

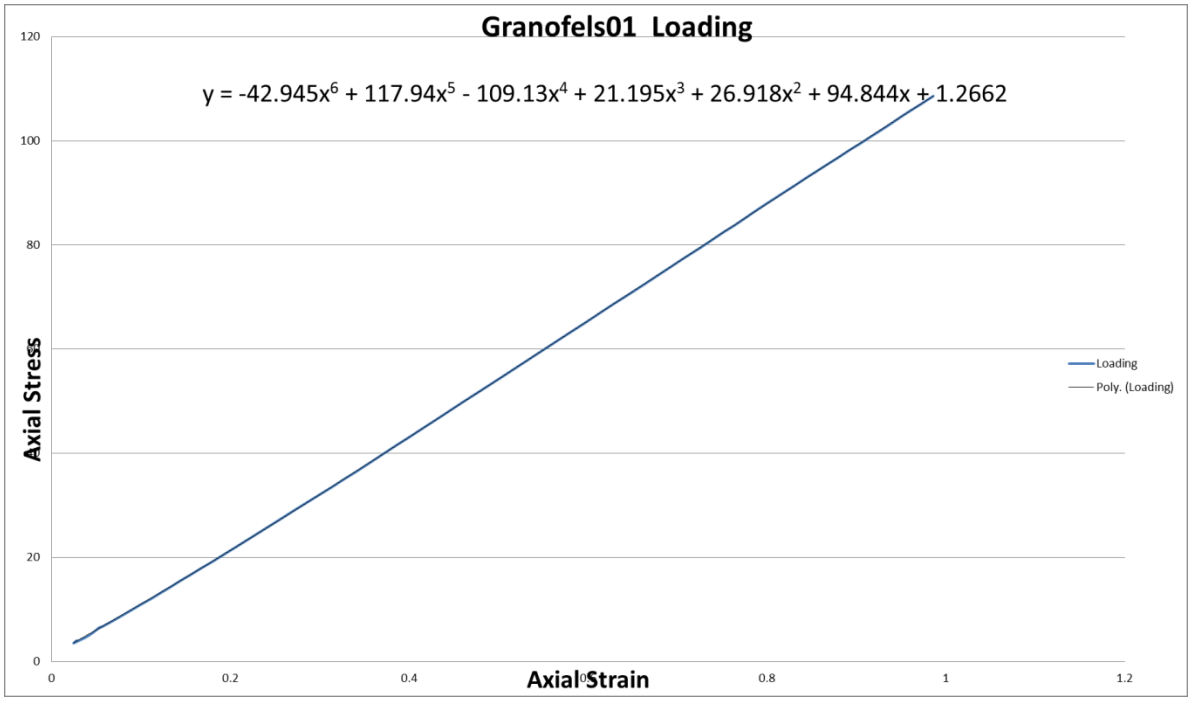
https://dspace.org/

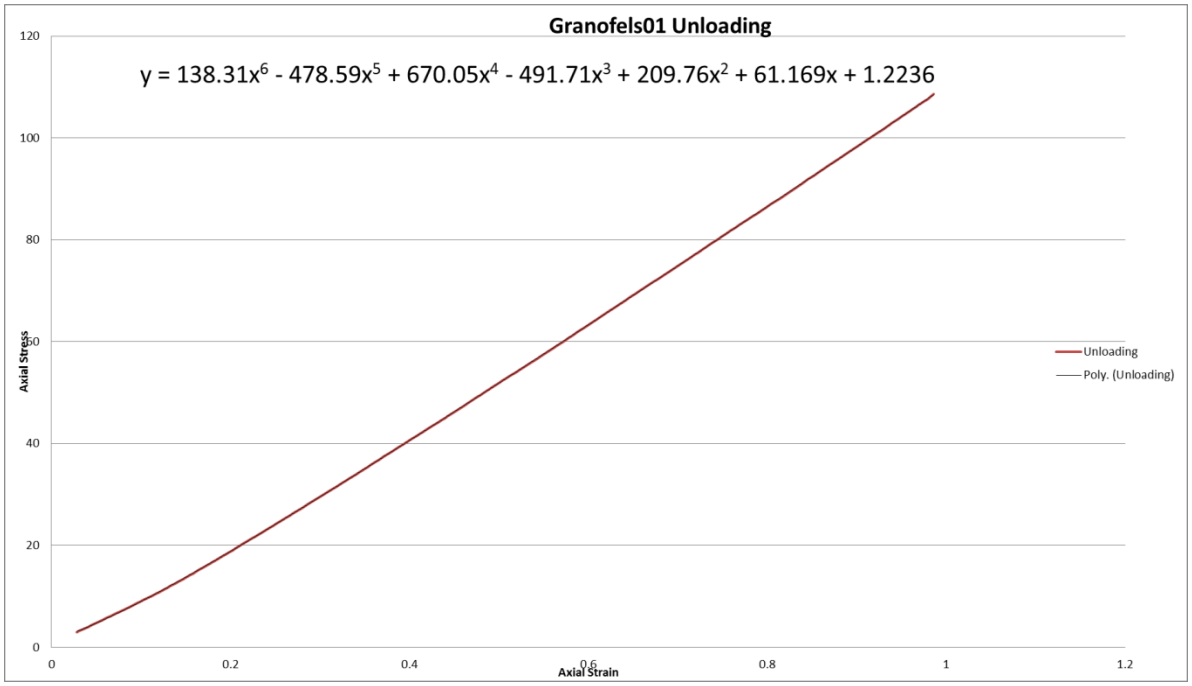
# Site-specific rock-fall parameters in a hard rock open pit environment

