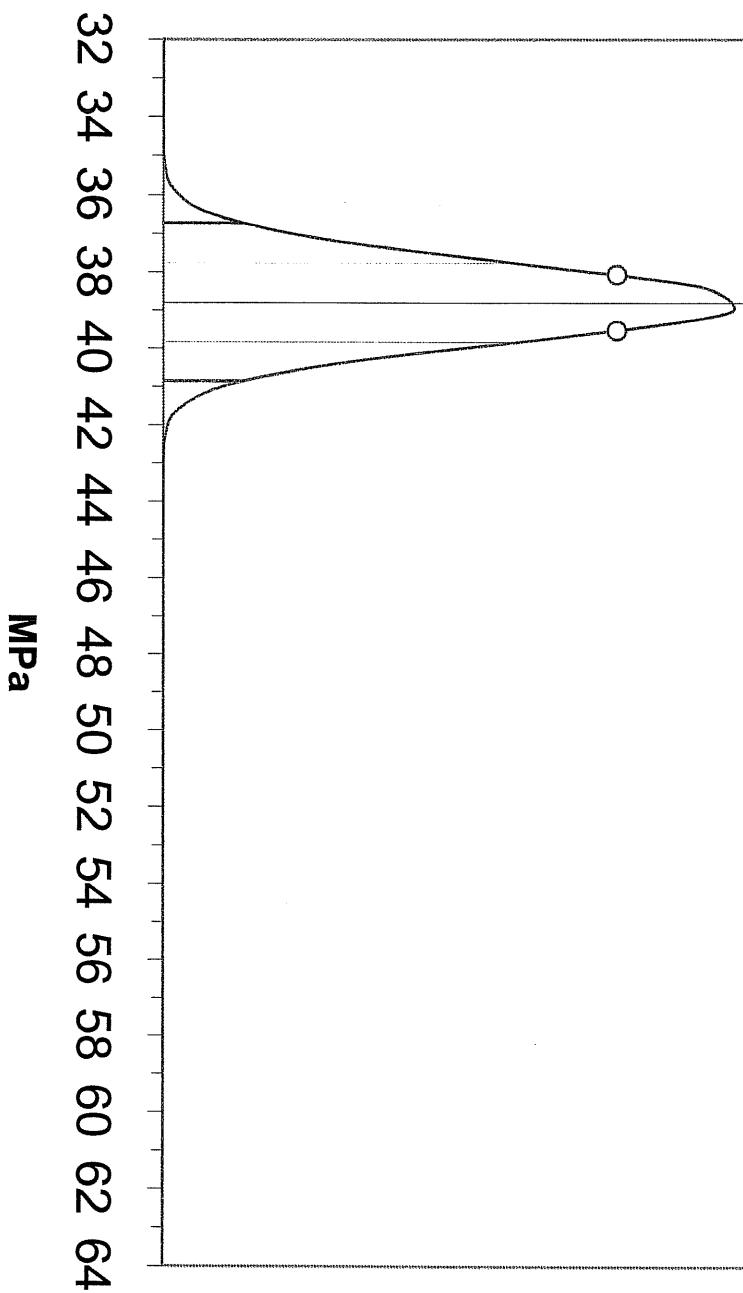
FDM PPSF Edge



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

Stress at Failure

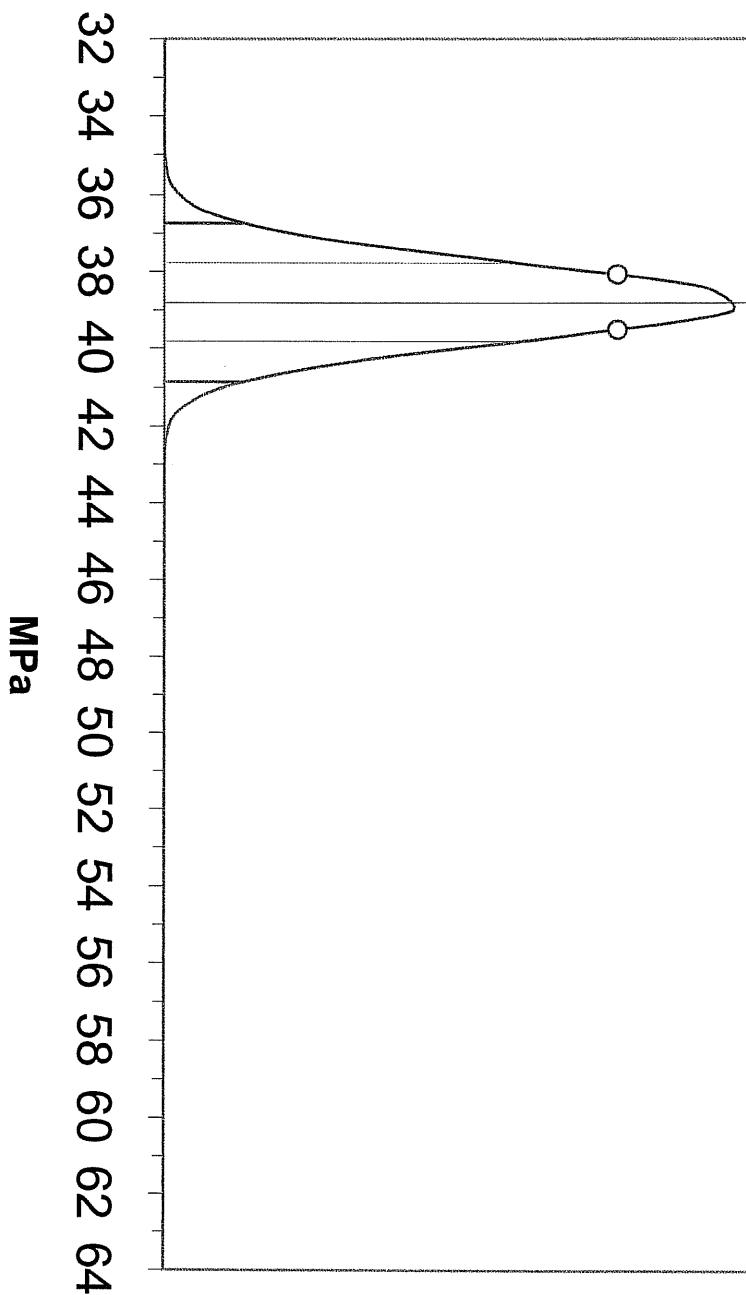
FDM PPSF Edge, Irradiated



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

Ultimate Strength

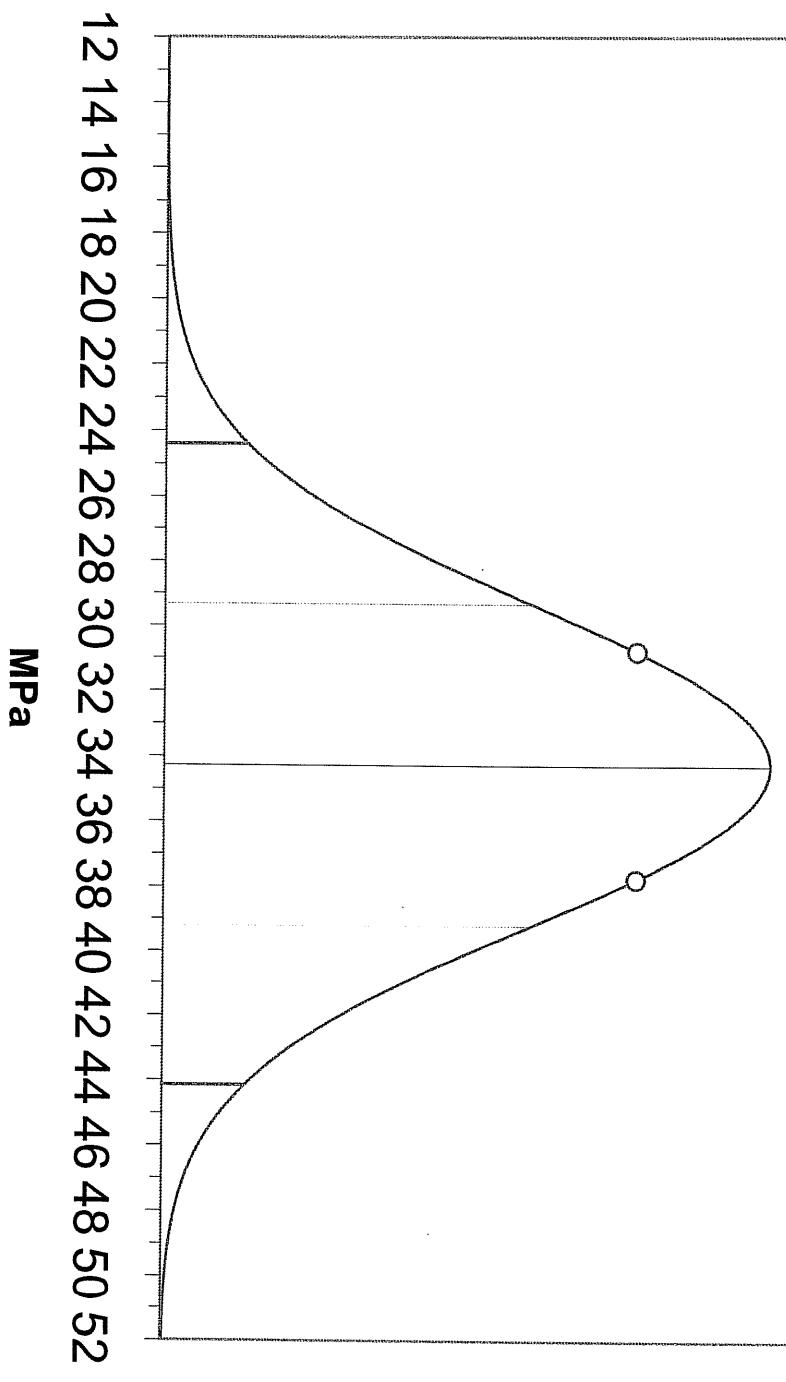
FDM PPSF Edge, Irradiated



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

Yield Strength

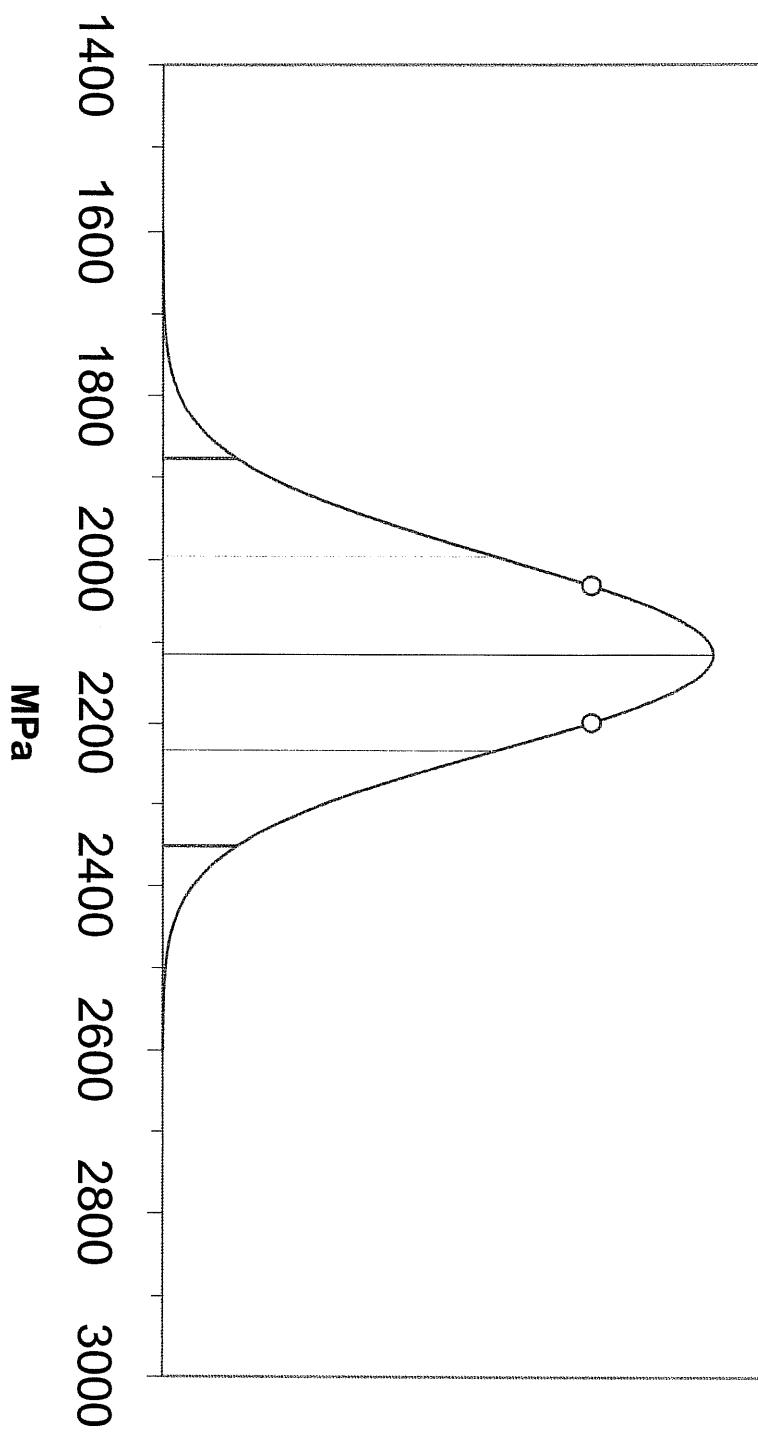
FDM PPSF Edge, Irradiated



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

Elastic Modulus

FDM PPSF Edge, Irradiated

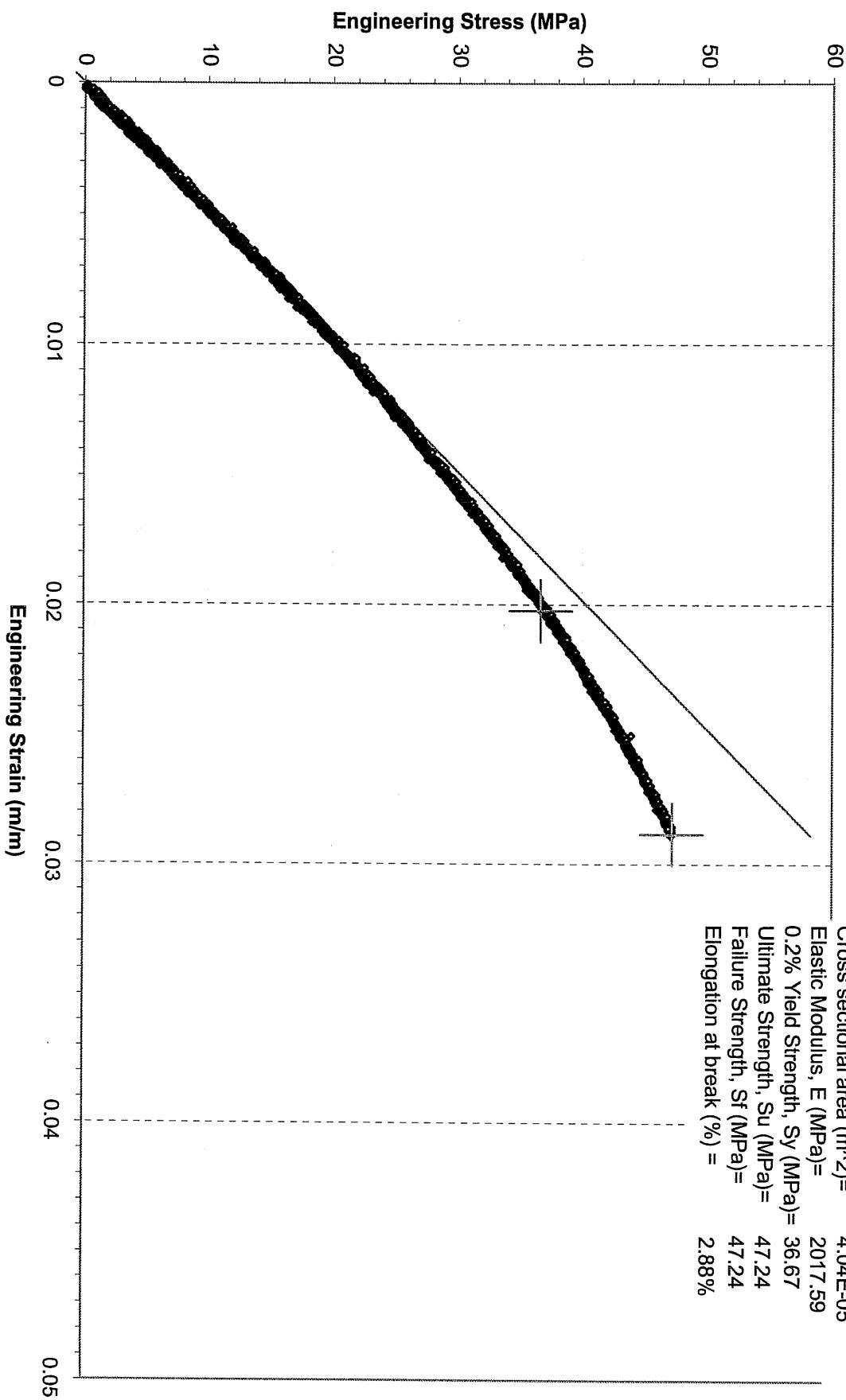


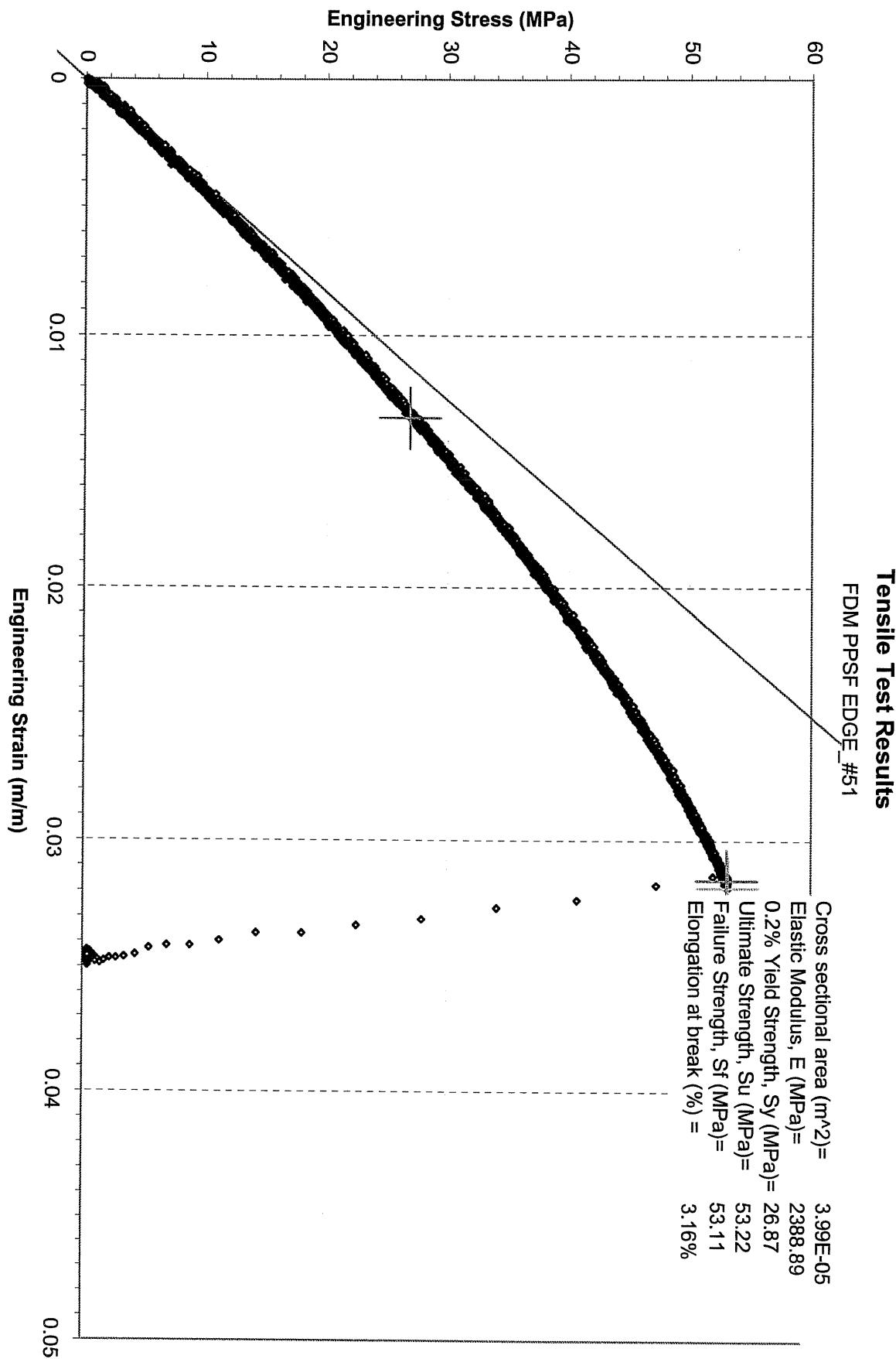
samples = 2.00
Average = 2114.42
Minimum = 2030.81
Maximum = 2198.03
Std dev = 118.24

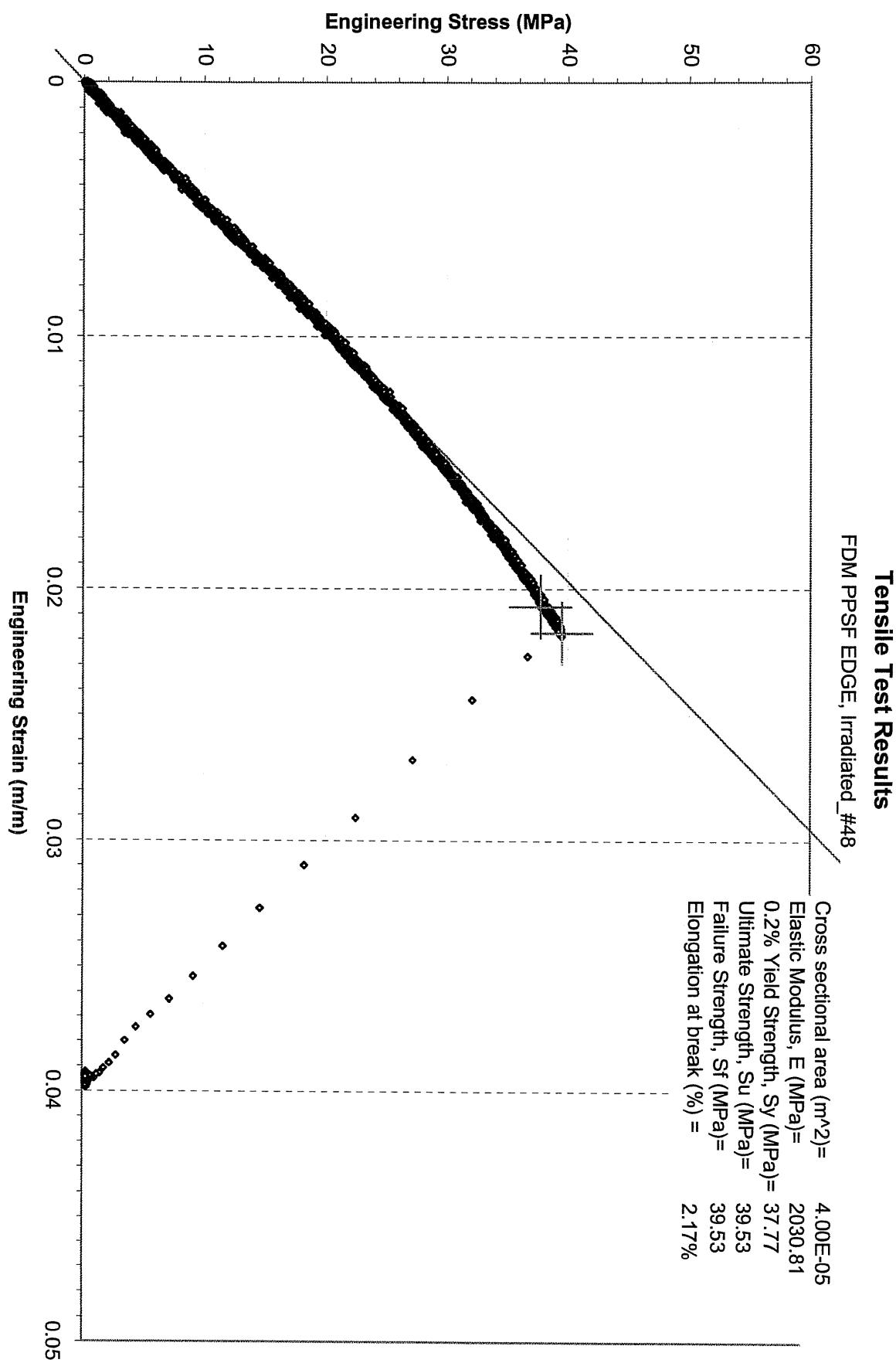
Tensile Test Results

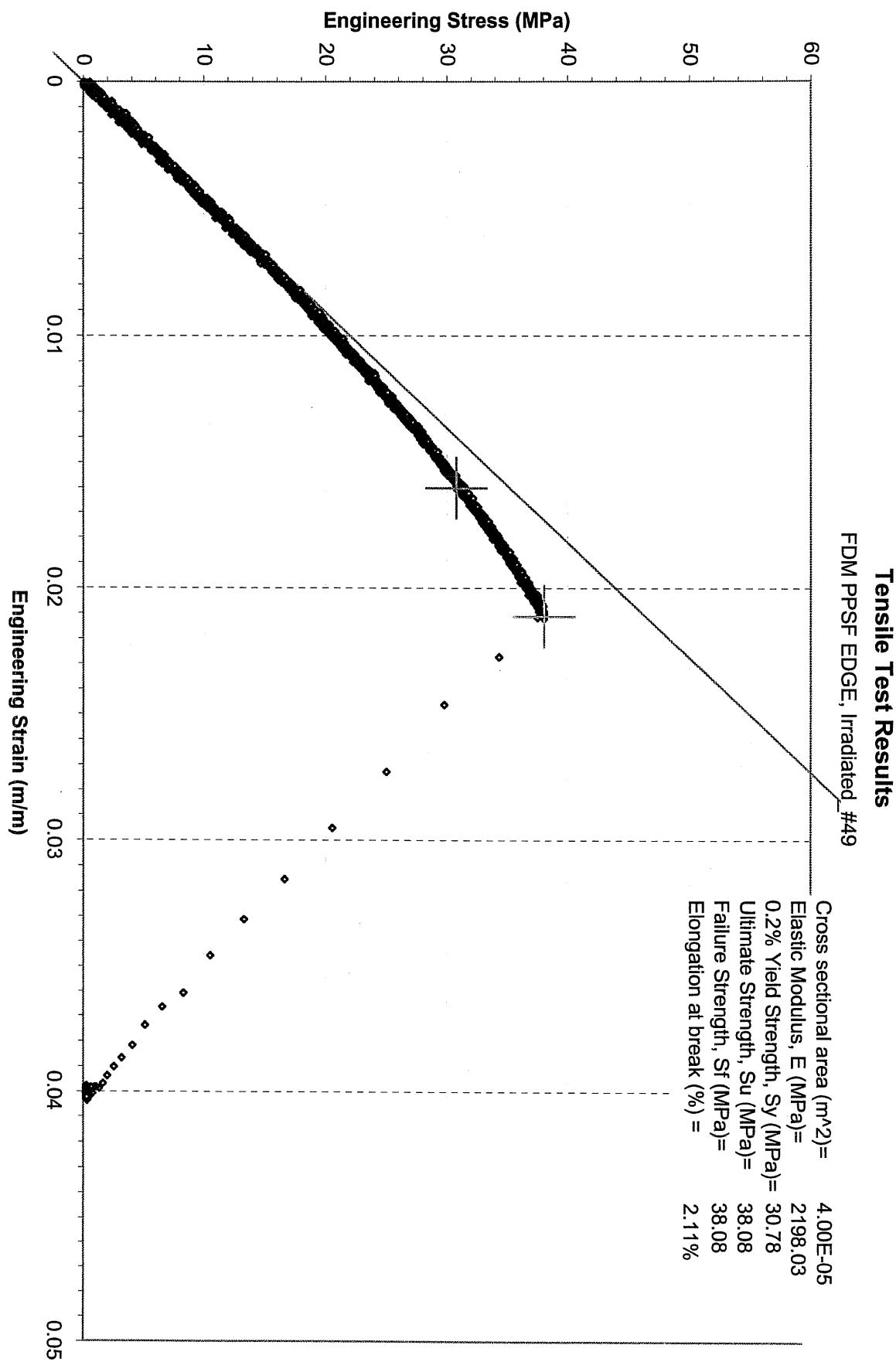
FDM PPSF EDGE #50

Cross sectional area (m^2)= 4.04E-05
Elastic Modulus, E (MPa)= 2017.59
0.2% Yield Strength, S_y (MPa)= 36.67
Ultimate Strength, S_u (MPa)= 47.24
Failure Strength, S_f (MPa)= 47.24
Elongation at break (%)= 2.88%