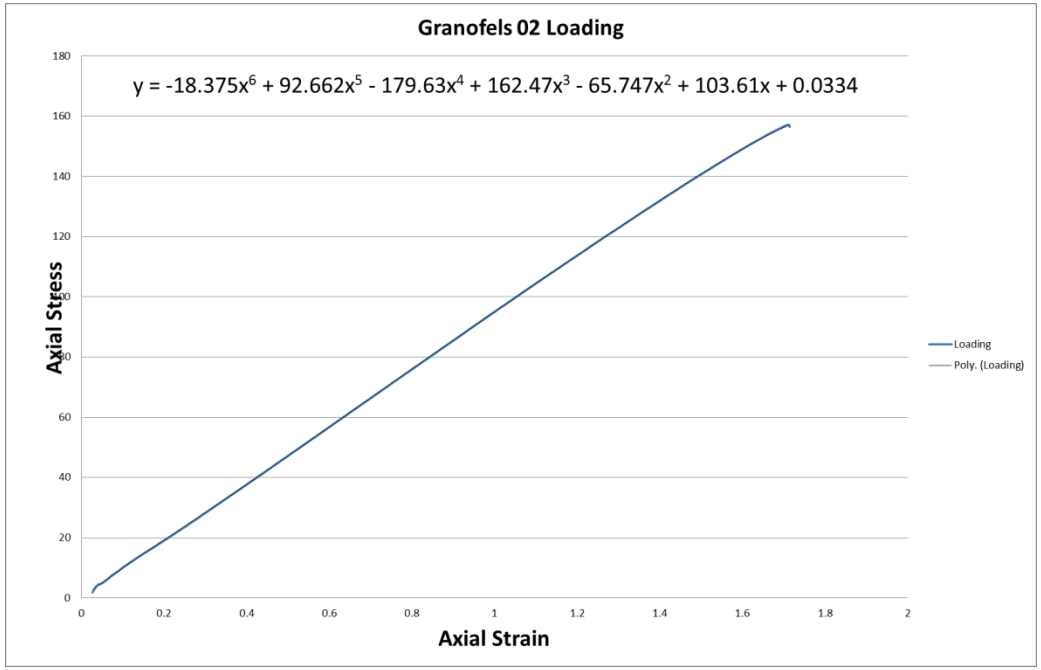
**Du Toit, Jacques**

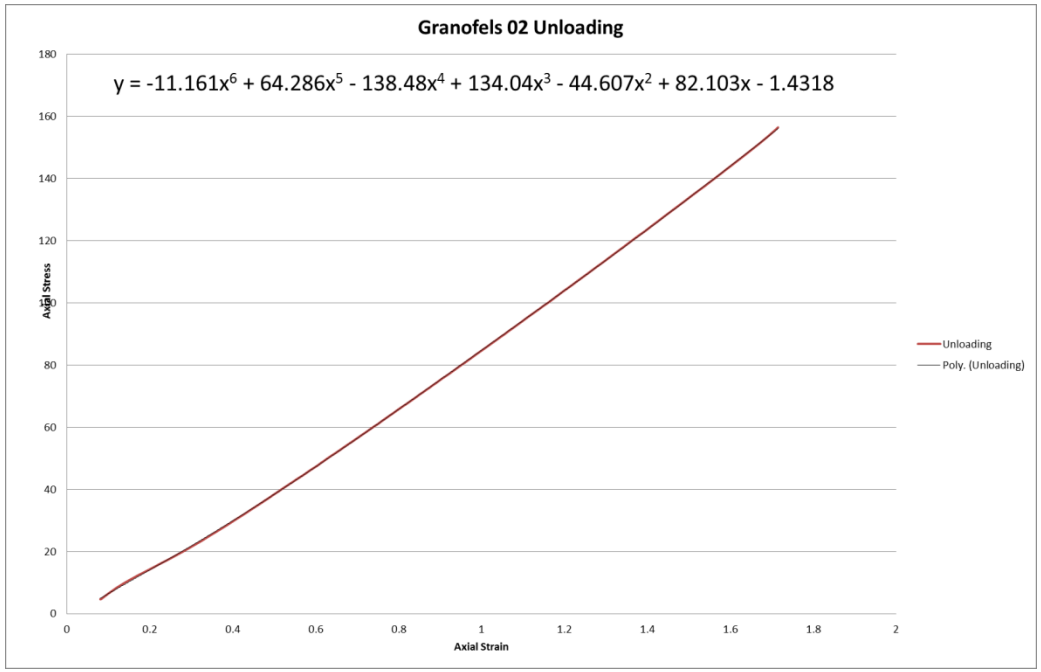
**2016-04-05**
http://hdl.handle.net/10539/20176

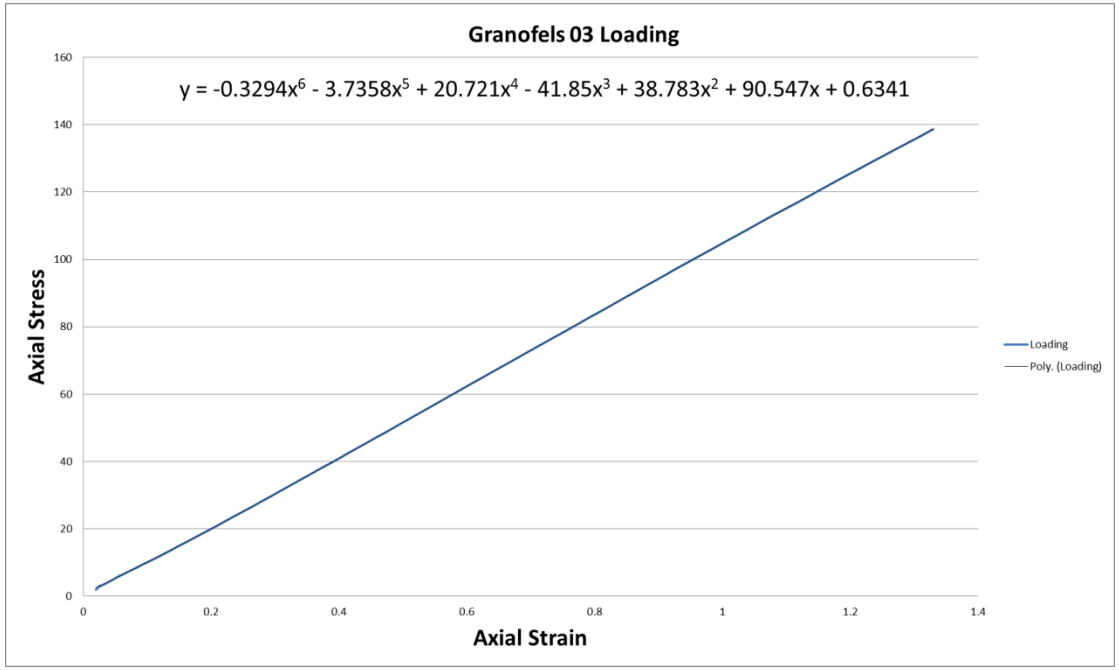
Downloaded from a DSpace repository. https://dspace.org/

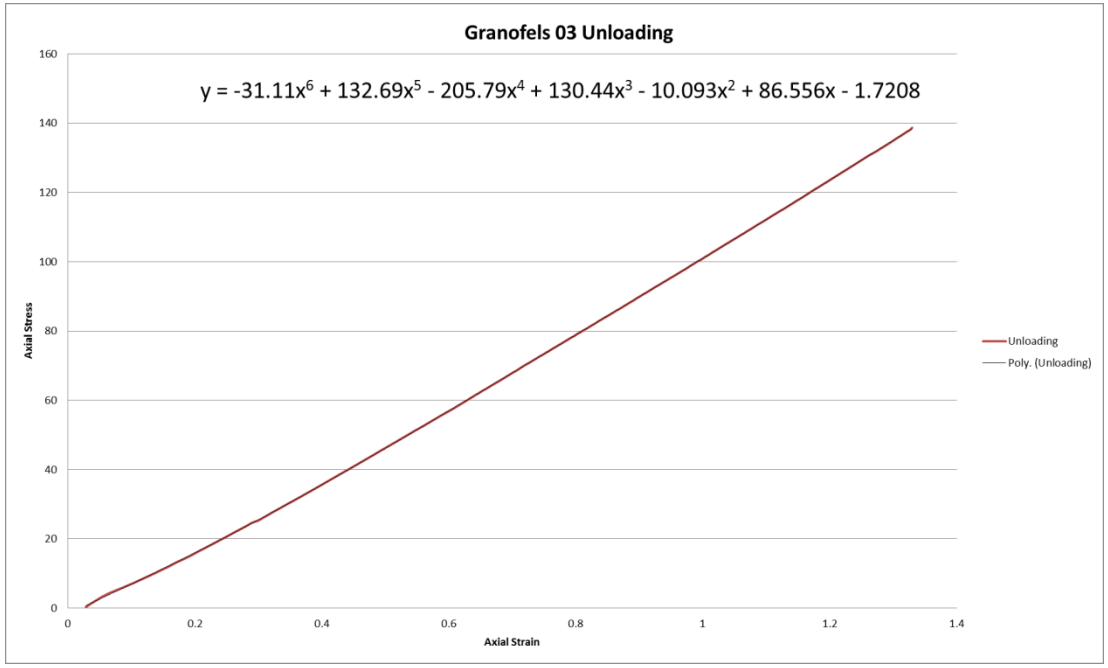

Granofels01 Loading
y = -42.945x6 + 117.94x5 - 109.13x4 + 21.195x3 + 26.918x2 + 94.844x + 1.2662
Axial Stress
Axial Strain
Loading
Poly. (Loading)
0
20
40
60
80
100
120
0
0.2
0.4
0.6
0.8
1
1.2

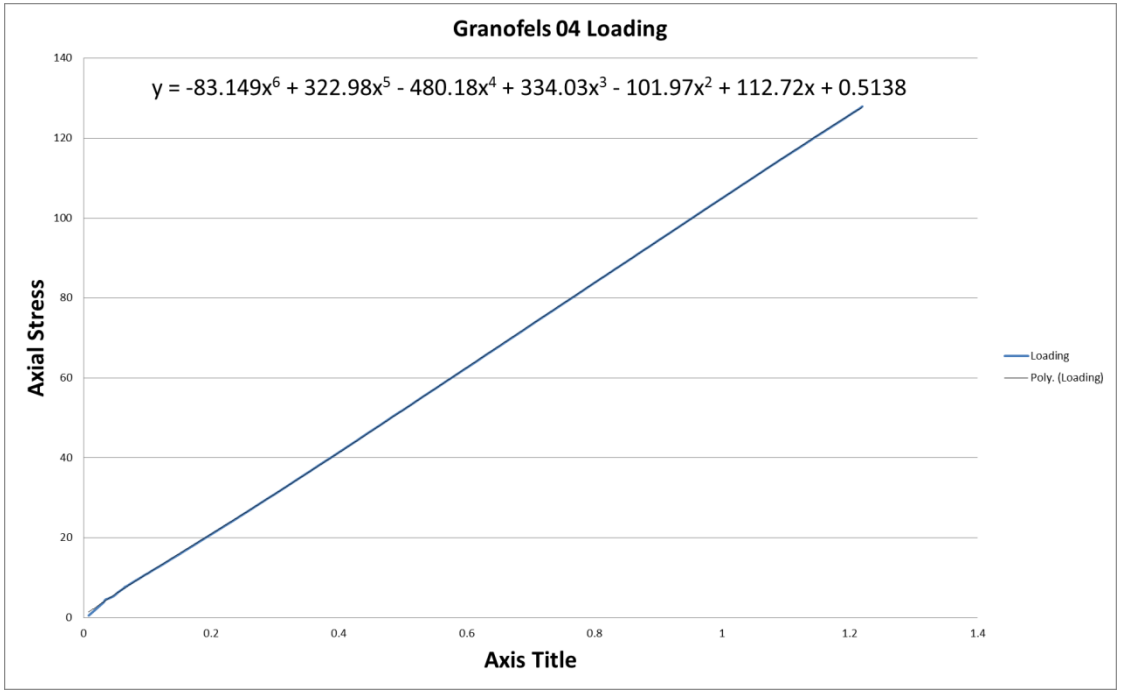

Granofels01 Unloading
y = 138.31x6 - 478.59x5 + 670.05x4 - 491.71x3 + 209.76x2 + 61.169x + 1.2236
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)
0
20
40
60
80
100
120
0
0.2
0.4
0.6
0.8
1
1.2