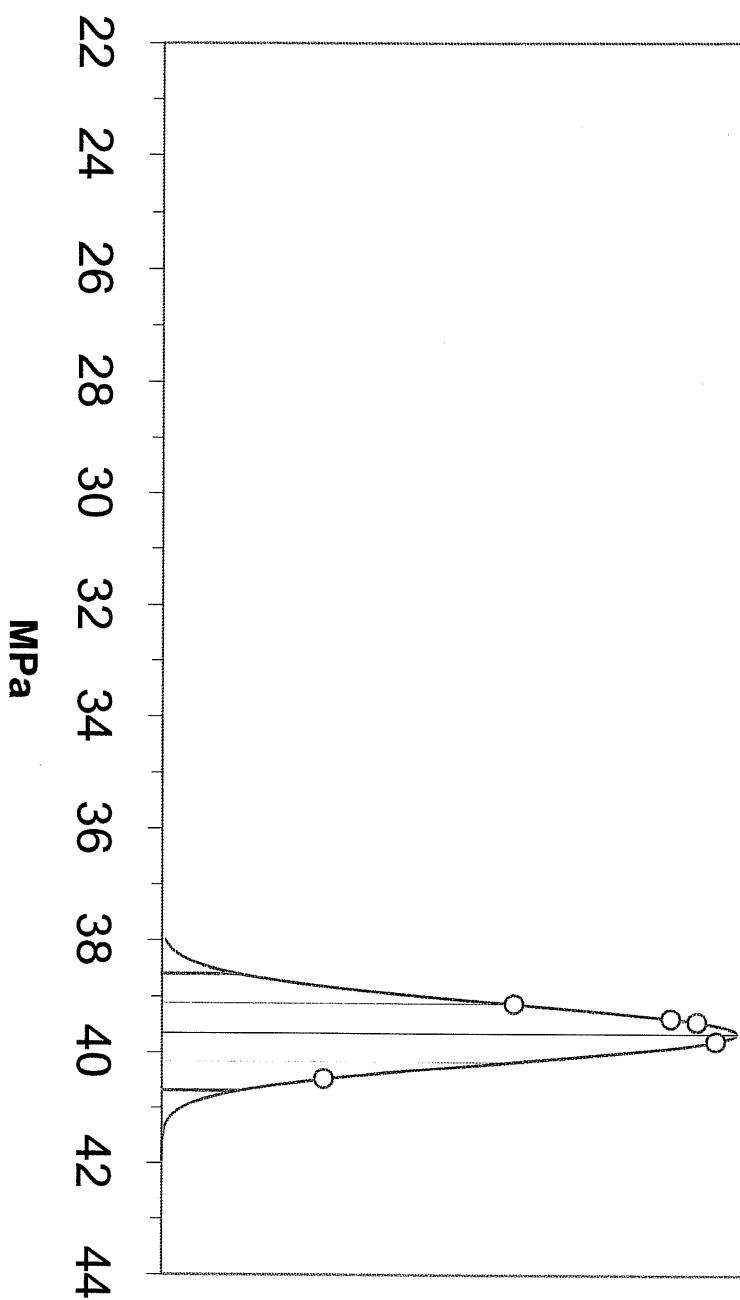






Ultimate Strength

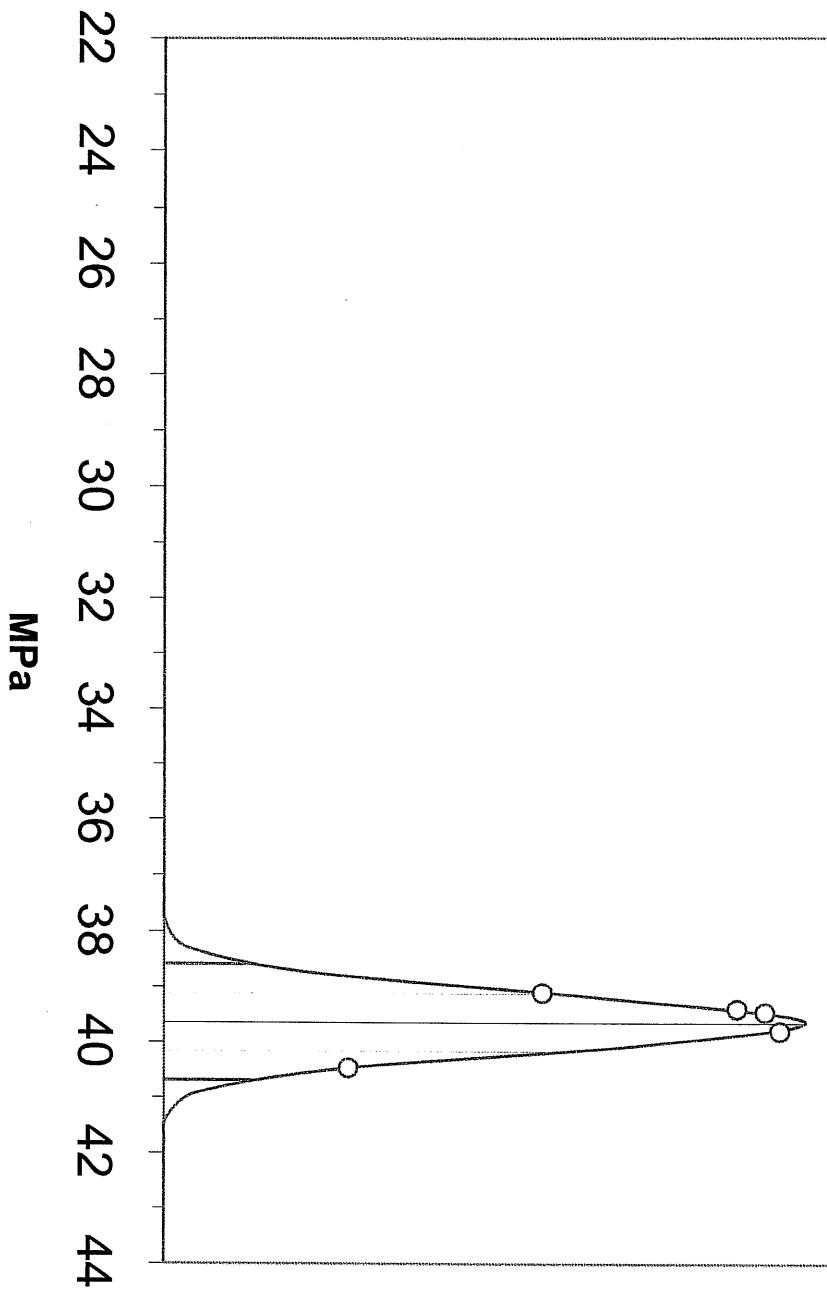
FDM PC



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

Stress at Failure

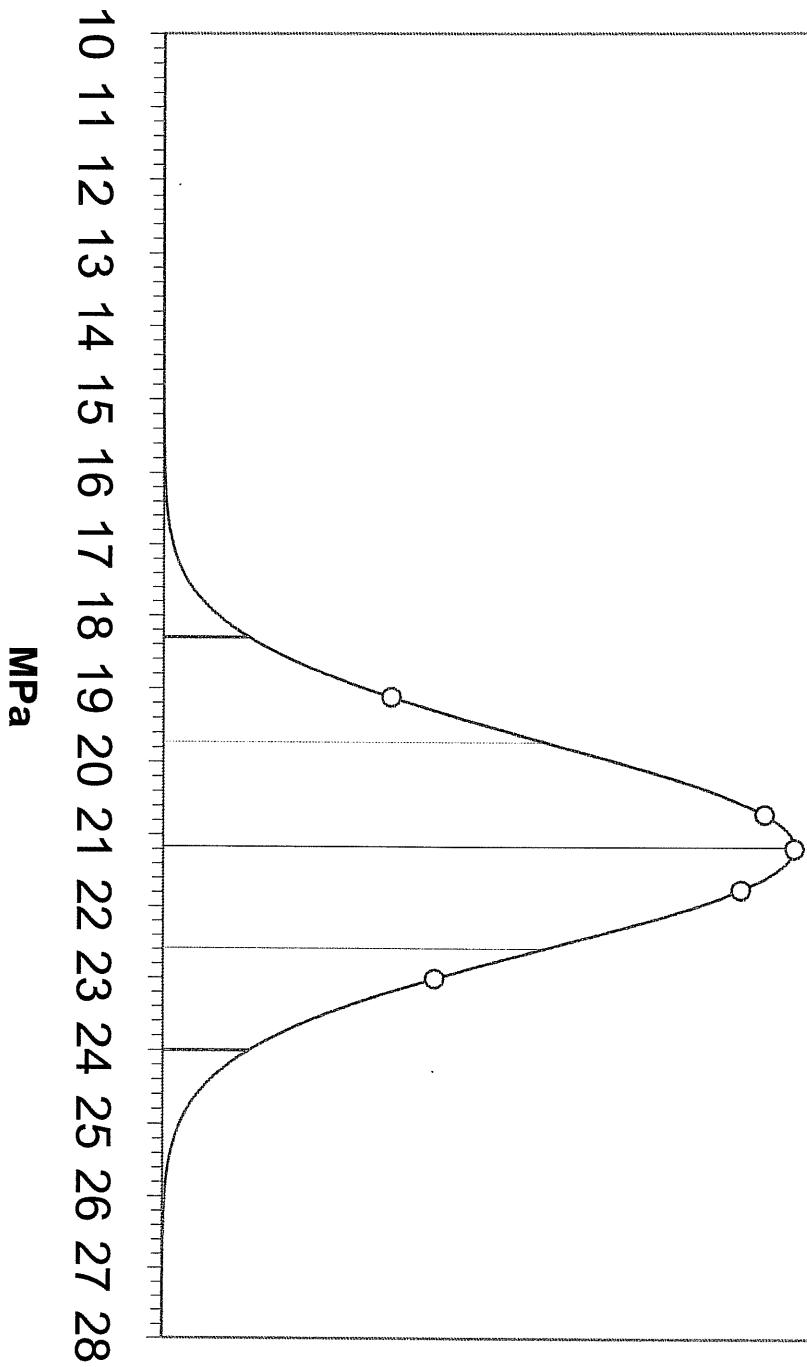
FDM PC



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

Yield Strength

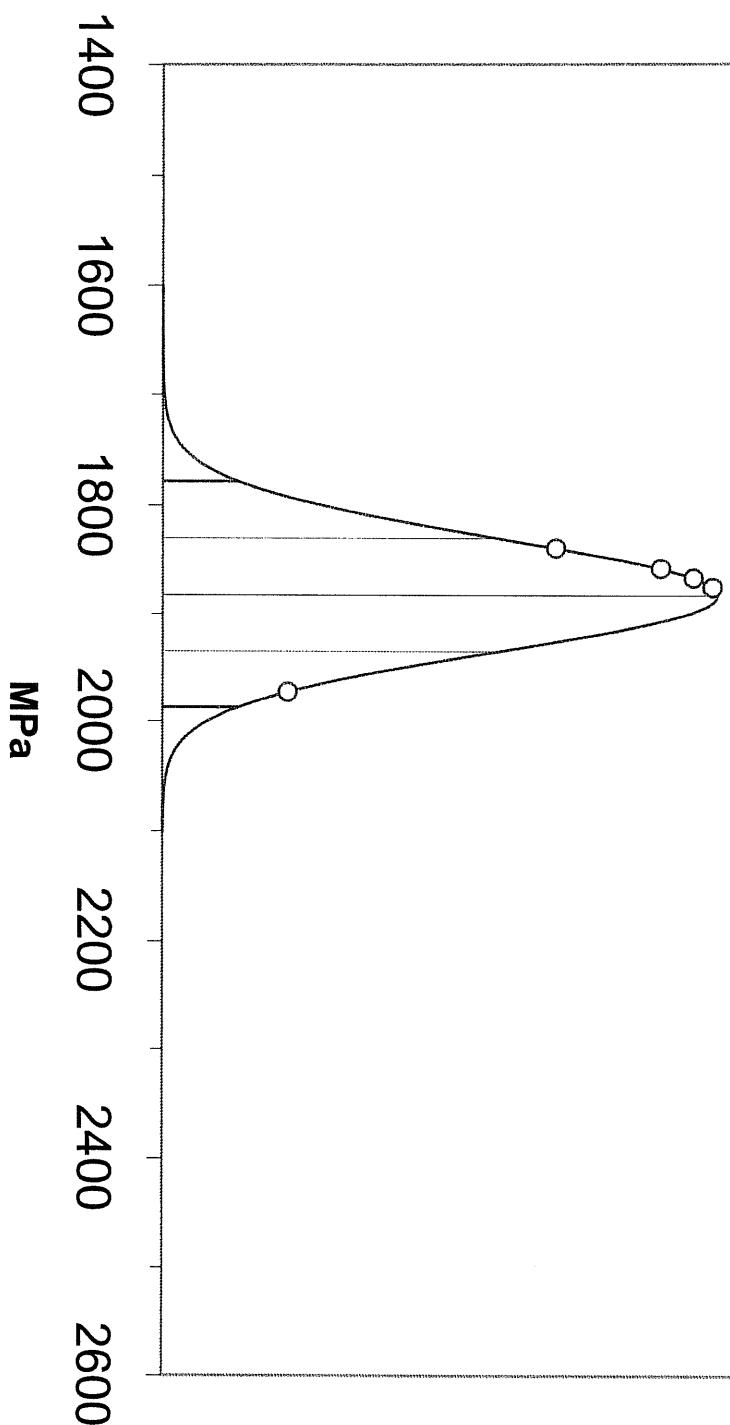
FDM PC



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

Elastic Modulus

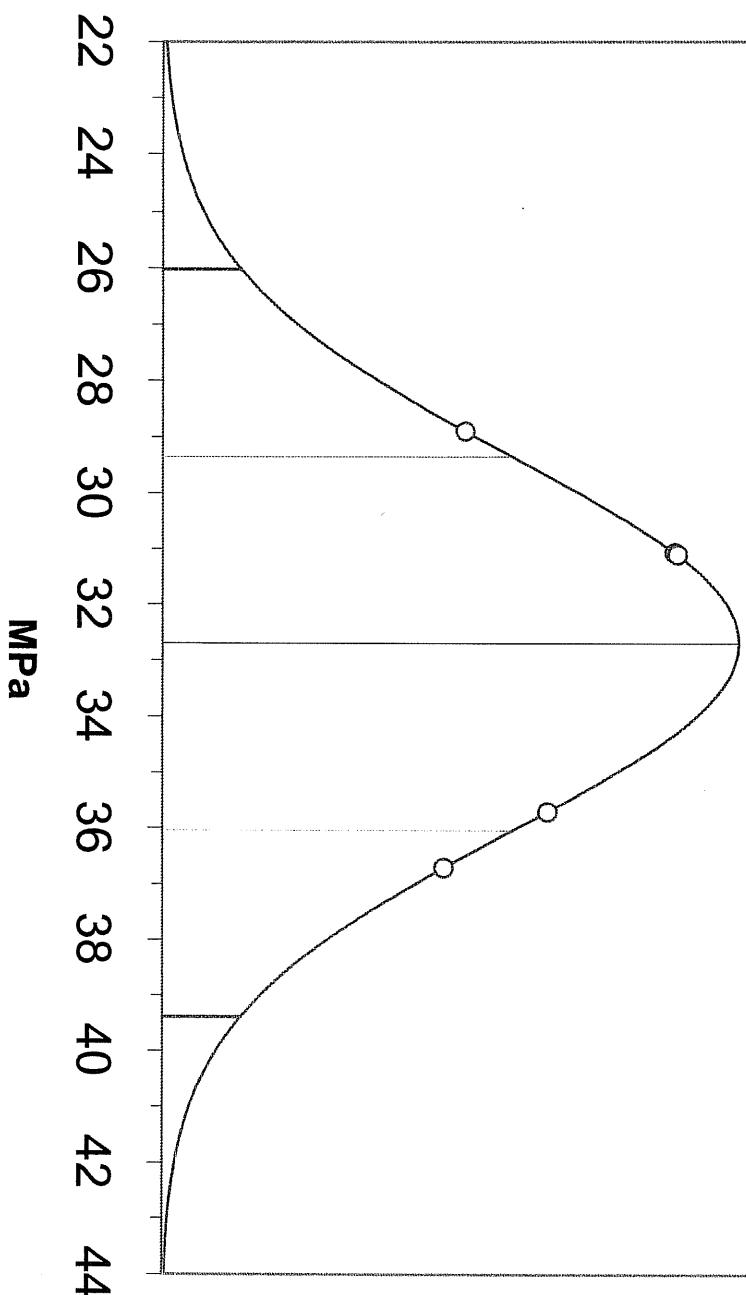
FDM PC



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

Ultimate Strength

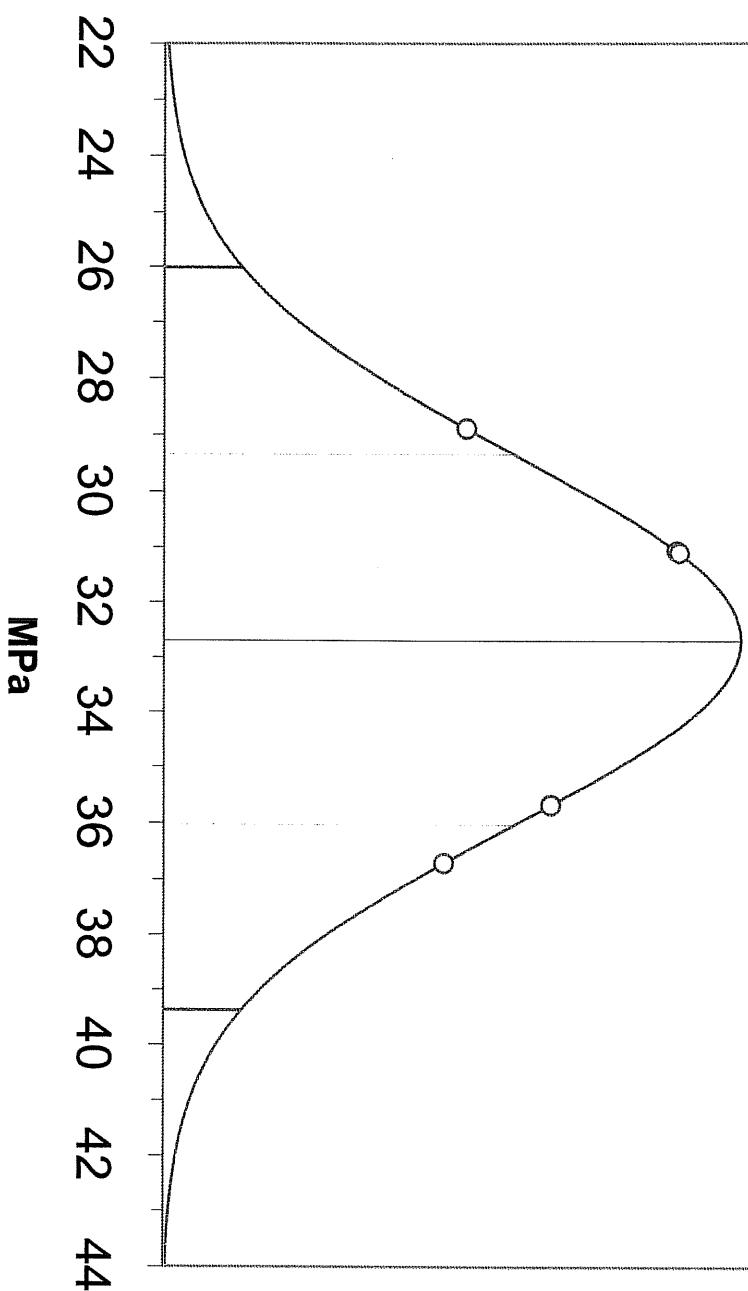
FDM PC, irradiated



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

Stress at Failure

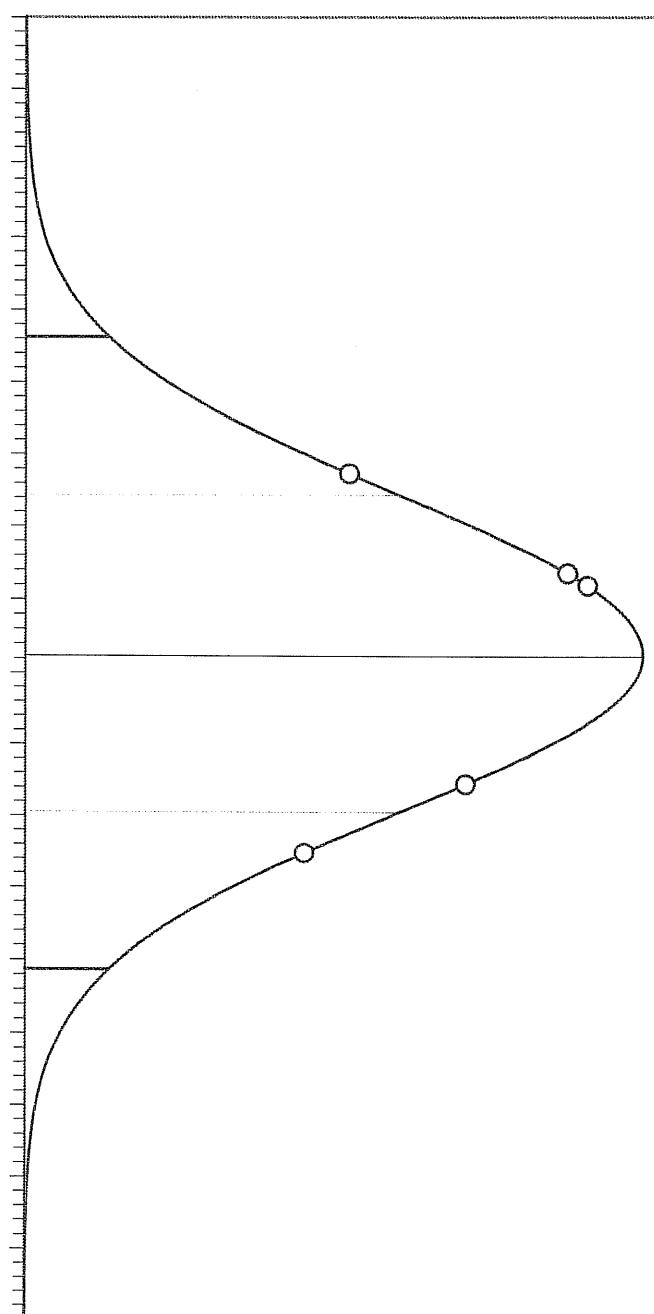
FDM PC, irradiated



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

Yield Strength

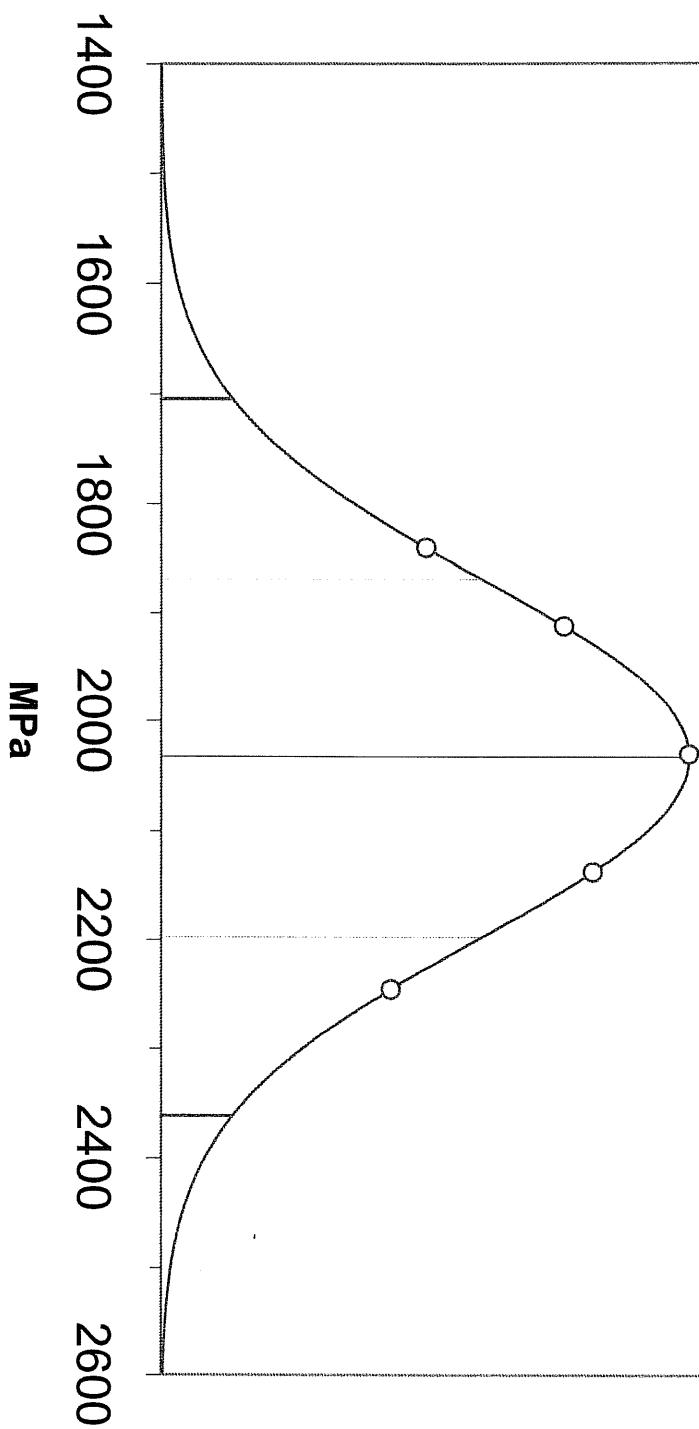
FDM PC, irradiated



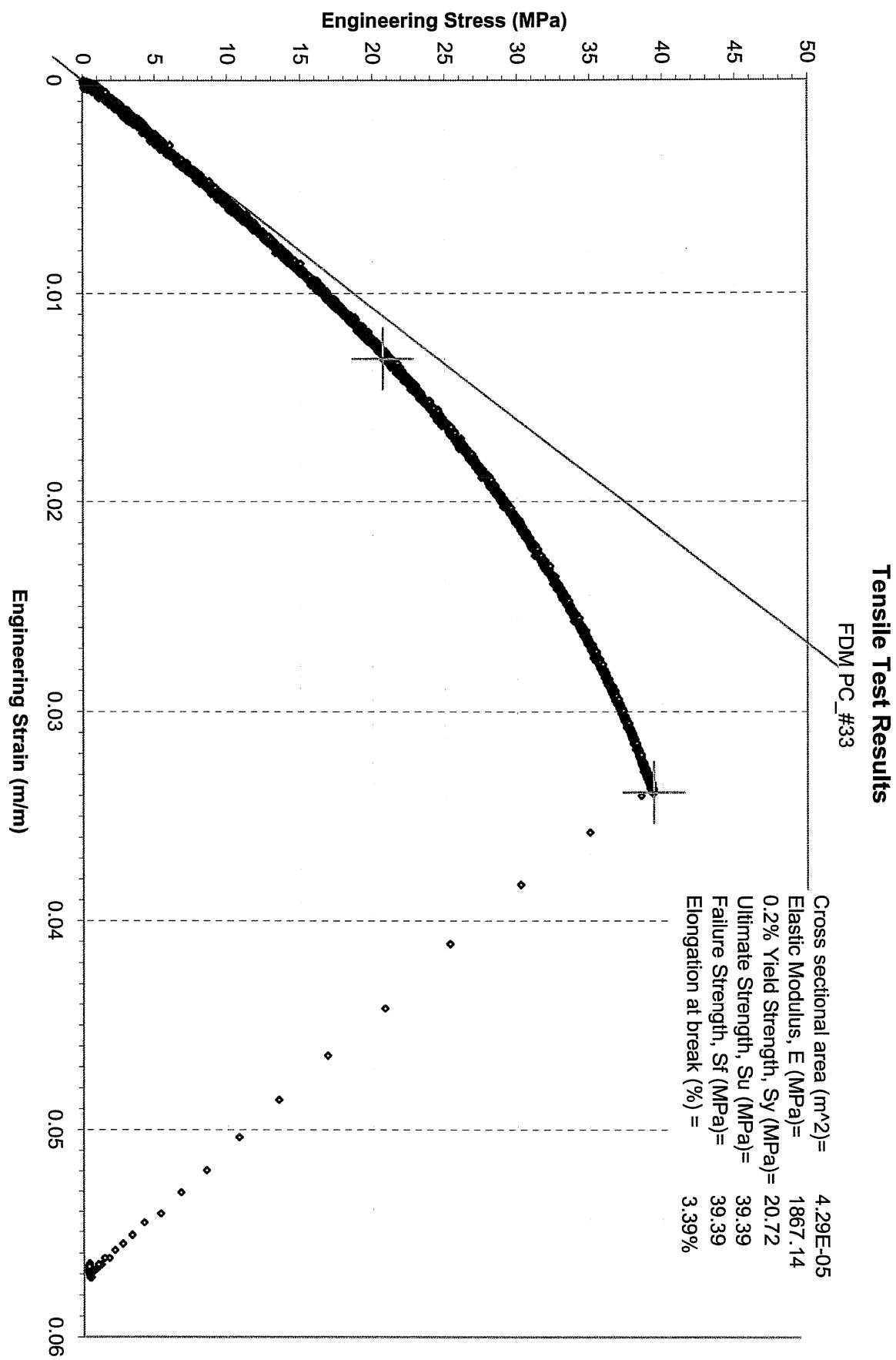
samples = 5.00
Average = 18.76
Minimum = 16.28
Maximum = 21.52
Std dev = 2.19