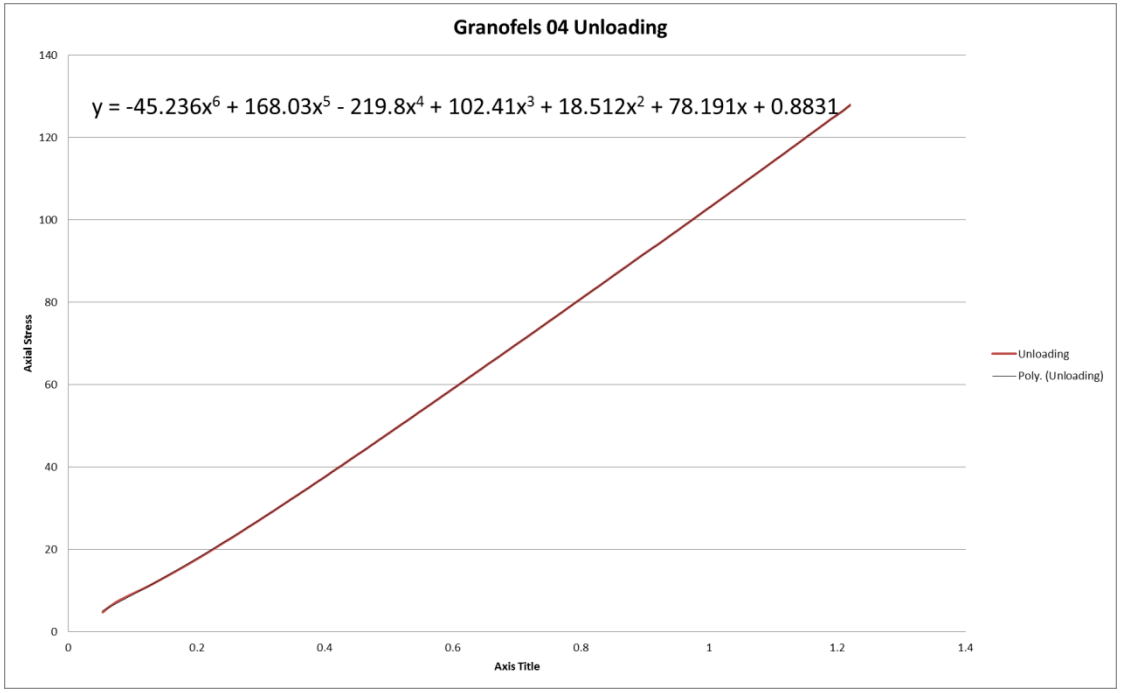

Granofels 02 Loading
y = -18.375x6 + 92.662x5 - 179.63x4 + 162.47x3 - 65.747x2 + 103.61x + 0.0334
Axial Stress
Axial Strain
Loading
Poly. (Loading)

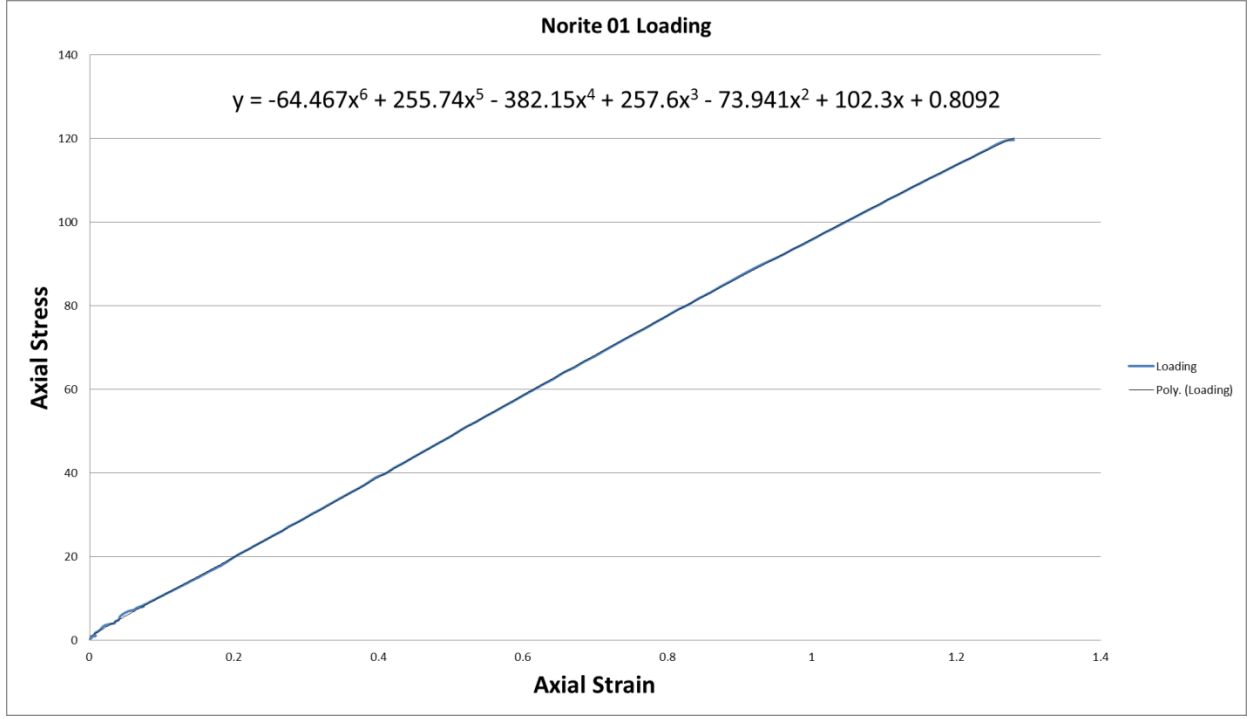

Granofels 02 Unloading
y = -11.161x6 + 64.286x5 - 138.48x4 + 134.04x3 - 44.607x2 + 82.103x - 1.4318
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)

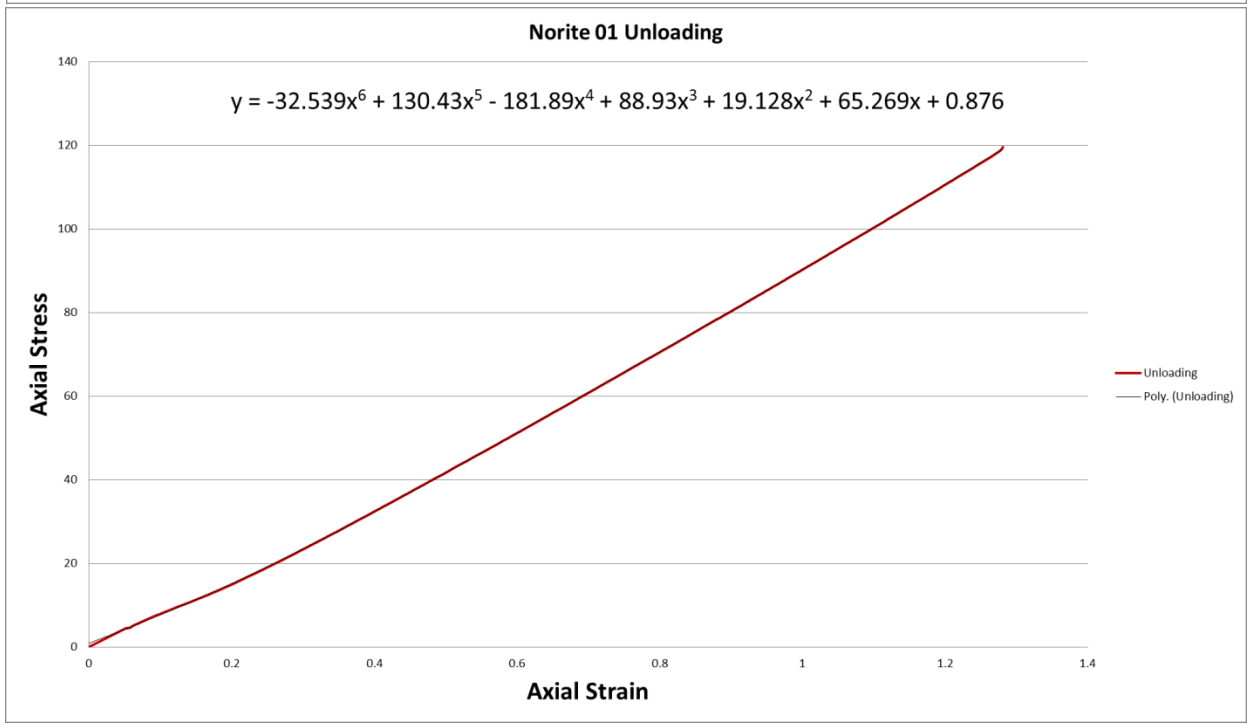

Granofels 03 Loading
y = -0.3294x^6 - 3.7358x^5 + 20.721x^4 - 41.85x^3 + 38.783x^2 + 90.547x + 0.6341
Axial Stress
Axial Strain
Loading
Poly. (Loading)

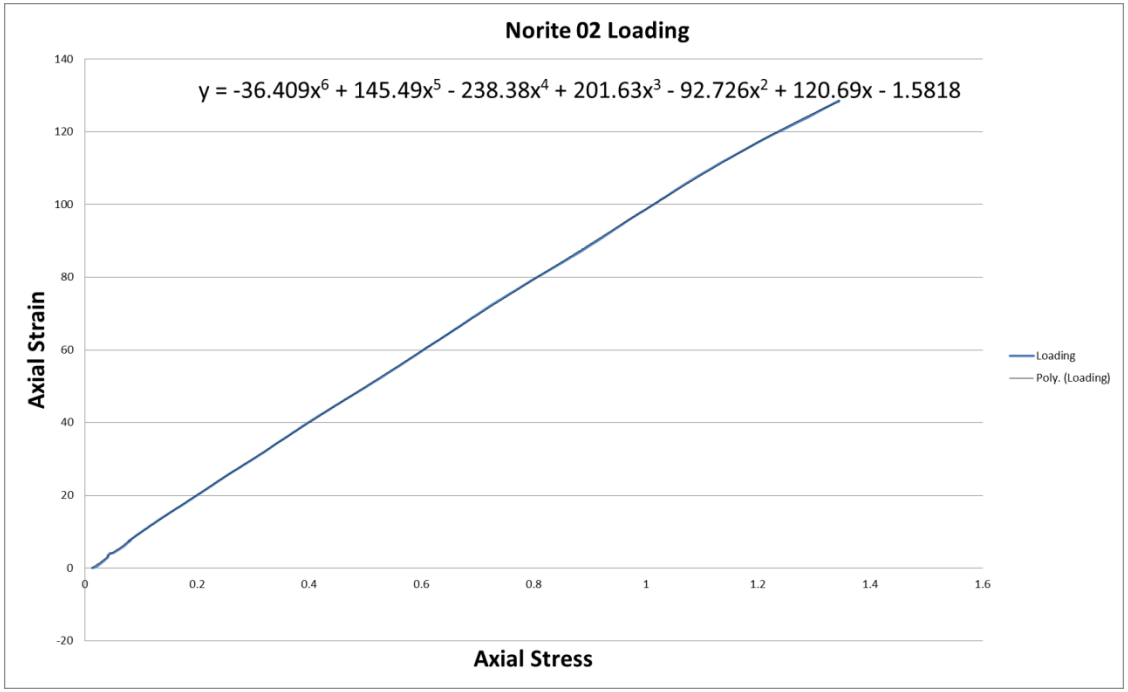

Granofels 03 Unloading
y = -31.11x^6 + 132.69x^5 - 205.79x^4 + 130.44x^3 - 10.093x^2 + 86.556x - 1.7208
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)

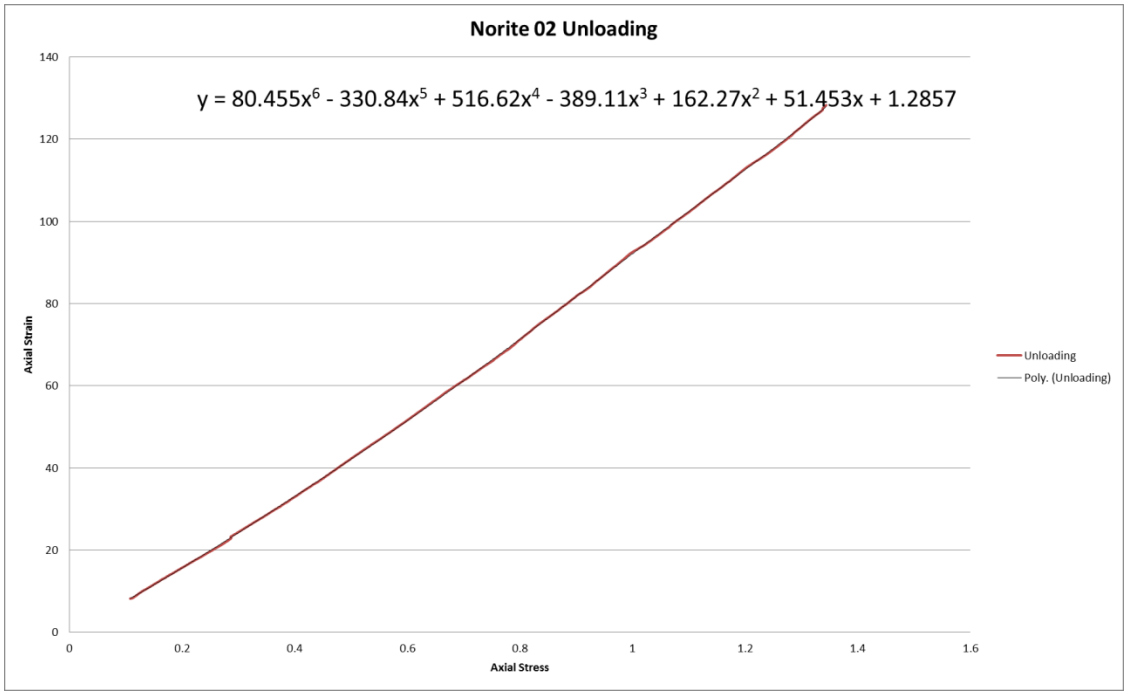

Granofels 04 Loading
y = -83.149x^6 + 322.98x^5 - 480.18x^4 + 334.03x^3 - 101.97x^2 + 112.72x + 0.5138
Axial Stress
Axis Title
Loading
Poly. (Loading)

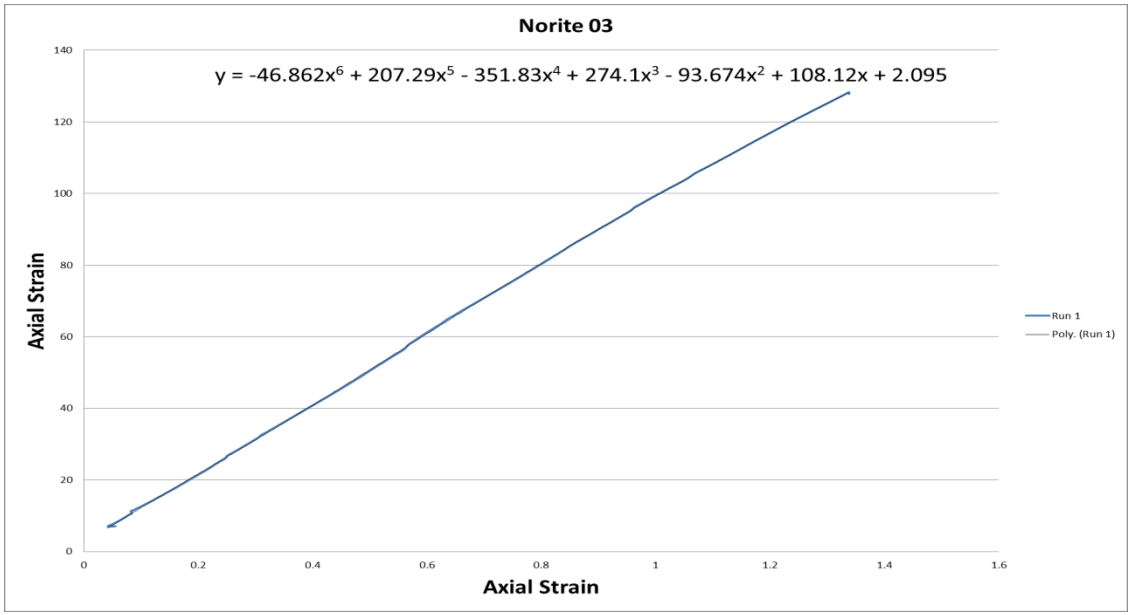

Granofels 04 Unloading
y = -45.236x^6 + 168.03x^5 - 219.8x^4 + 102.41x^3 + 18.512x^2 + 78.191x + 0.8831
Axial Stress
Axis Title
Unloading
Poly. (Unloading)