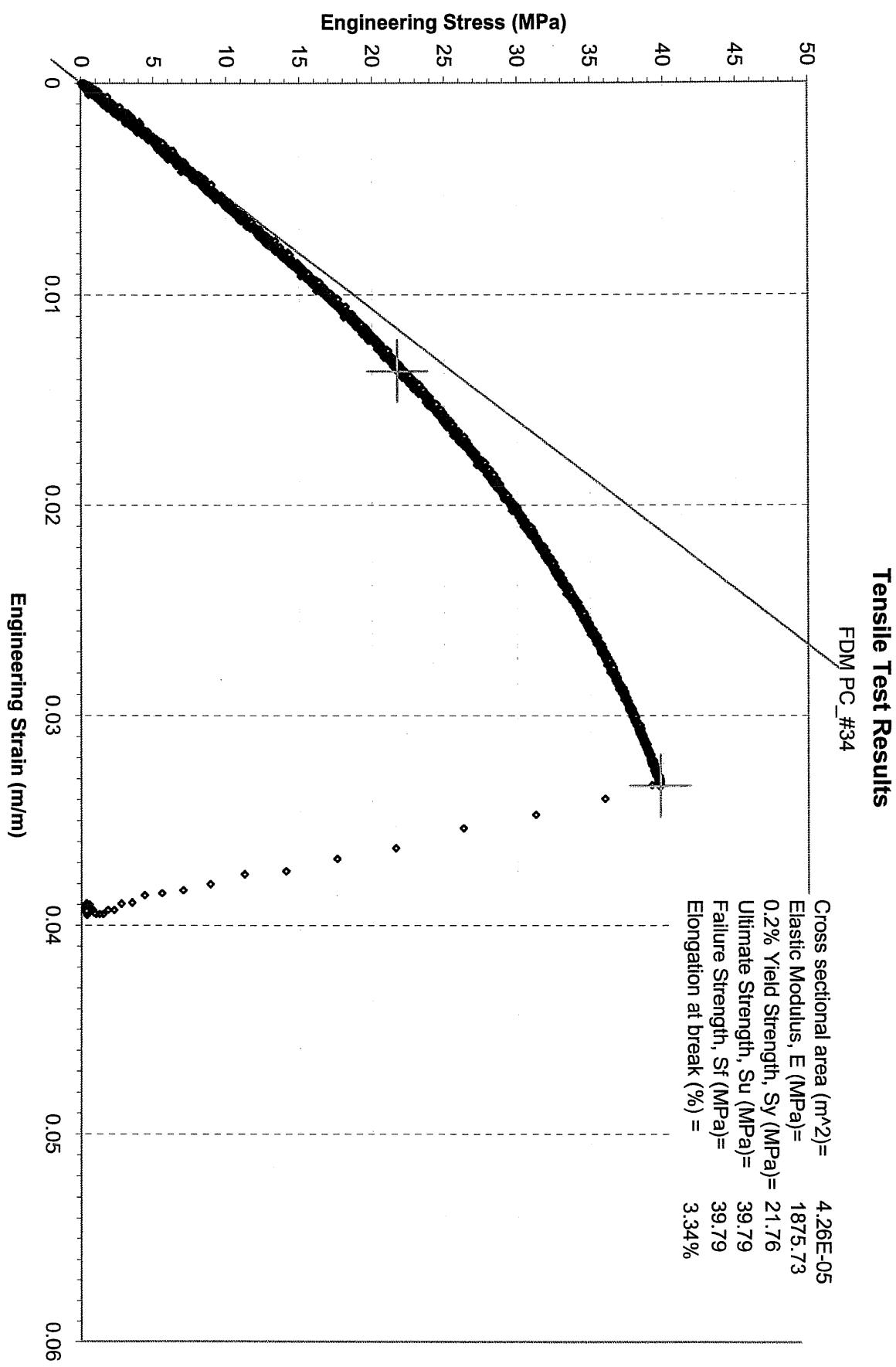
Elastic Modulus

FDM PC, irradiated



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

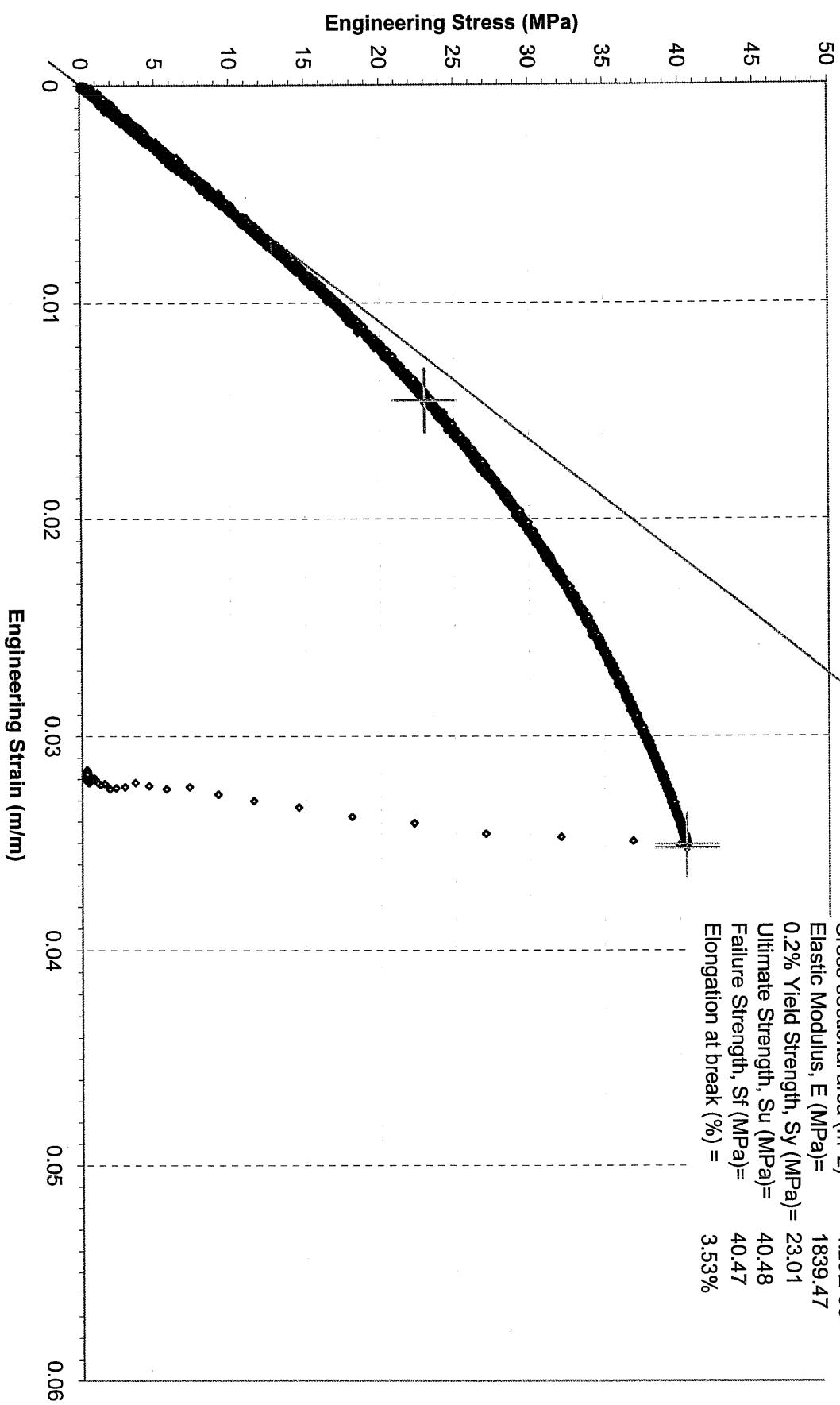




Tensile Test Results

FDM PC #35

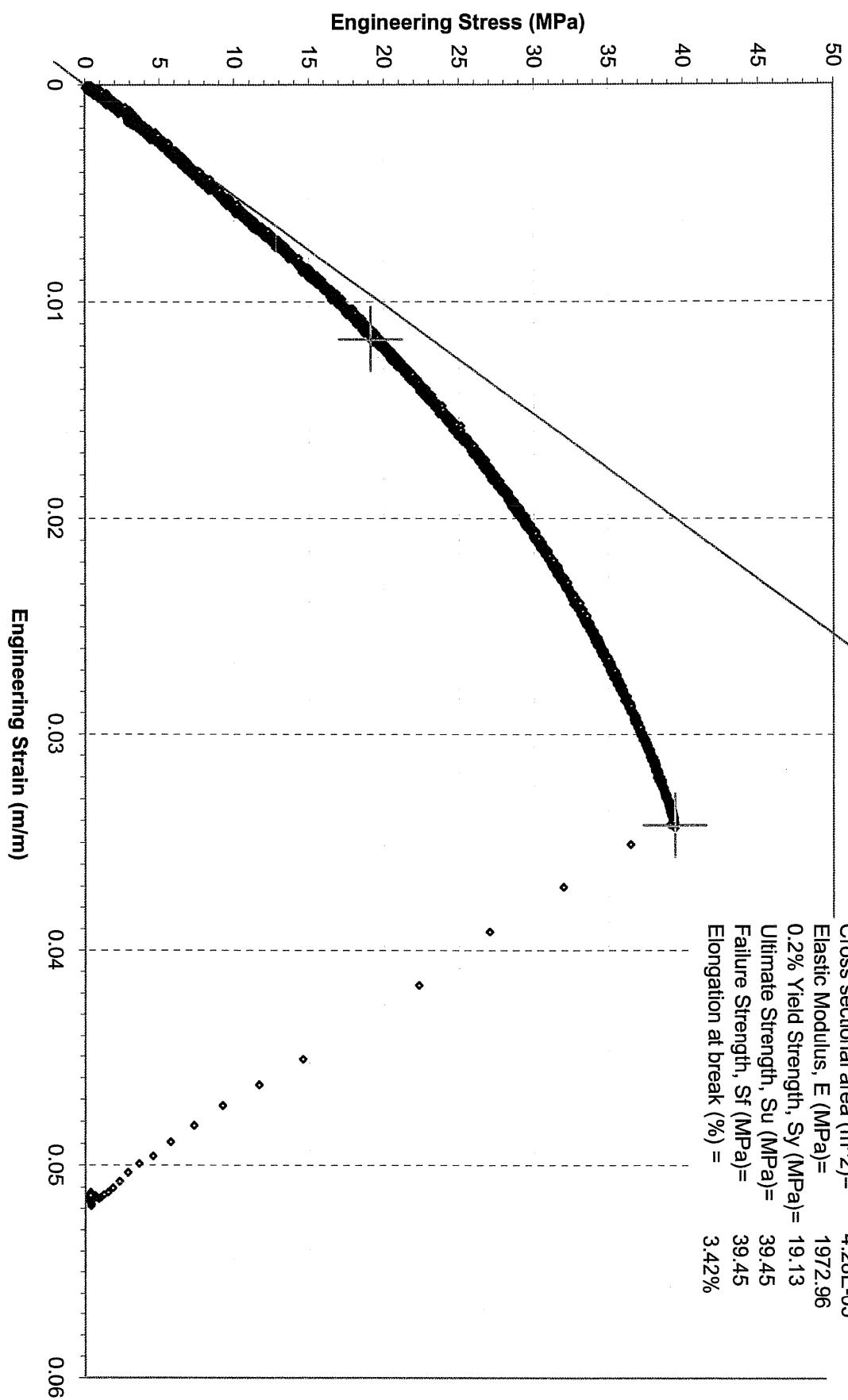
Cross sectional area (m^2) = 4.25E-05
Elastic Modulus, E (MPa) = 1839.47
0.2% Yield Strength, S_y (MPa) = 23.01
Ultimate Strength, S_u (MPa) = 40.48
Failure Strength, S_f (MPa) = 40.47
Elongation at break (%) = 3.53%



Tensile Test Results

FDM PC #36

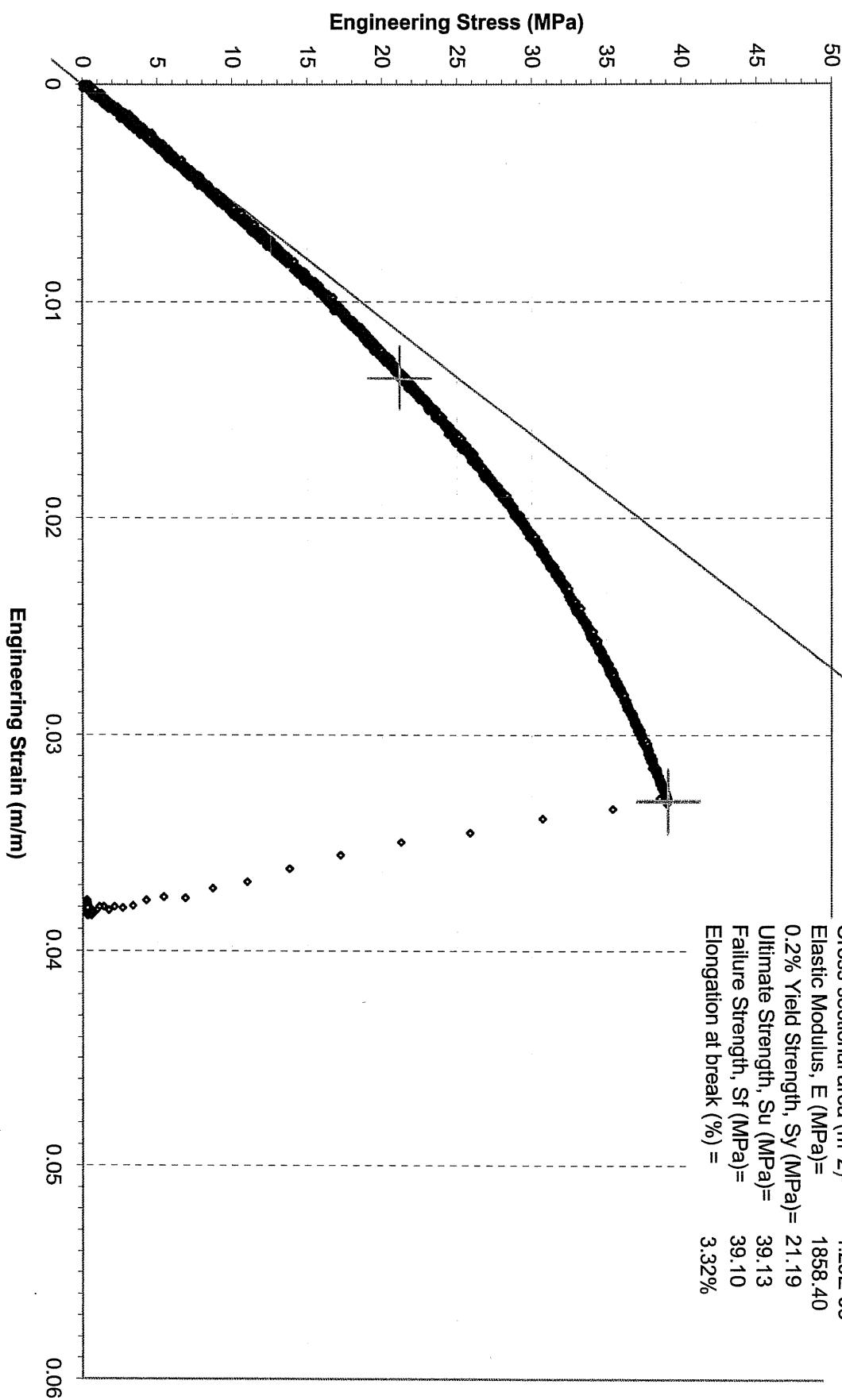
Cross sectional area (m^2) = 4.28E-05
Elastic Modulus, E (MPa) = 1972.96
0.2% Yield Strength, S_y (MPa) = 19.13
Ultimate Strength, S_u (MPa) = 39.45
Failure Strength, S_f (MPa) = 39.45
Elongation at break (%) = 3.42%



Tensile Test Results

FDM PC #37

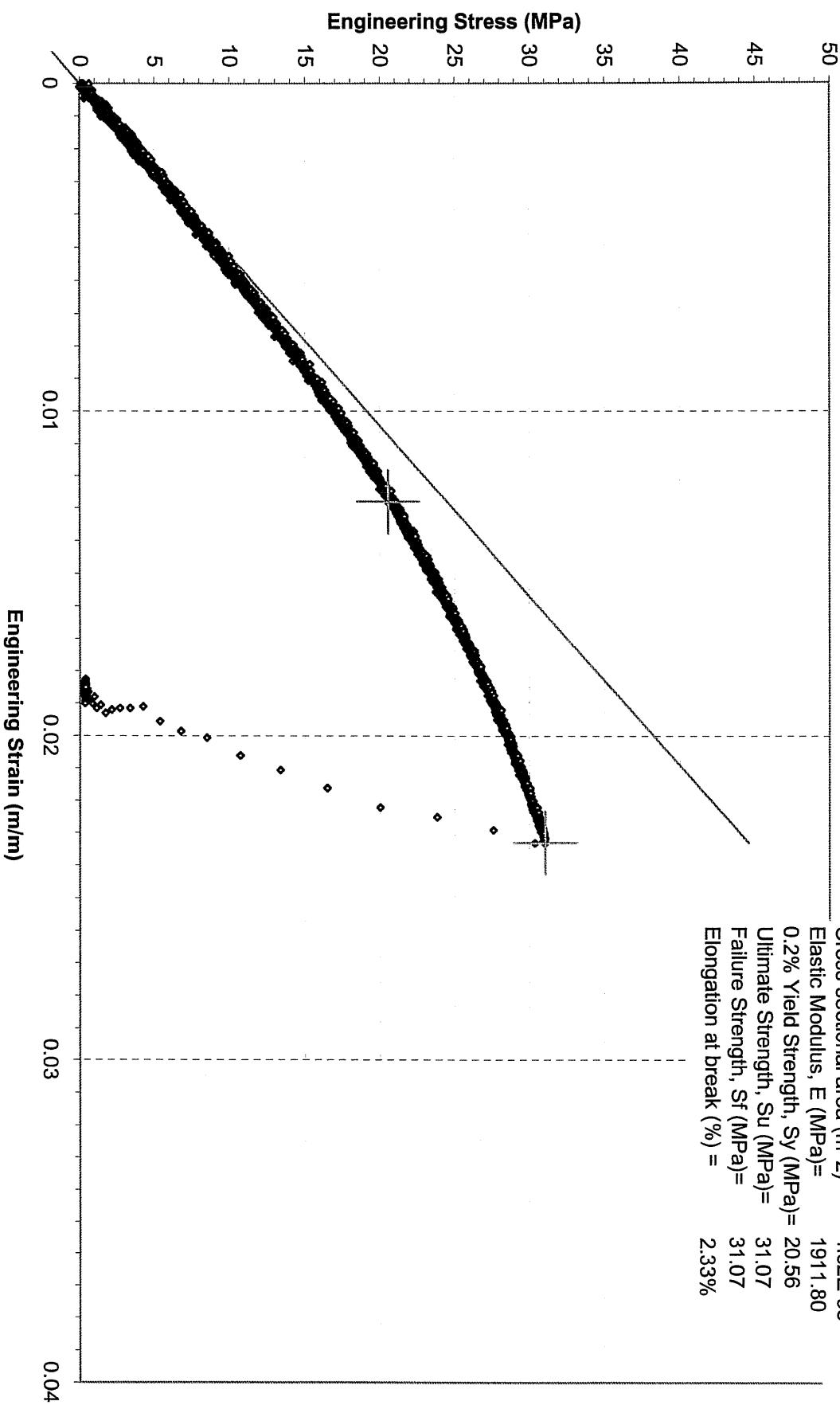
Cross sectional area (m^2) = 4.25E-05
Elastic Modulus, E (MPa) = 1858.40
0.2% Yield Strength, S_y (MPa) = 21.19
Ultimate Strength, S_u (MPa) = 39.13
Failure Strength, S_f (MPa) = 39.10
Elongation at break (%) = 3.32%