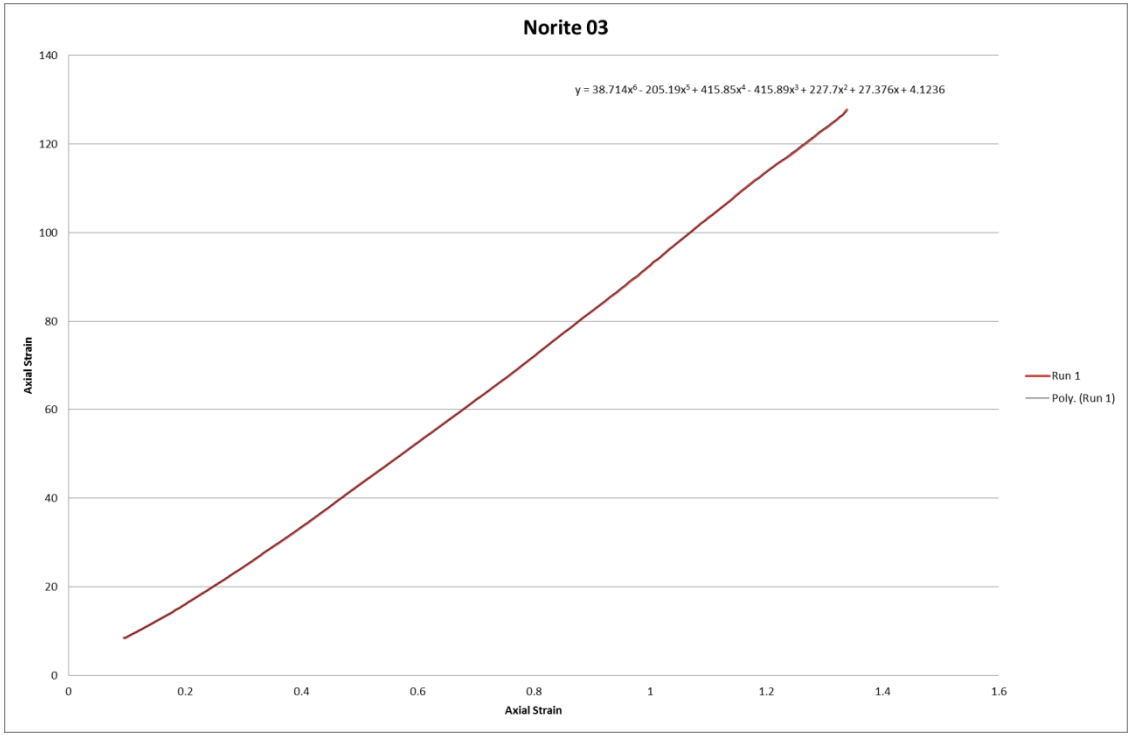

Norite 01 Loading
y = -64.467x6 + 255.74x5 - 382.15x4 + 257.6x3 - 73.941x2 + 102.3x + 0.8092
Axial Stress
Axial Strain
Loading
Poly. (Loading)
0
20
40
60
80
100
120
140
0
0.2
0.4
0.6
0.8
1
1.2
1.4

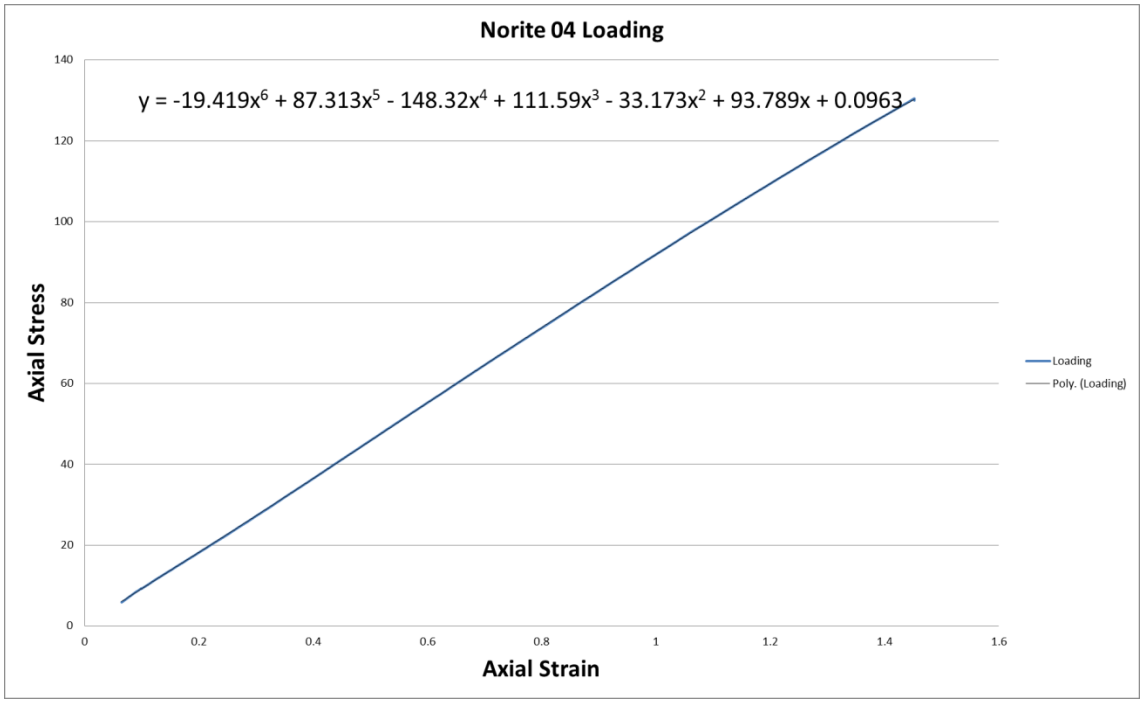

Norite 01 Unloading
y = -32.539x6 + 130.43x5 - 181.89x4 + 88.93x3 + 19.128x2 + 65.269x + 0.876
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)
0
20
40
60
80
100
120
140
0
0.2
0.4
0.6
0.8
1
1.2
1.4

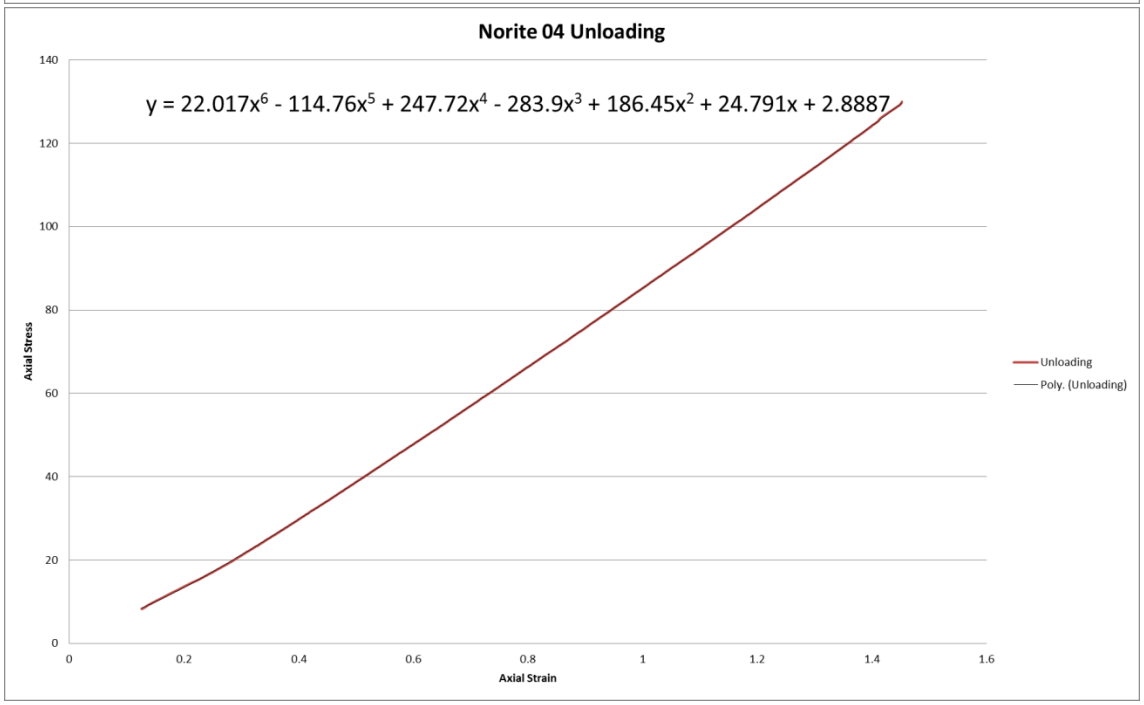

Norite 02 Loading
y = -36.409x^6 + 145.49x^5 - 238.38x^4 + 201.63x^3 - 92.726x^2 + 120.69x - 1.5818
Axial Strain
Axial Stress
140
120
100
80
60
40
20
0
-20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Loading
Poly. (Loading)

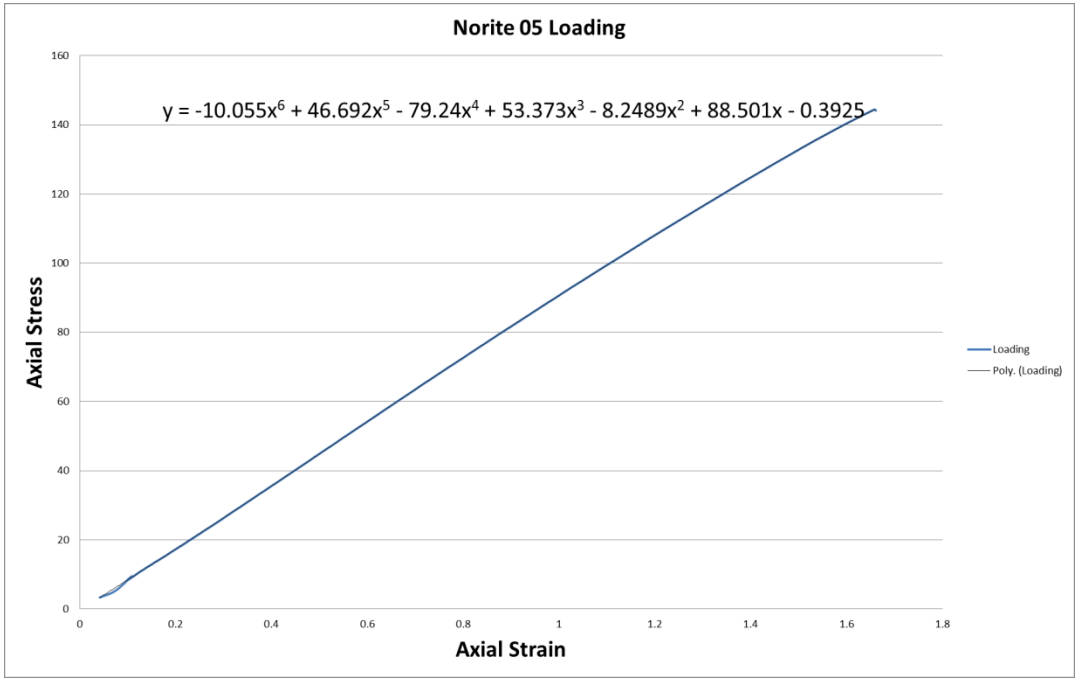

Norite 02 Unloading
y = 80.455x^6 - 330.84x^5 + 516.62x^4 - 389.11x^3 + 162.27x^2 + 51.453x + 1.2857
Axial Strain
Axial Stress
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Unloading
Poly. (Unloading)

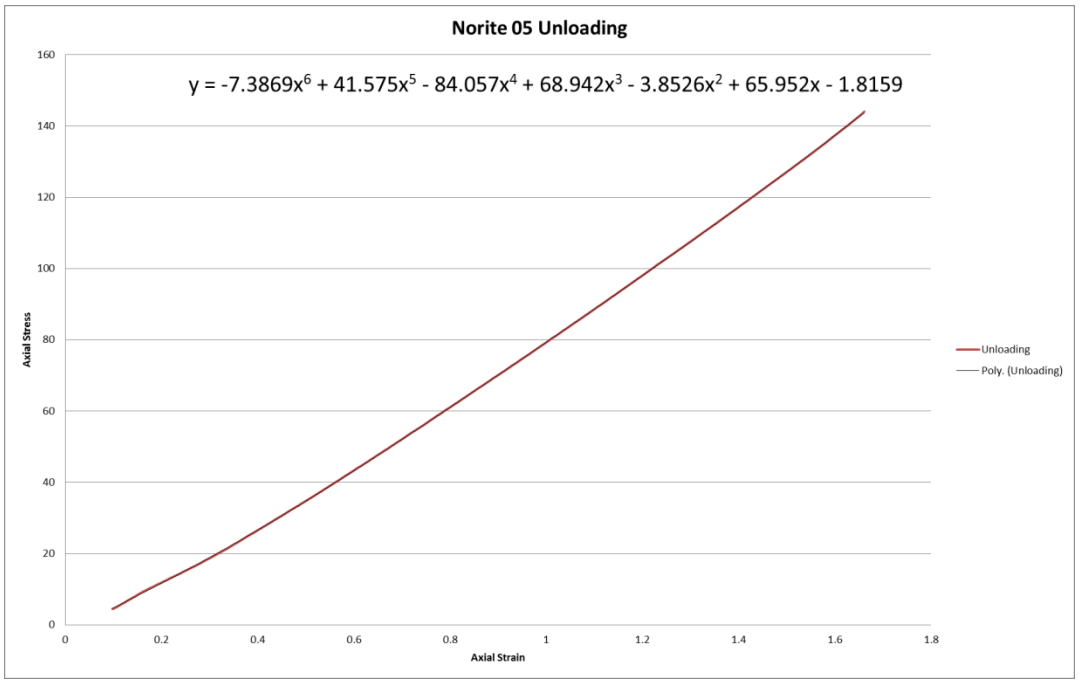

Norite 03
y = -46.862x⁶ + 207.29x⁵ - 351.83x⁴ + 274.1x³ - 93.674x² + 108.12x + 2.095
Axial Strain
Axial Strain
Run 1
Poly. (Run 1)

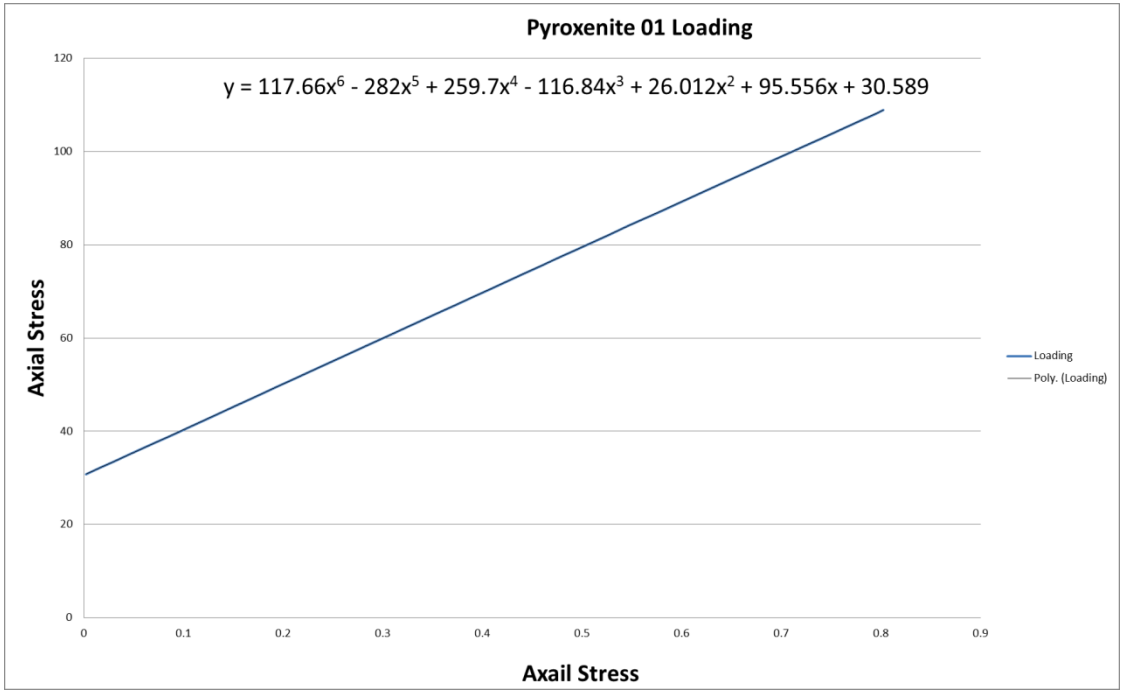

Norite 03
y = 38.714x⁶ - 205.19x⁵ + 415.85x⁴ - 415.89x³ + 227.7x² + 27.376x + 4.1236
Axial Strain
Axial Strain
Run 1
Poly. (Run 1)