Tensile Test Results

FDM PC Irradiated #28

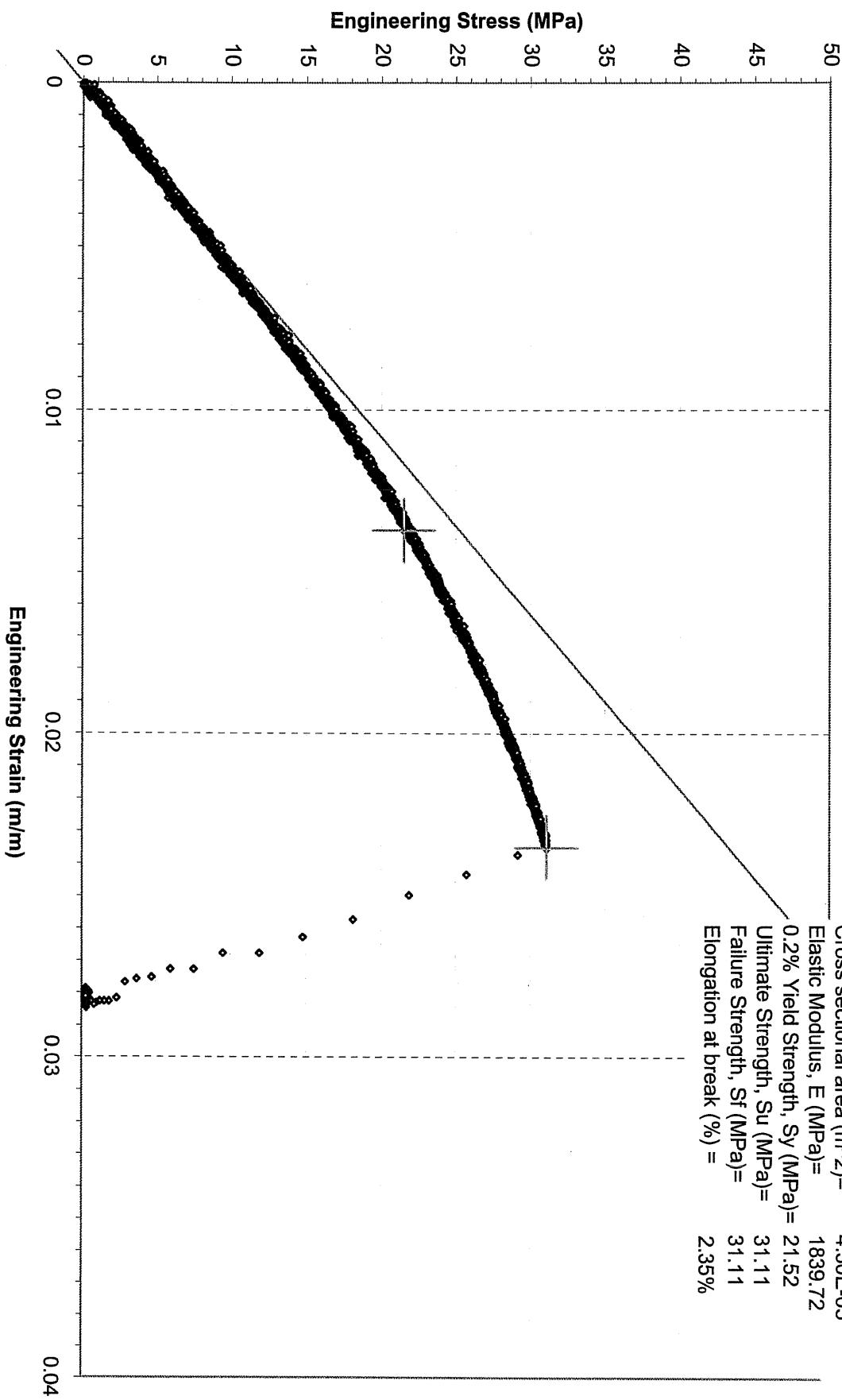
Cross sectional area (m^2) = 4.32E-05
Elastic Modulus, E (MPa) = 1911.80
0.2% Yield Strength, S_y (MPa) = 20.56
Ultimate Strength, S_u (MPa) = 31.07
Failure Strength, S_f (MPa) = 31.07
Elongation at break (%) = 2.33%



Tensile Test Results

FDM PC Irradiated #29

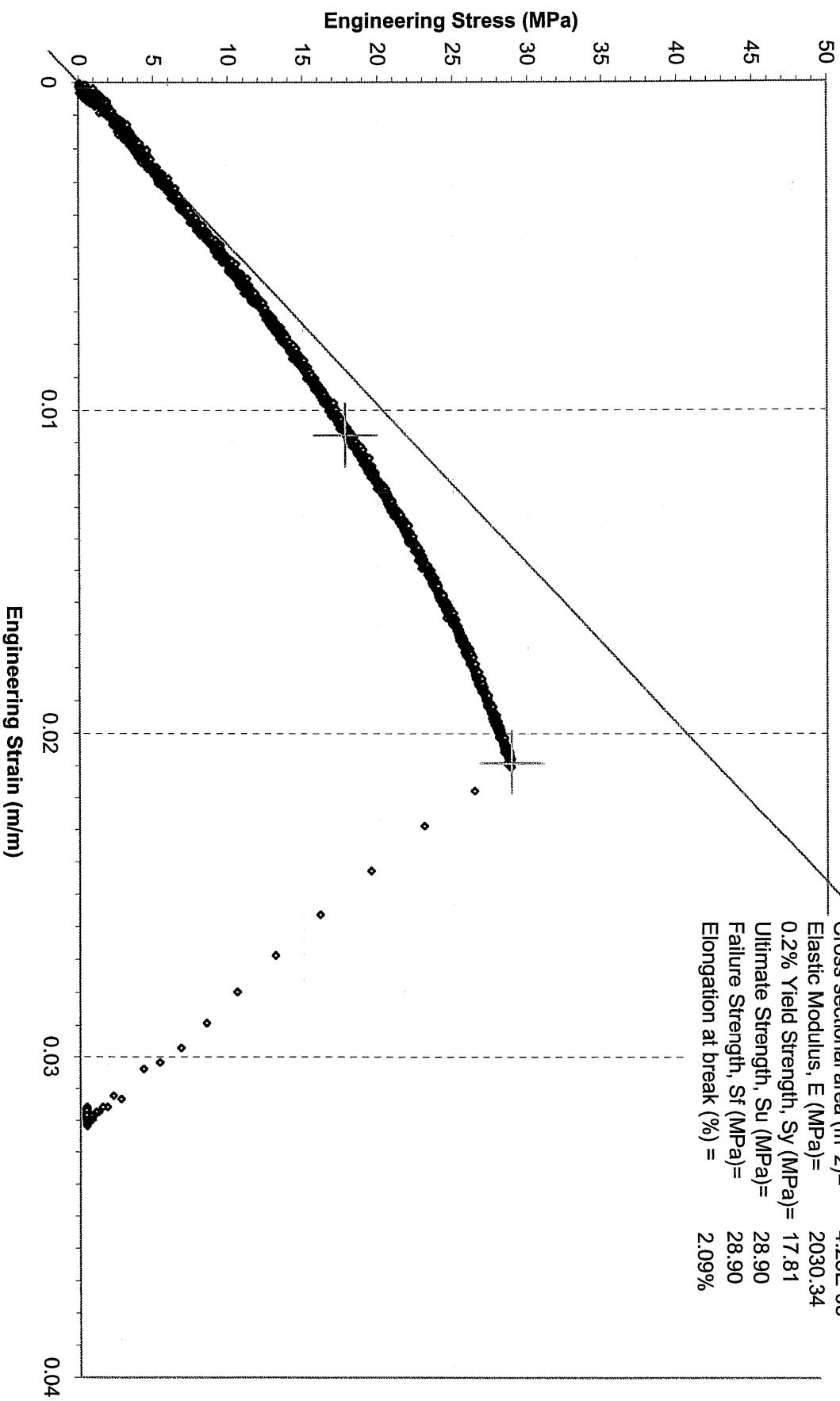
Cross sectional area (m^2) =	4.30E-05
Elastic Modulus, E (MPa) =	1839.72
0.2% Yield Strength, S_y (MPa) =	21.52
Ultimate Strength, S_u (MPa) =	31.11
Failure Strength, S_f (MPa) =	31.11
Elongation at break (%) =	2.35%



Tensile Test Results

FDM PC Irradiated _#30

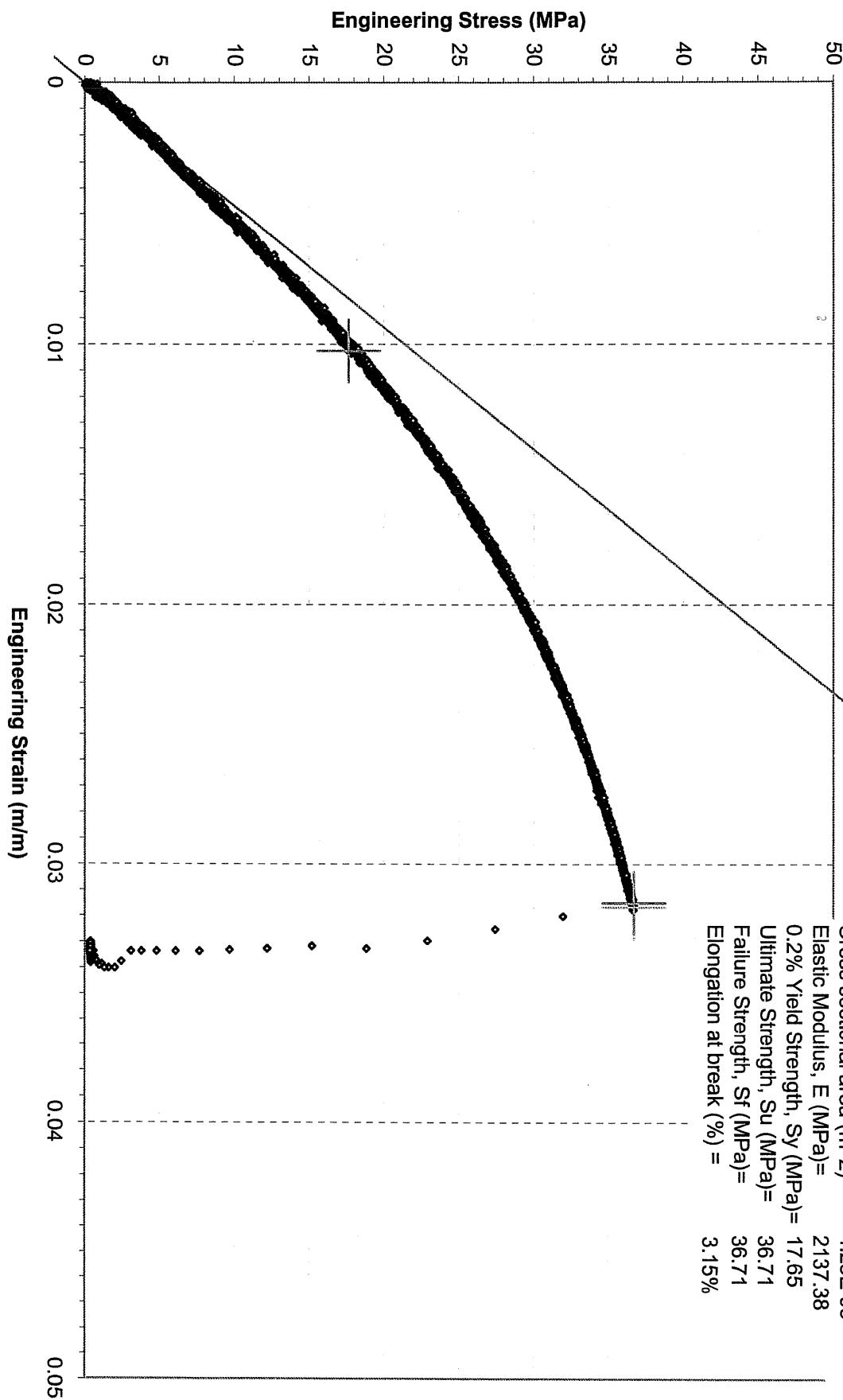
Cross sectional area (m^2)= 4.28E-05
Elastic Modulus, E (MPa)= 2030.34
0.2% Yield Strength, S_y (MPa)= 17.81
Ultimate Strength, S_u (MPa)= 28.90
Failure Strength, S_f (MPa)= 28.90
Elongation at break (%)= 2.09%

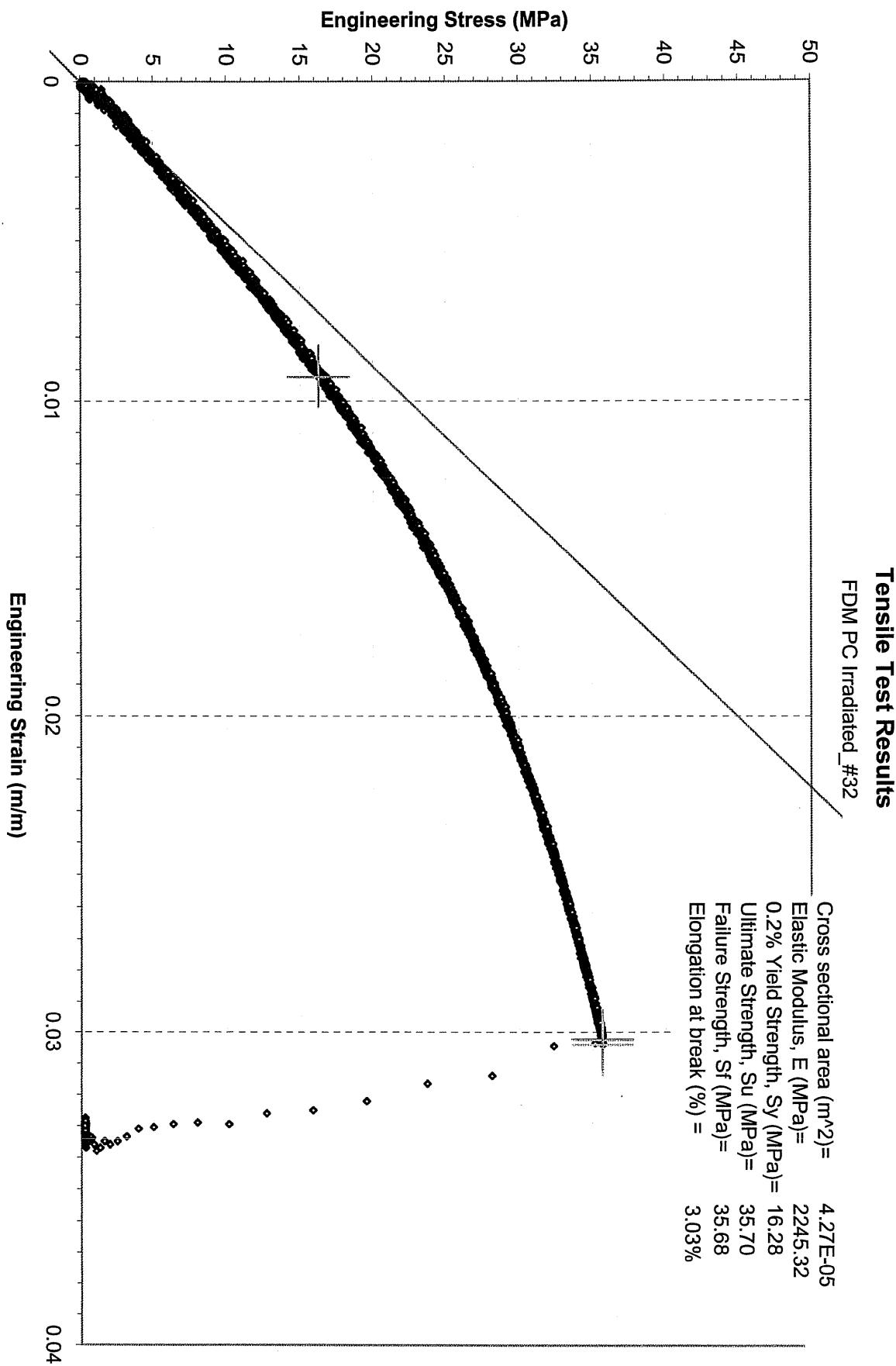


Tensile Test Results

FDM PC Irradiated #31

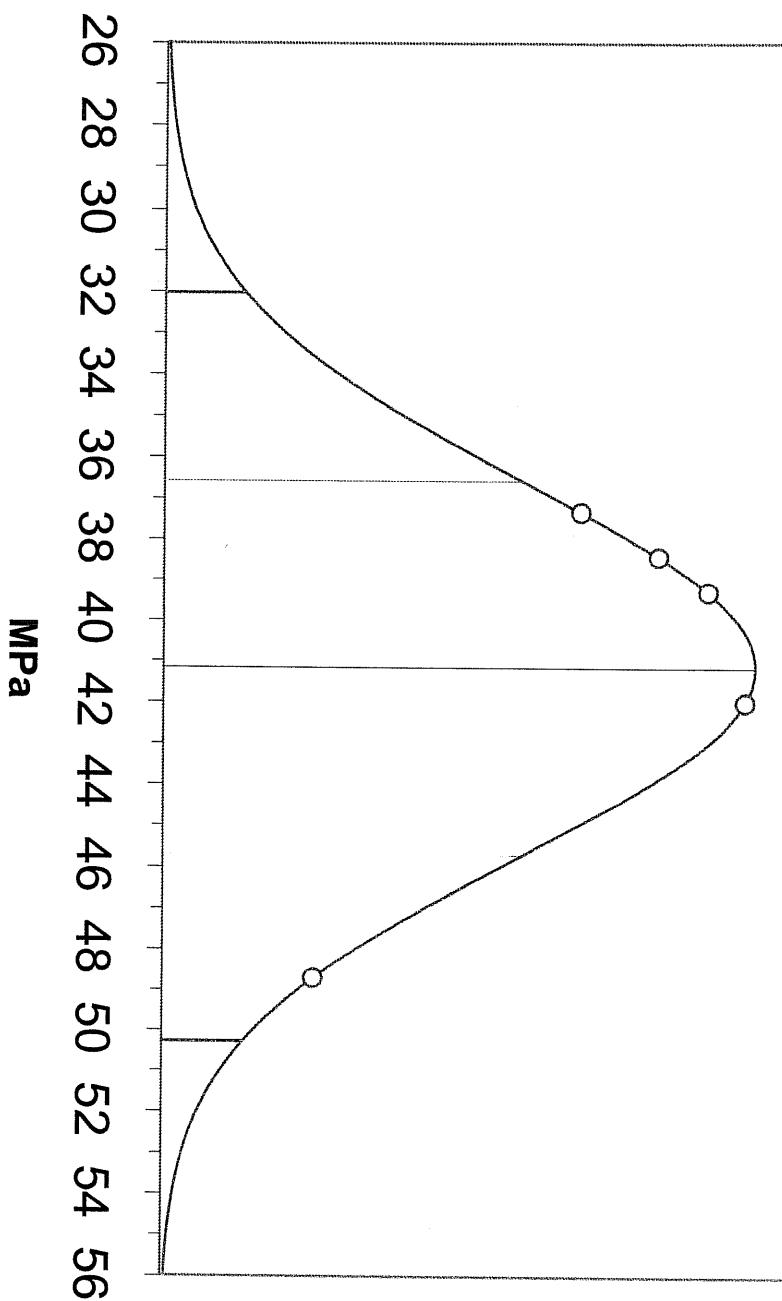
Cross sectional area (m^2)= 4.28E-05
Elastic Modulus, E (MPa)= 2137.38
0.2% Yield Strength, S_y (MPa)= 17.65
Ultimate Strength, S_u (MPa)= 36.71
Failure Strength, S_f (MPa)= 36.71
Elongation at break (%)= 3.15%