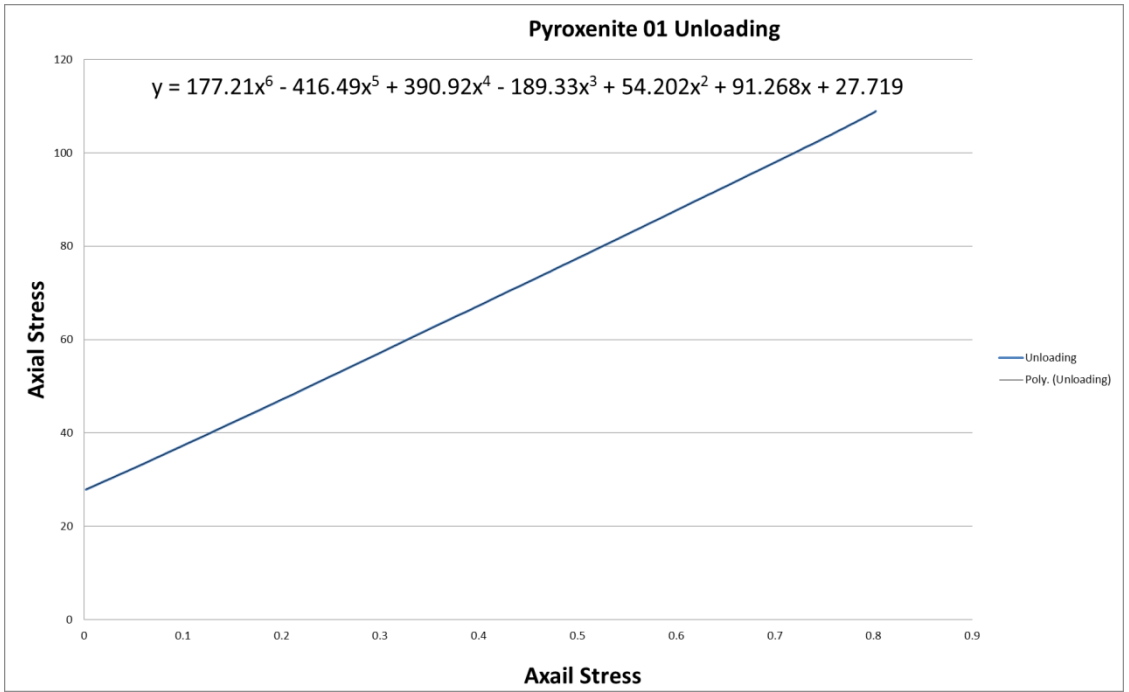

Norite 04 Loading
y = -19.419x6 + 87.313x5 - 148.32x4 + 111.59x3 - 33.173x2 + 93.789x + 0.0963
Axial Stress
Axial Strain
Loading
Poly. (Loading)

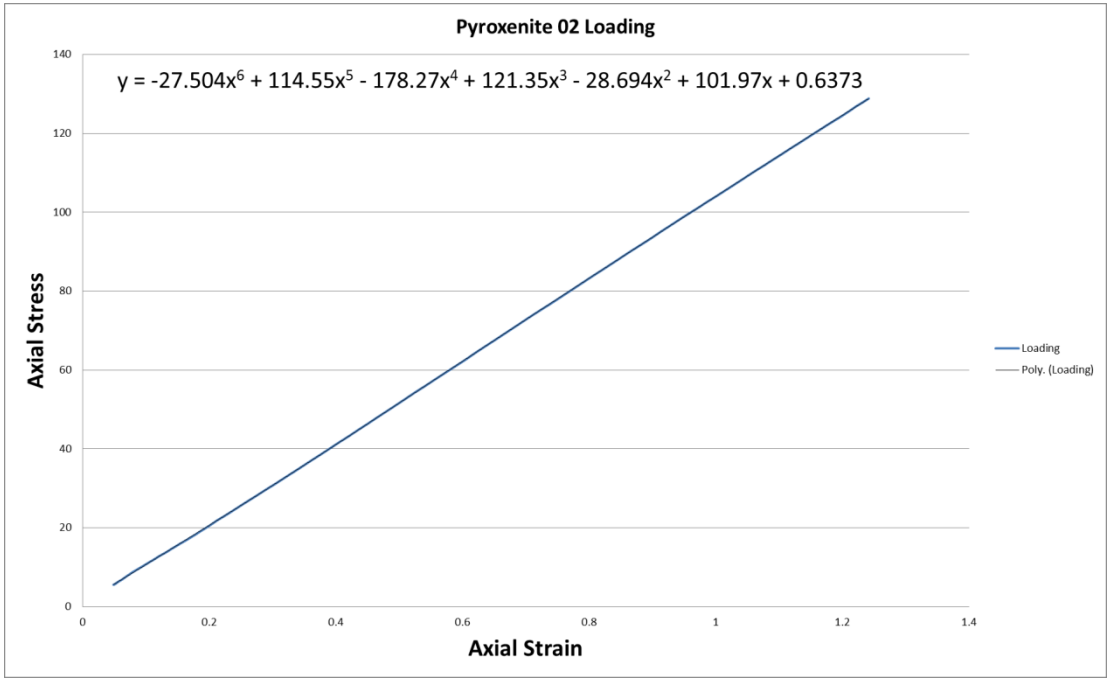

Norite 04 Unloading
y = 22.017x6 - 114.76x5 + 247.72x4 - 283.9x3 + 186.45x2 + 24.791x + 2.8887
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)

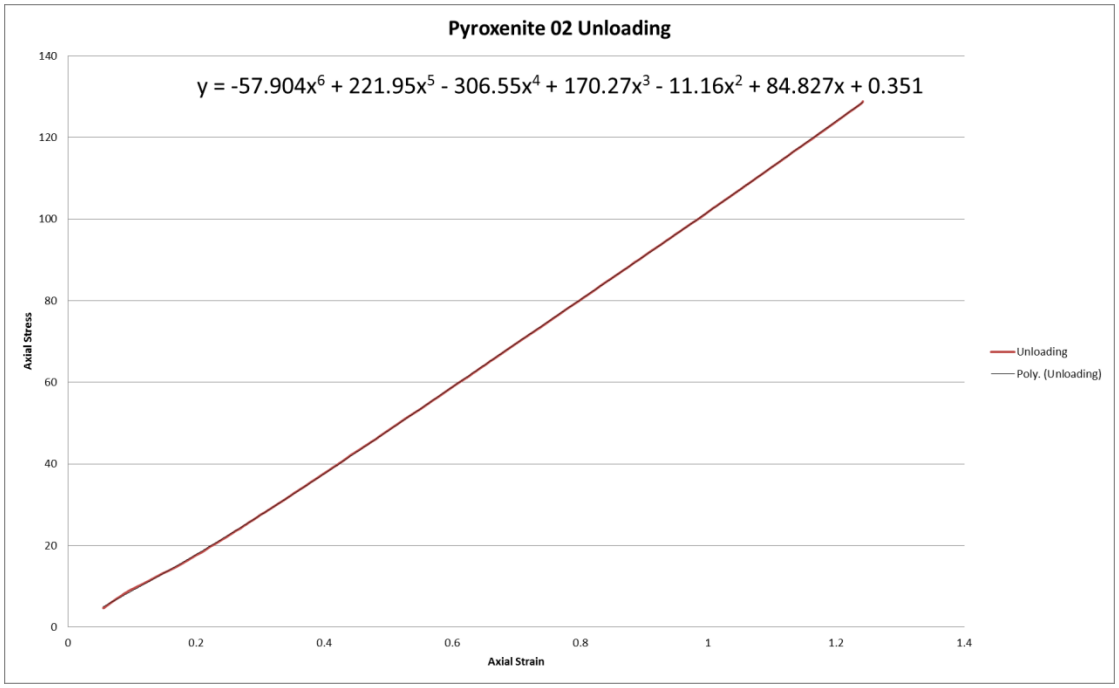

Norite 05 Loading
y = -10.055x^6 + 46.692x^5 - 79.24x^4 + 53.373x^3 - 8.2489x^2 + 88.501x - 0.3925
Axial Stress
Axial Strain
0
20
40
60
80
100
120
140
160
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Loading
Poly. (Loading)