Ultimate Strength

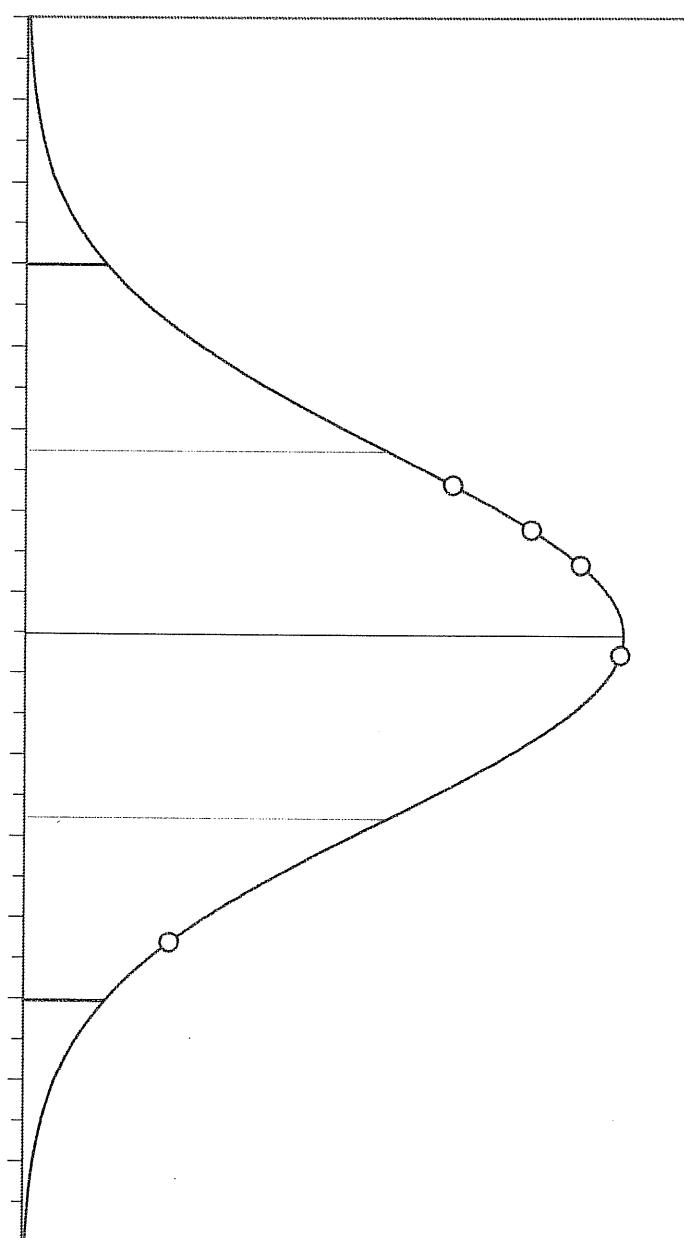
FDM PPSF, irradiated



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

Stress at Failure

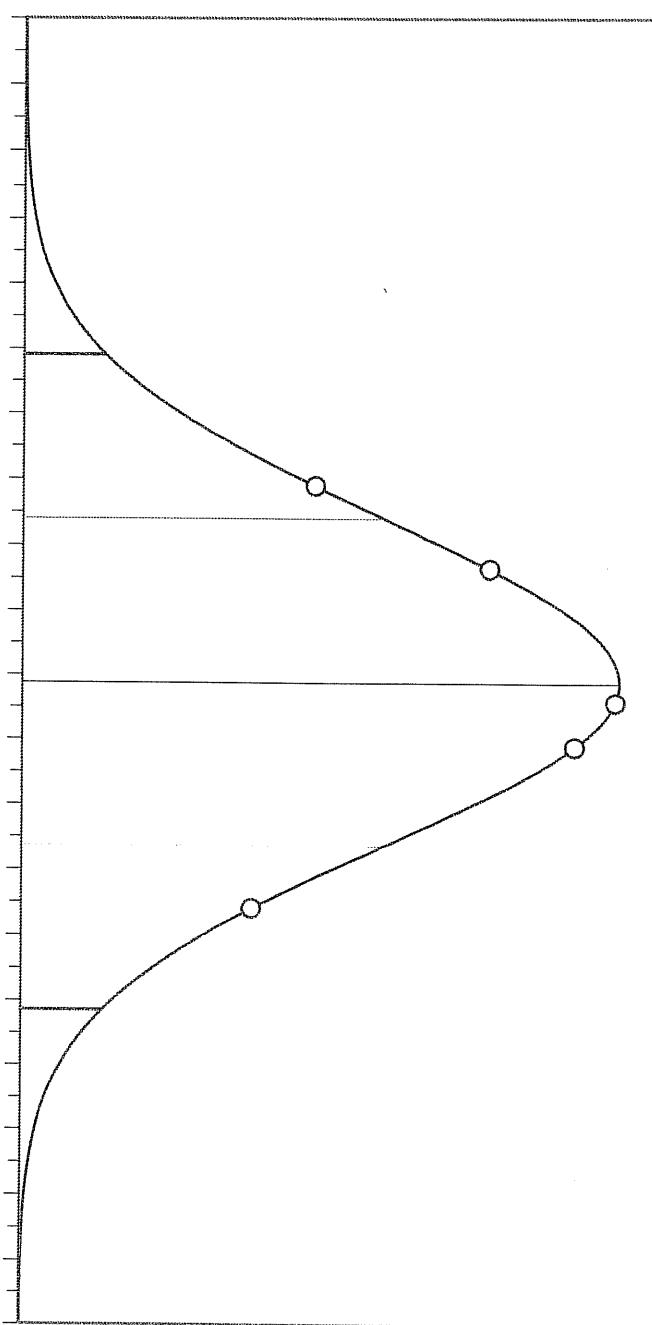
FDM PPSF, irradiated



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

Yield Strength

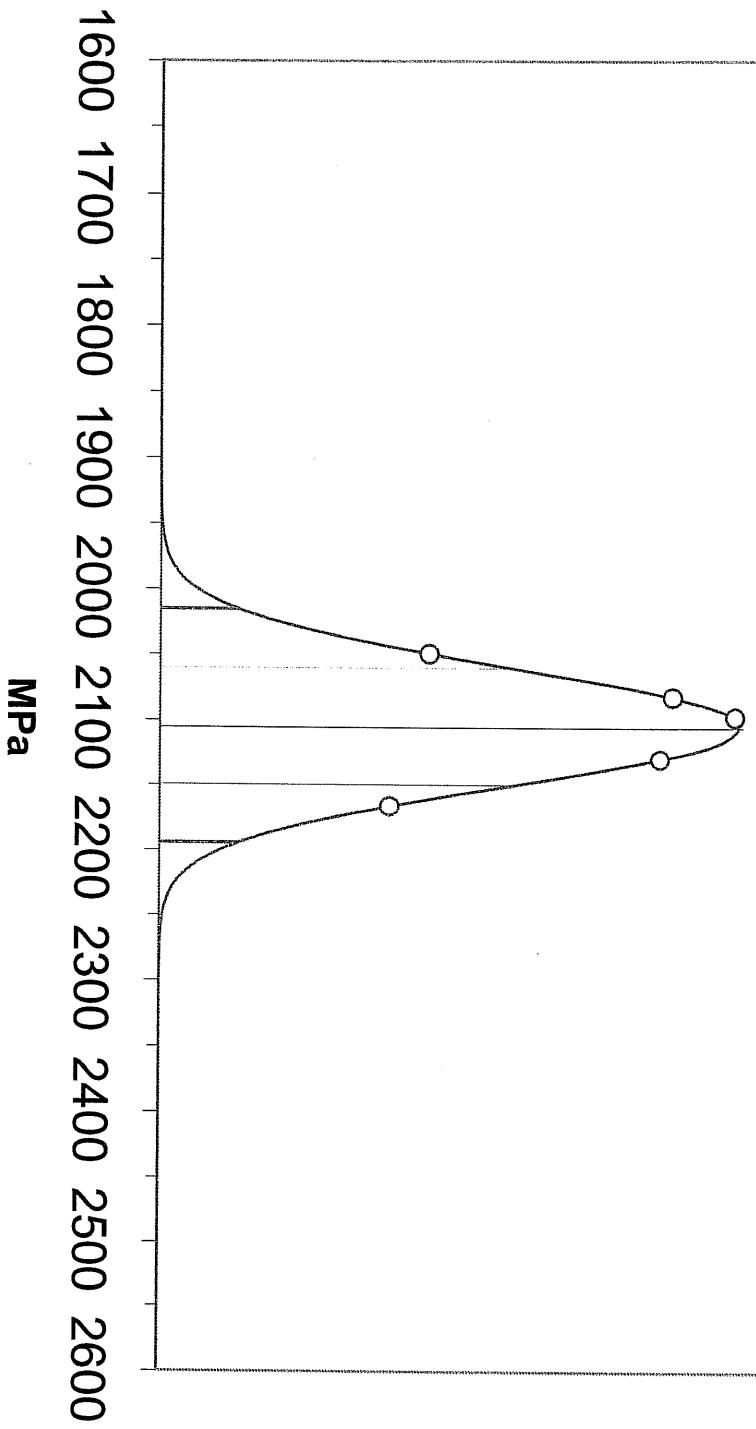
FDM PPSF, irradiated



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

Elastic Modulus

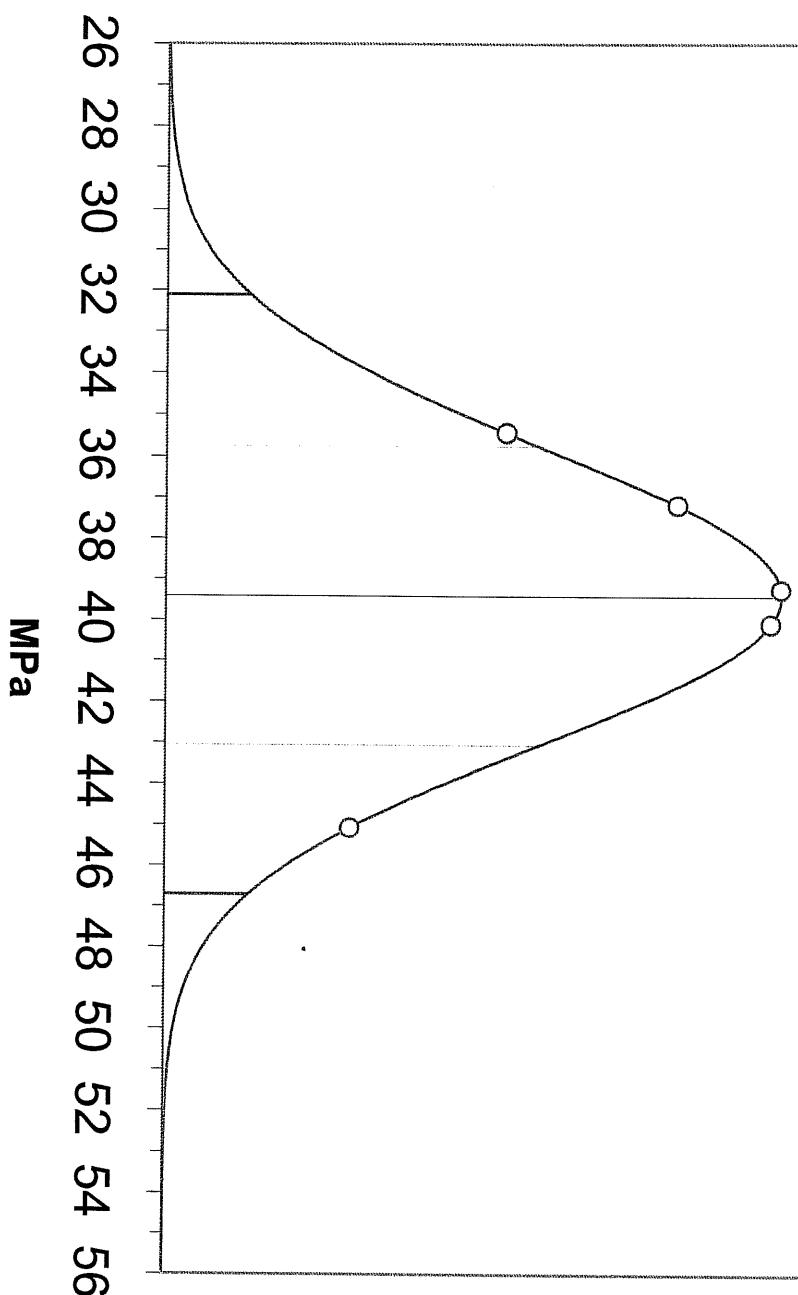
FDM PPSF, irradiated



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

Ultimate Strength

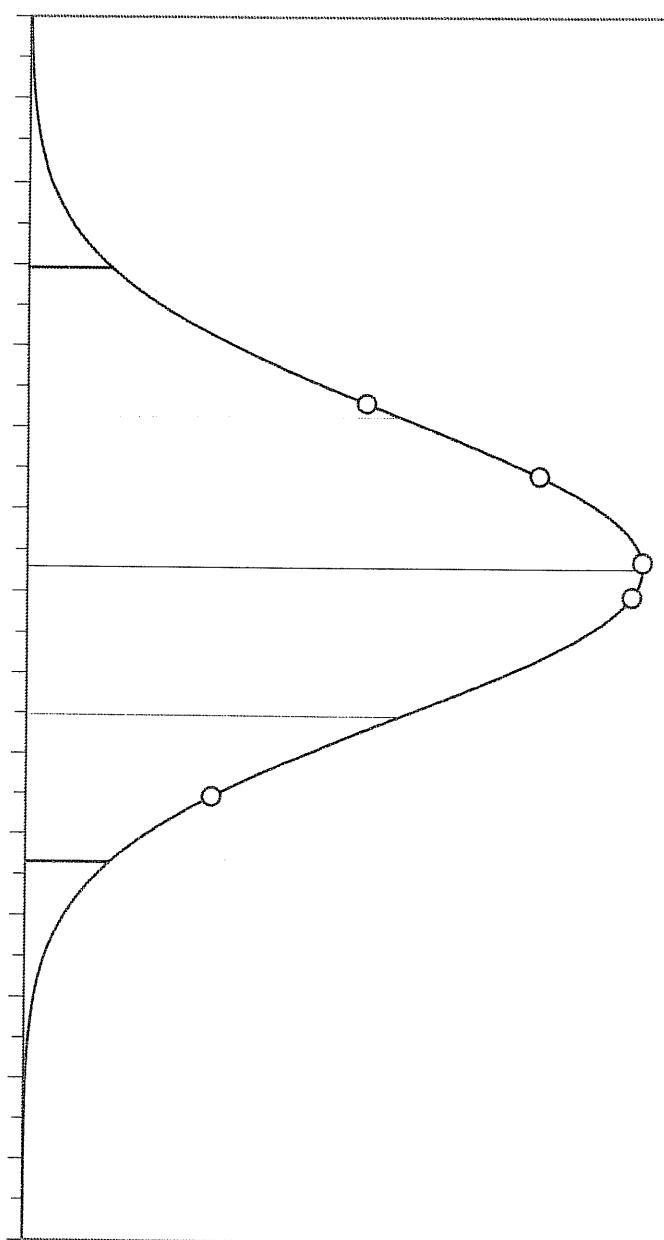
FDM PPSF



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

Stress at Failure

FDM PPSF

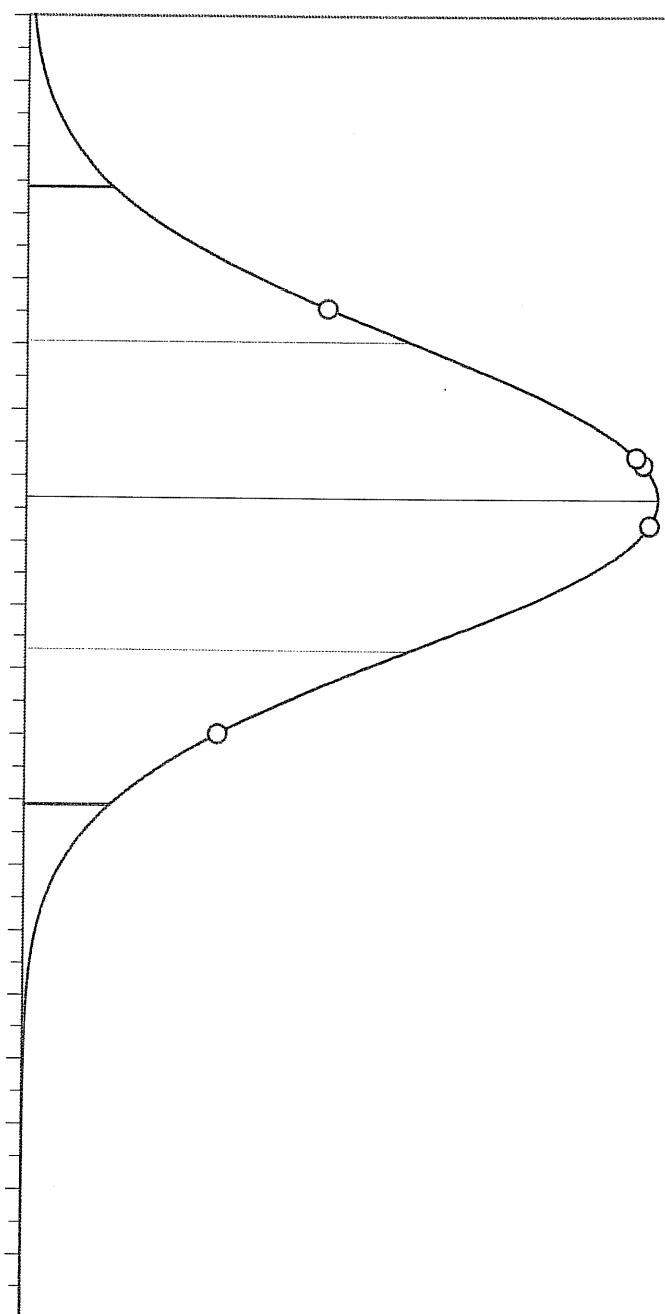


samples = 5.00
Average = 39.40
Minimum = 35.41
Maximum = 45.07
Std dev = 3.66

Yield Strength

FDM PPSF

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

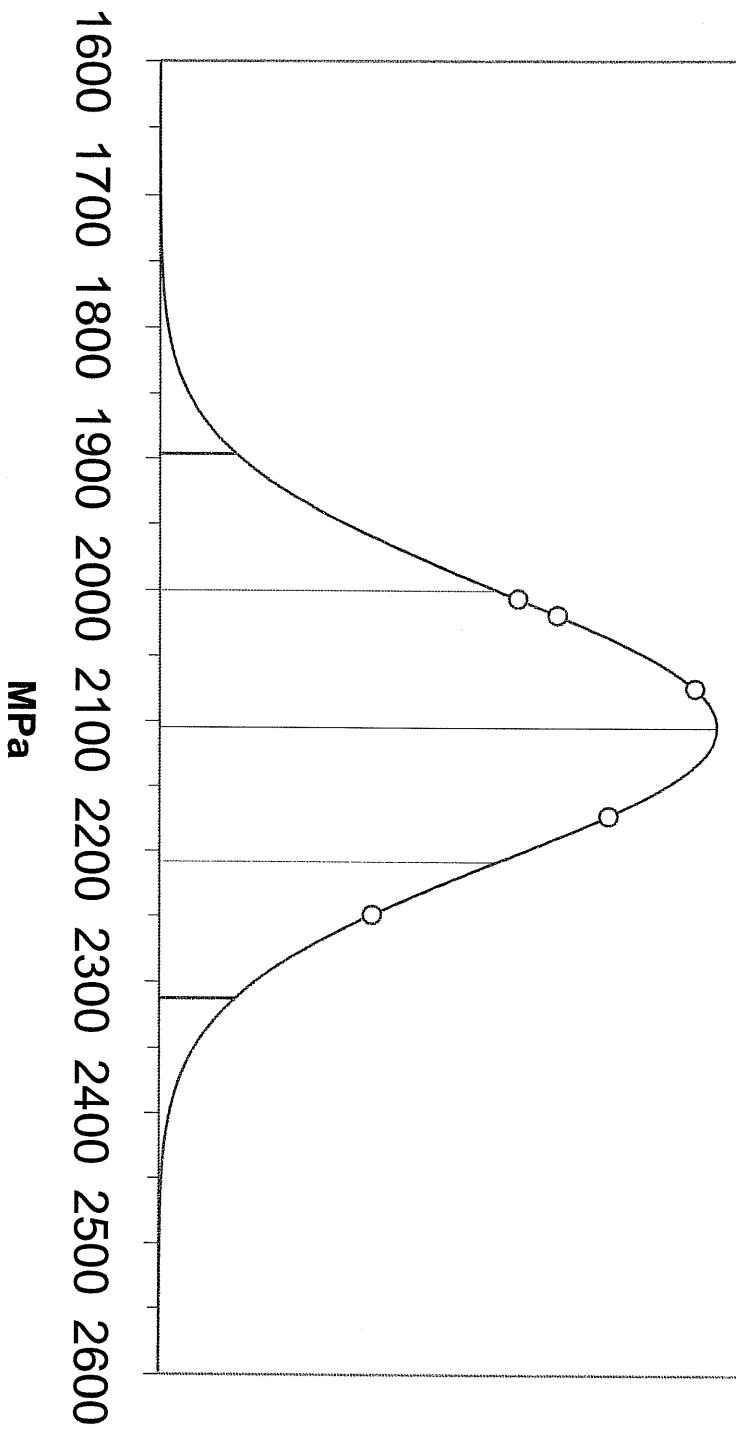


16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

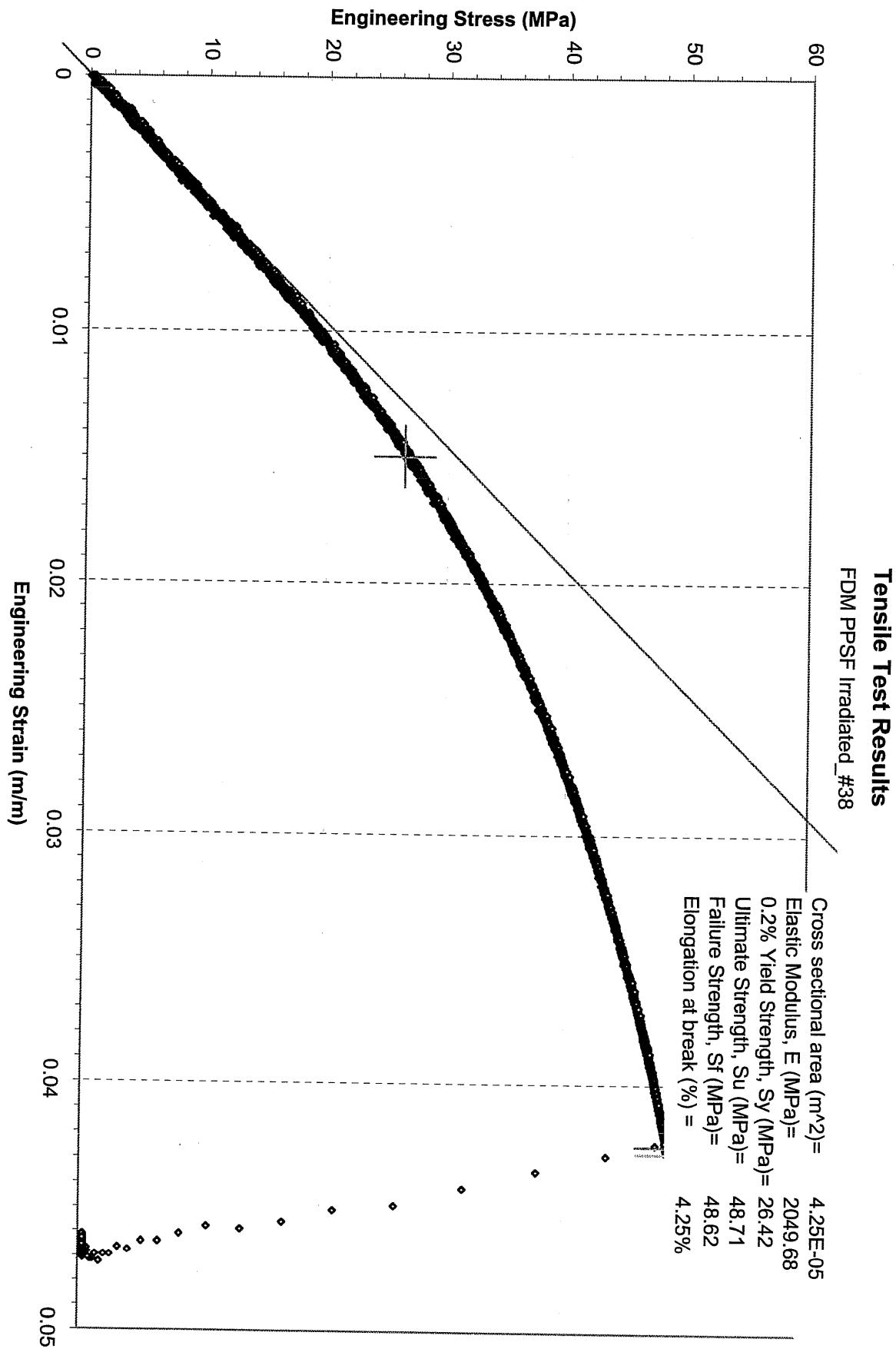
MPa

Elastic Modulus

FDM PPSF



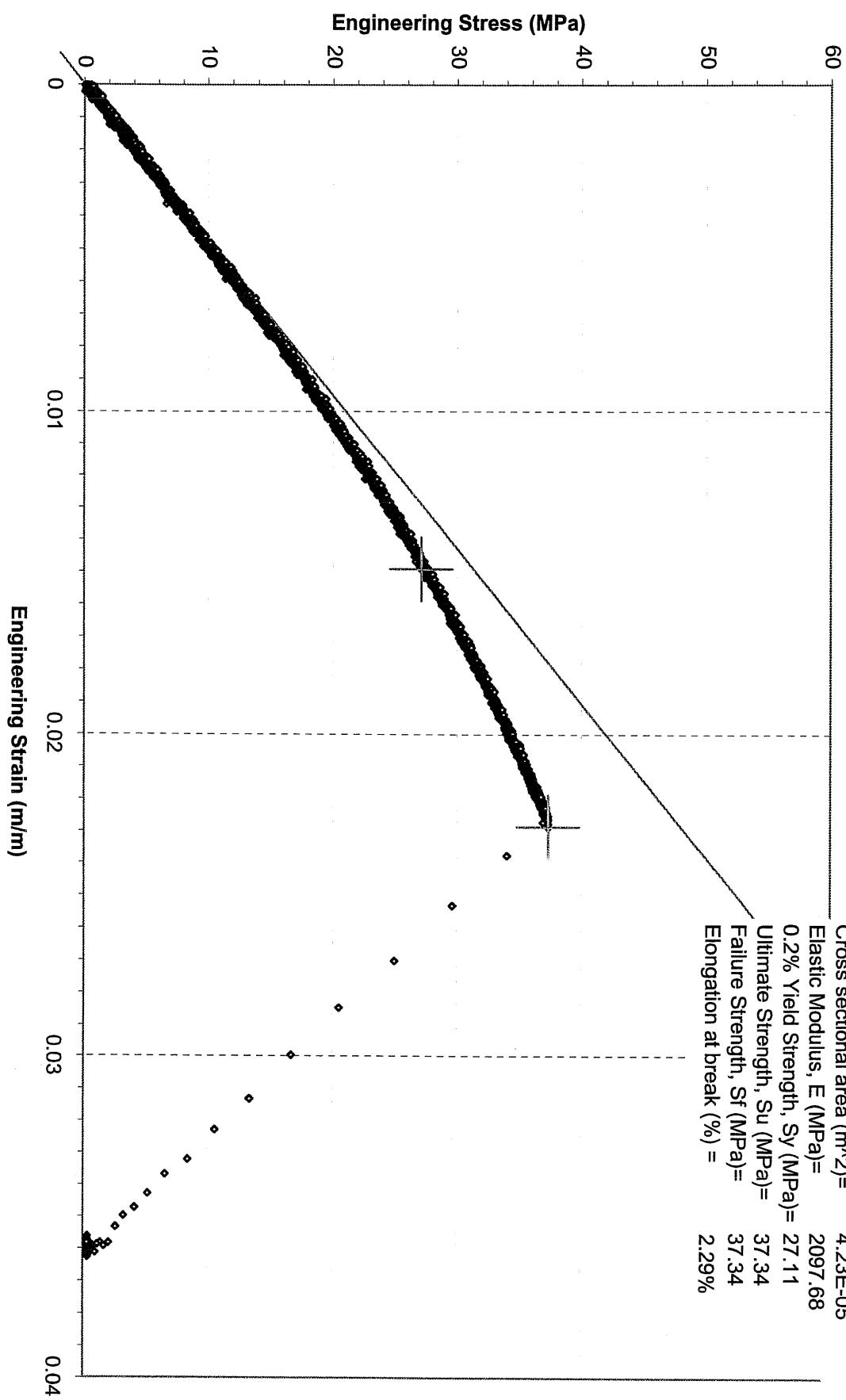
samples = 5.00
Average = 2104.63
Minimum = 2006.81
Maximum = 2249.19
Std dev = 104.03



Tensile Test Results

FDM PPSF Irradiated #39

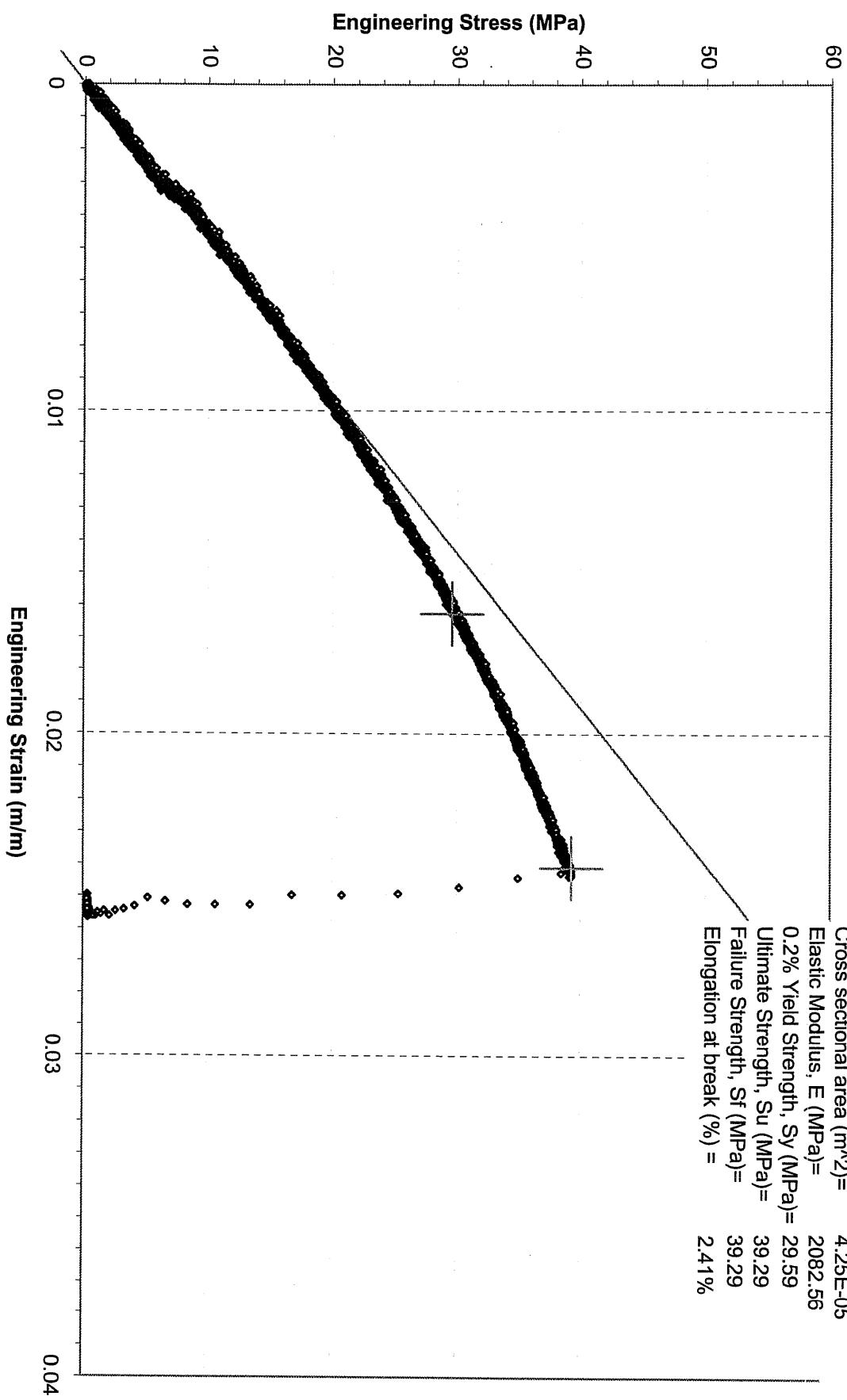
Cross sectional area (m^2)= 4.23E-05
Elastic Modulus, E (MPa)= 2097.68
0.2% Yield Strength, S_y (MPa)= 27.11
Ultimate Strength, S_u (MPa)= 37.34
Failure Strength, S_f (MPa)= 37.34
Elongation at break (%)= 2.29%



Tensile Test Results

FDM PPSF Irradiated #40

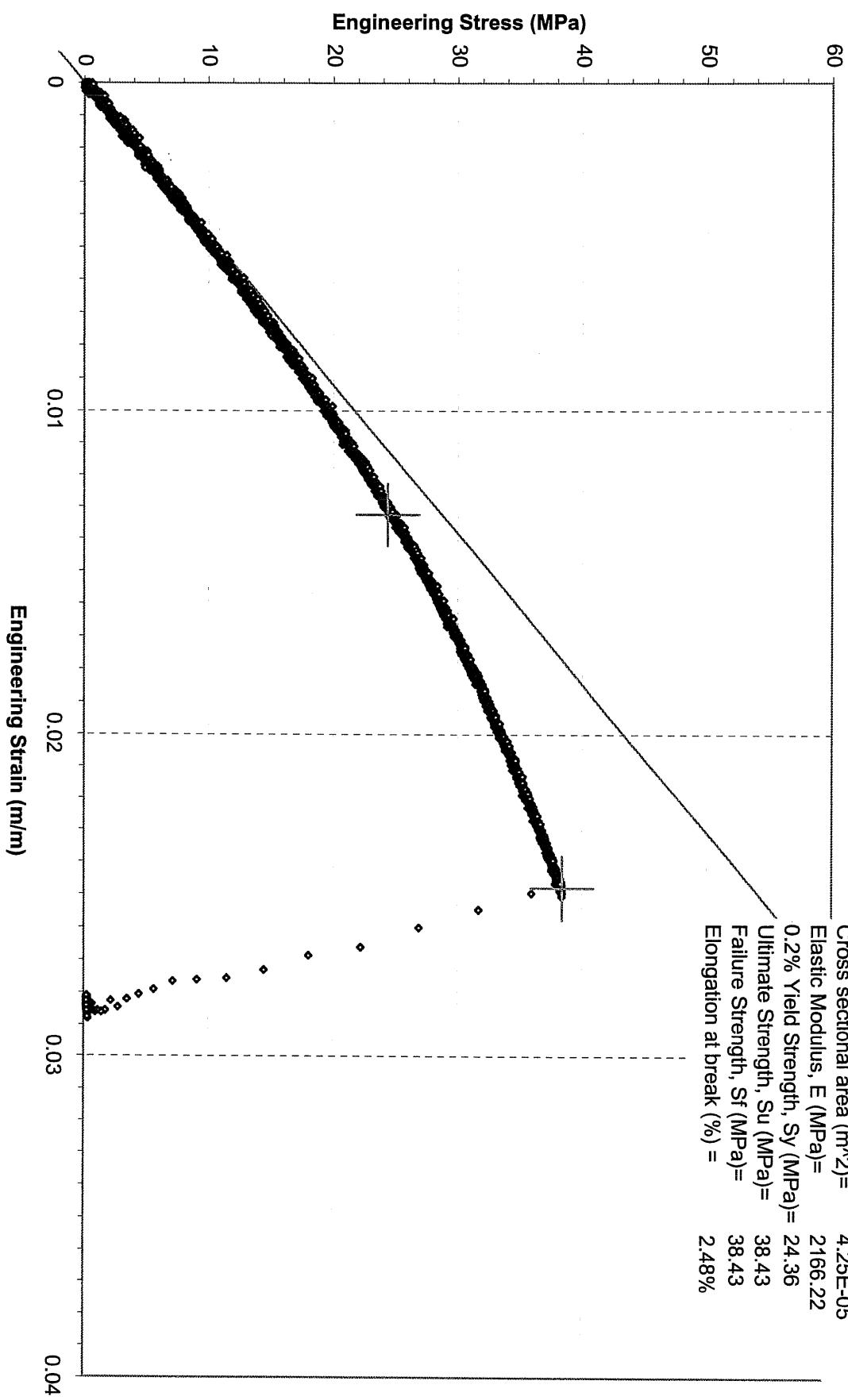
Cross sectional area (m^2)= 4.25E-05
Elastic Modulus, E (MPa)= 2082.56
0.2% Yield Strength, S_y (MPa)= 29.59
Ultimate Strength, S_u (MPa)= 39.29
Failure Strength, S_f (MPa)= 39.29
Elongation at break (%)= 2.41%

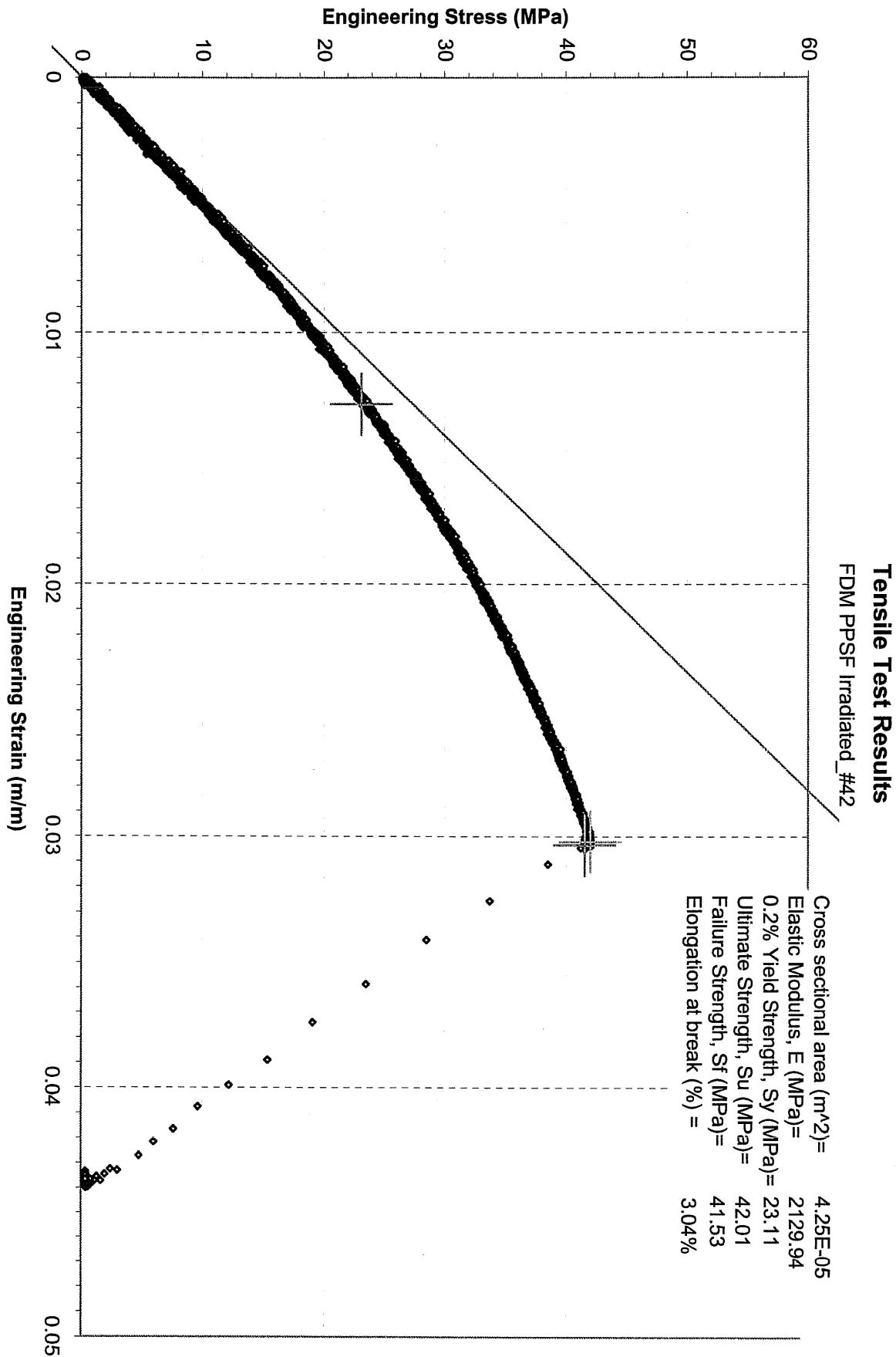


Tensile Test Results

FDM PPSF Irradiated #41

Cross sectional area (m^2)= 4.25E-05
Elastic Modulus, E (MPa)= 2166.22
0.2% Yield Strength, S_y (MPa)= 24.36
Ultimate Strength, S_u (MPa)= 38.43
Failure Strength, S_f (MPa)= 38.43
Elongation at break (%)= 2.48%

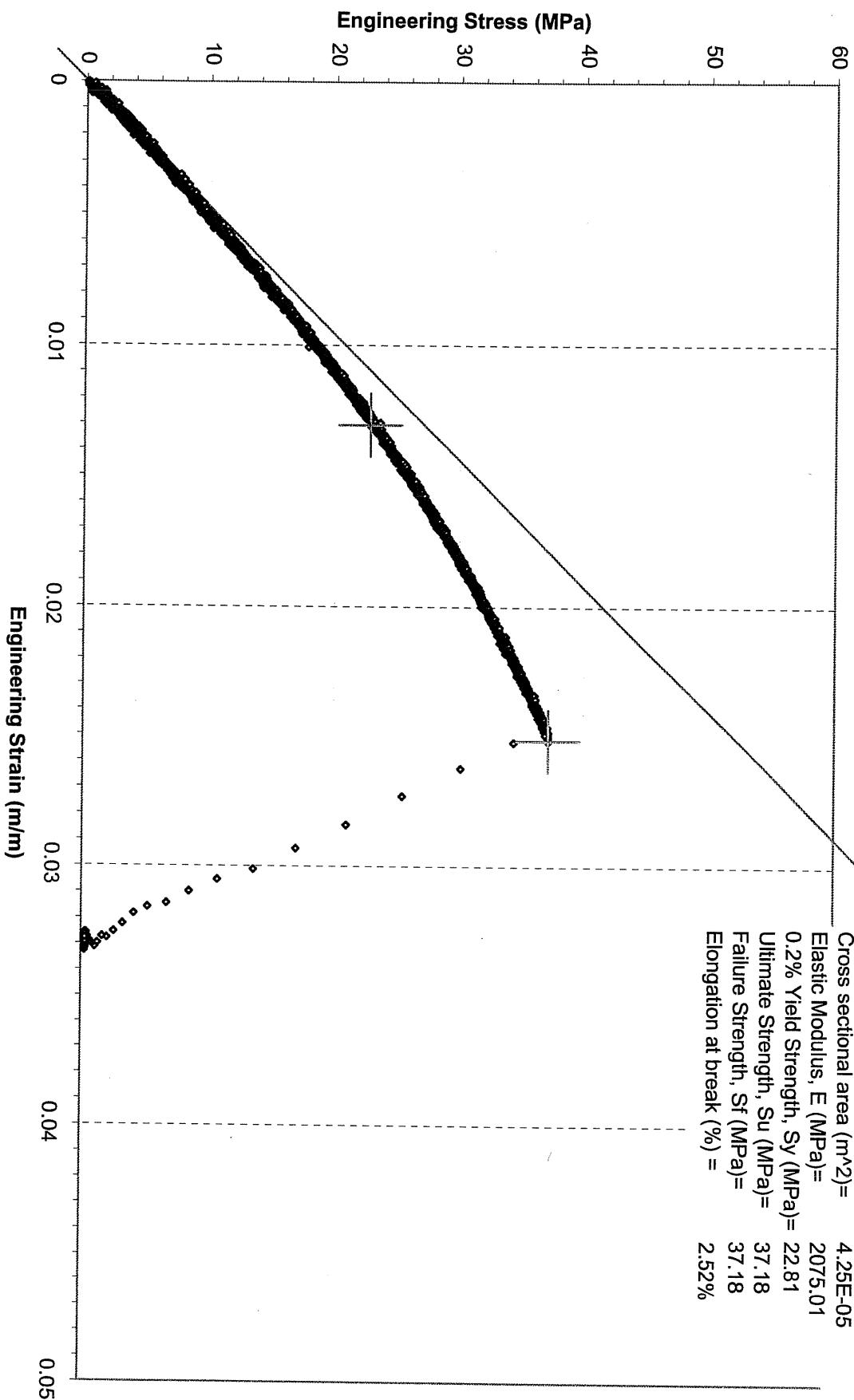




Tensile Test Results

FDM PPSF #43

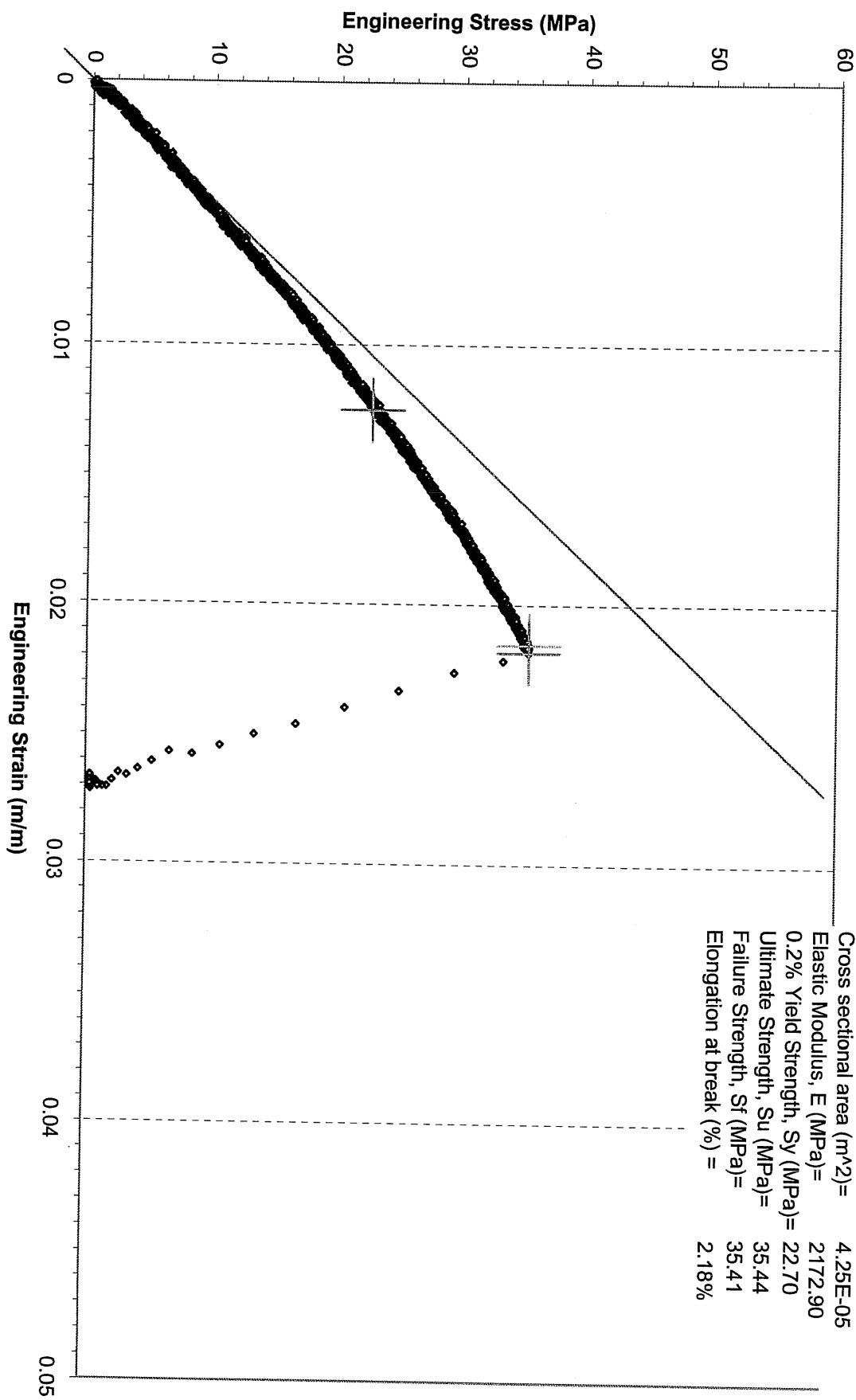
Cross sectional area (m^2) = 4.25E-05
Elastic Modulus, E (MPa) = 2075.01
0.2% Yield Strength, S_y (MPa) = 22.81
Ultimate Strength, S_u (MPa) = 37.18
Failure Strength, S_f (MPa) = 37.18
Elongation at break (%) = 2.52%



Tensile Test Results

FDM PPSF #44

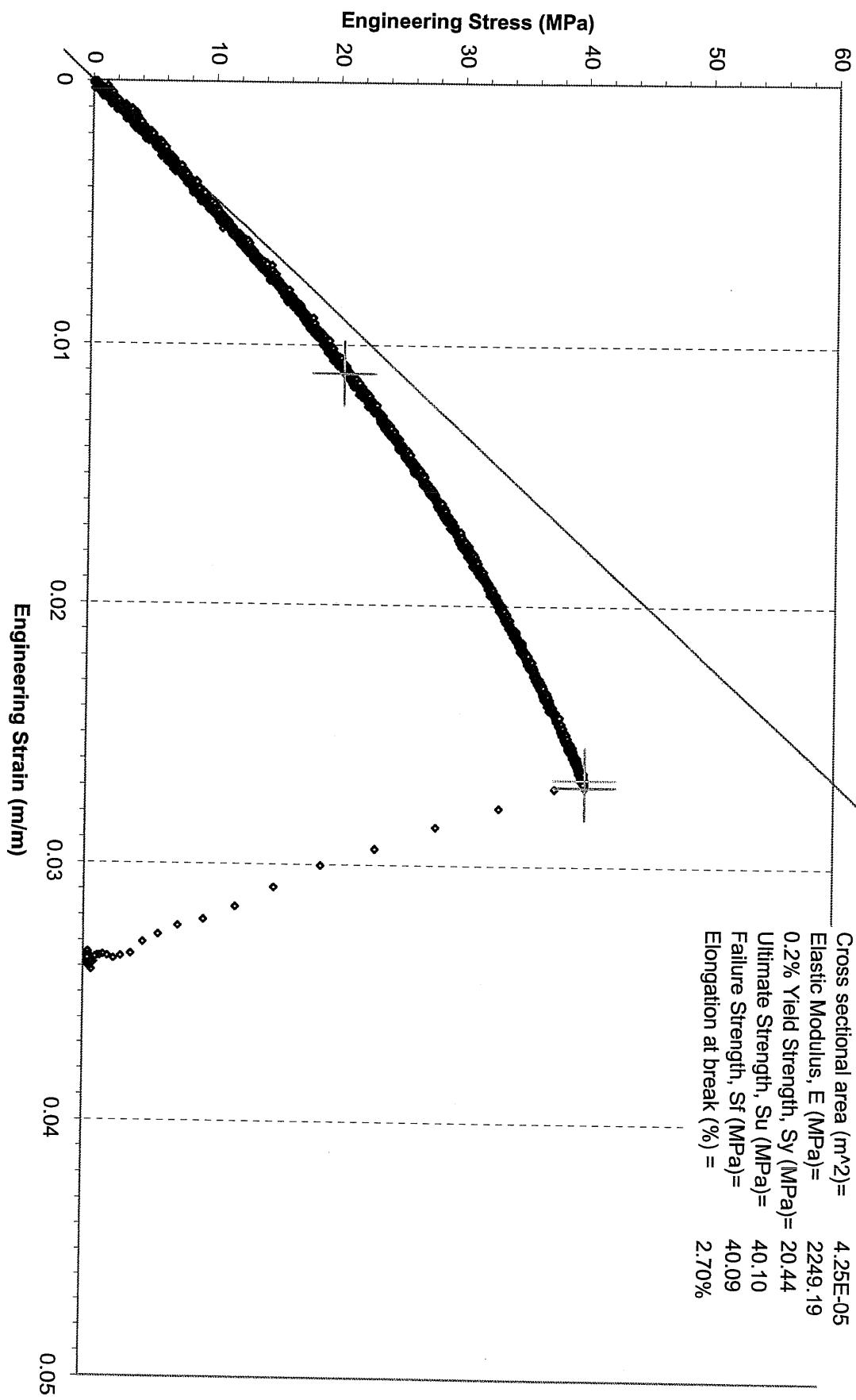
Cross sectional area (m^2) = 4.25E-05
Elastic Modulus, E (MPa) = 2172.90
0.2% Yield Strength, S_y (MPa) = 22.70
Ultimate Strength, S_u (MPa) = 35.44
Failure Strength, S_f (MPa) = 35.41
Elongation at break (%) = 2.18%



Tensile Test Results

FDM PPSF #45

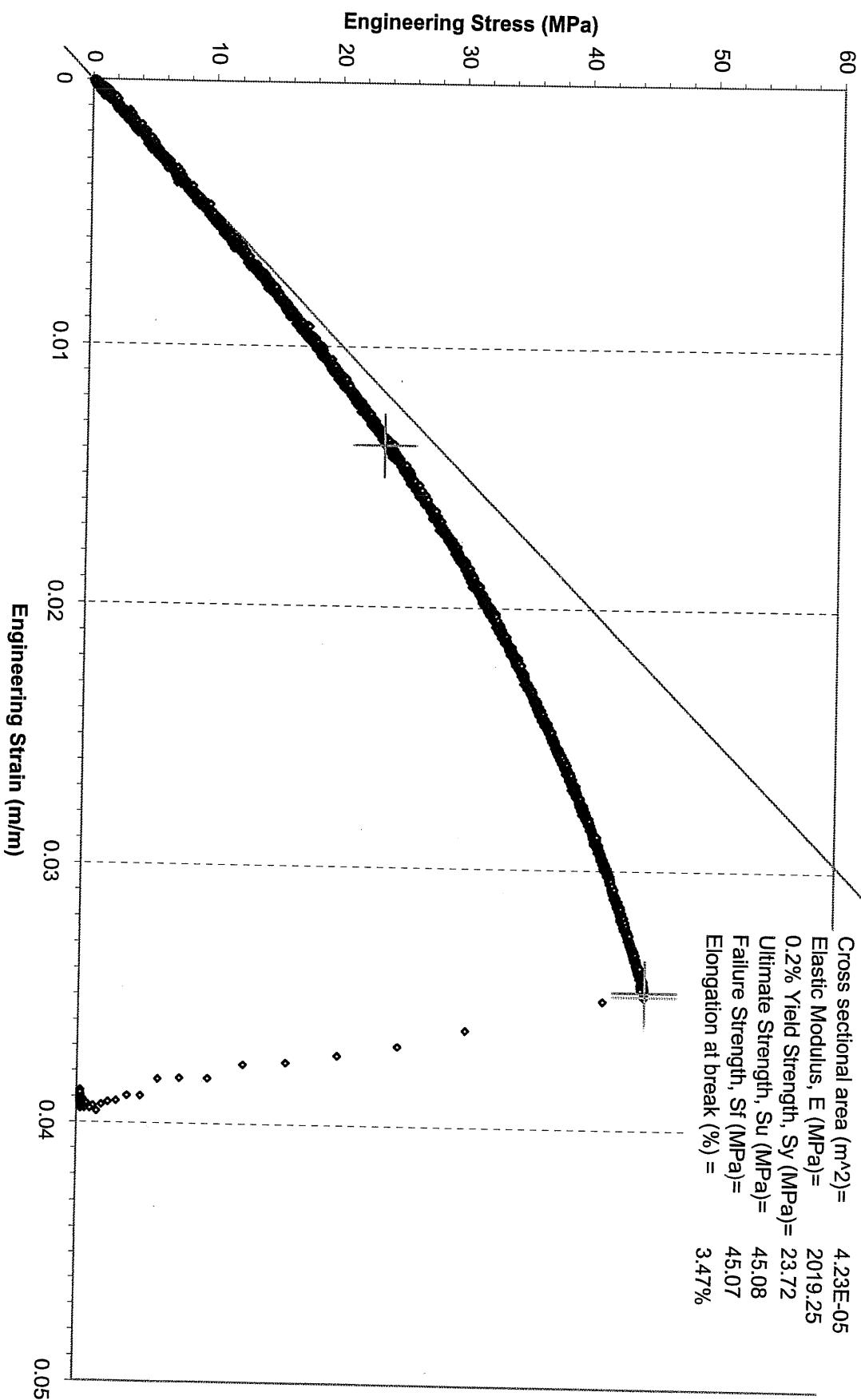
Cross sectional area (m^2) = 4.25E-05
Elastic Modulus, E (MPa) = 2249.19
0.2% Yield Strength, Sy (MPa) = 20.44
Ultimate Strength, Su (MPa) = 40.10
Failure Strength, Sf (MPa) = 40.09
Elongation at break (%) = 2.70%



Tensile Test Results

FDM PPSF #46

Cross sectional area (m^2) = 4.23E-05
Elastic Modulus, E (MPa) = 2019.25
0.2% Yield Strength, S_y (MPa) = 23.72
Ultimate Strength, S_u (MPa) = 45.08
Failure Strength, S_f (MPa) = 45.07
Elongation at break (%) = 3.47%



Tensile Test Results

FDM PPSF #47

Cross sectional area (m^2) = 4.25E-05
Elastic Modulus, E (MPa) = 2006.81
0.2% Yield Strength, S_y (MPa) = 26.98
Ultimate Strength, S_u (MPa) = 39.26
Failure Strength, S_f (MPa) = 39.26
Elongation at break (%) = 2.68%