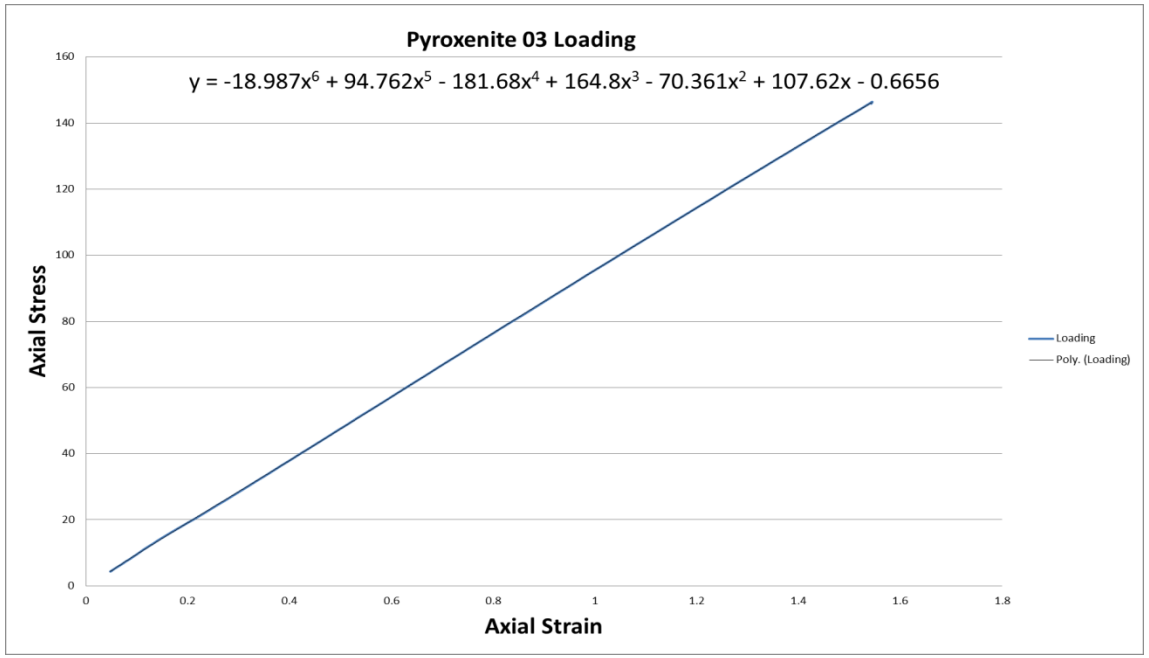

Norite 05 Unloading
y = -7.3869x^6 + 41.575x^5 - 84.057x^4 + 68.942x^3 - 3.8526x^2 + 65.952x - 1.8159
Axial Stress
Axial Strain
0
20
40
60
80
100
120
140
160
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Unloading
Poly. (Unloading)

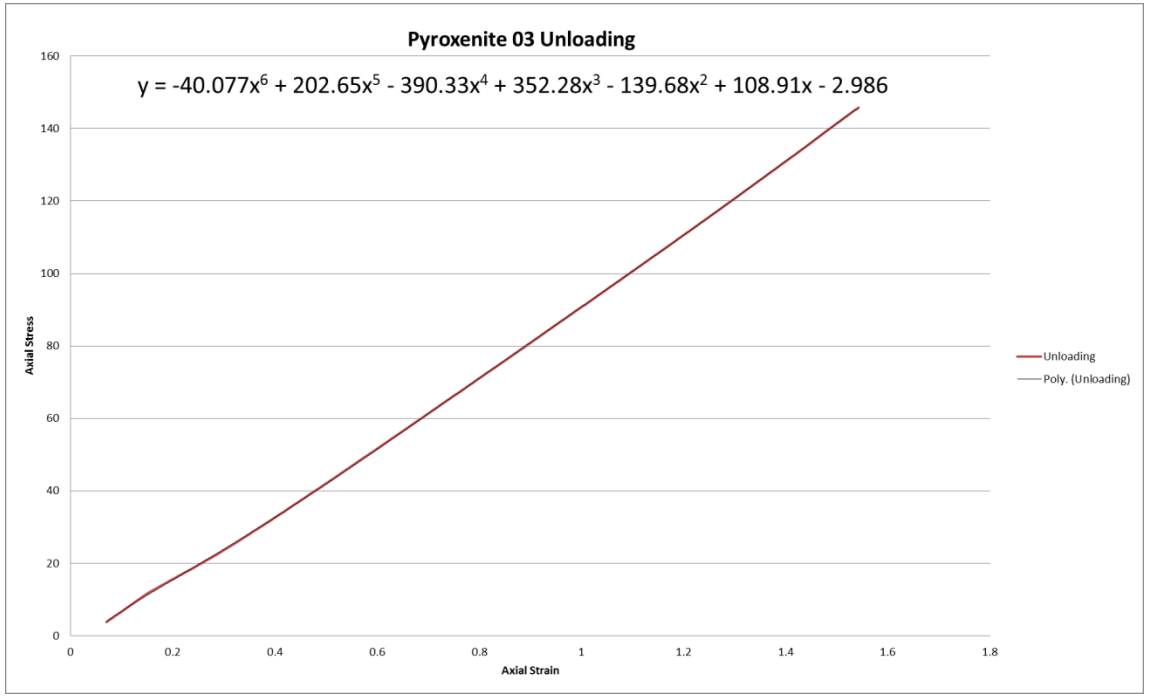

Pyroxenite 01 Loading
y = 117.66x^6 - 282x^5 + 259.7x^4 - 116.84x^3 + 26.012x^2 + 95.556x + 30.589
Axial Stress
Axail Stress
Loading
Poly. (Loading)
0
20
40
60
80
100
120
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

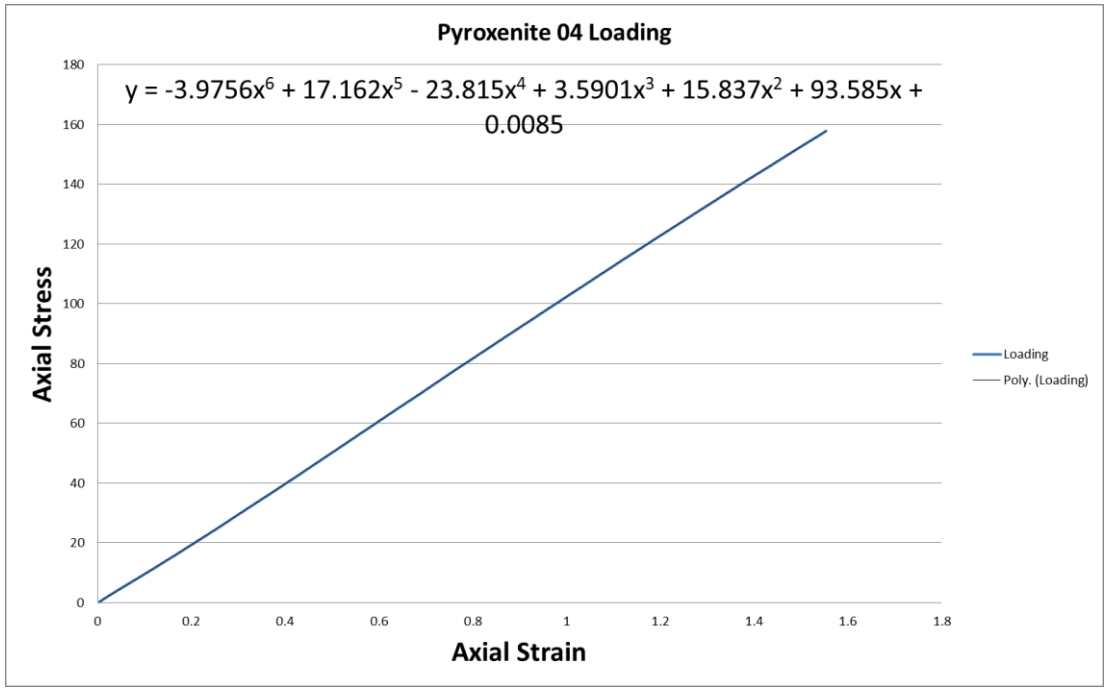

Pyroxenite 01 Unloading
y = 177.21x^6 - 416.49x^5 + 390.92x^4 - 189.33x^3 + 54.202x^2 + 91.268x + 27.719
Axial Stress
Axail Stress
Unloading
Poly. (Unloading)
0
20
40
60
80
100
120
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

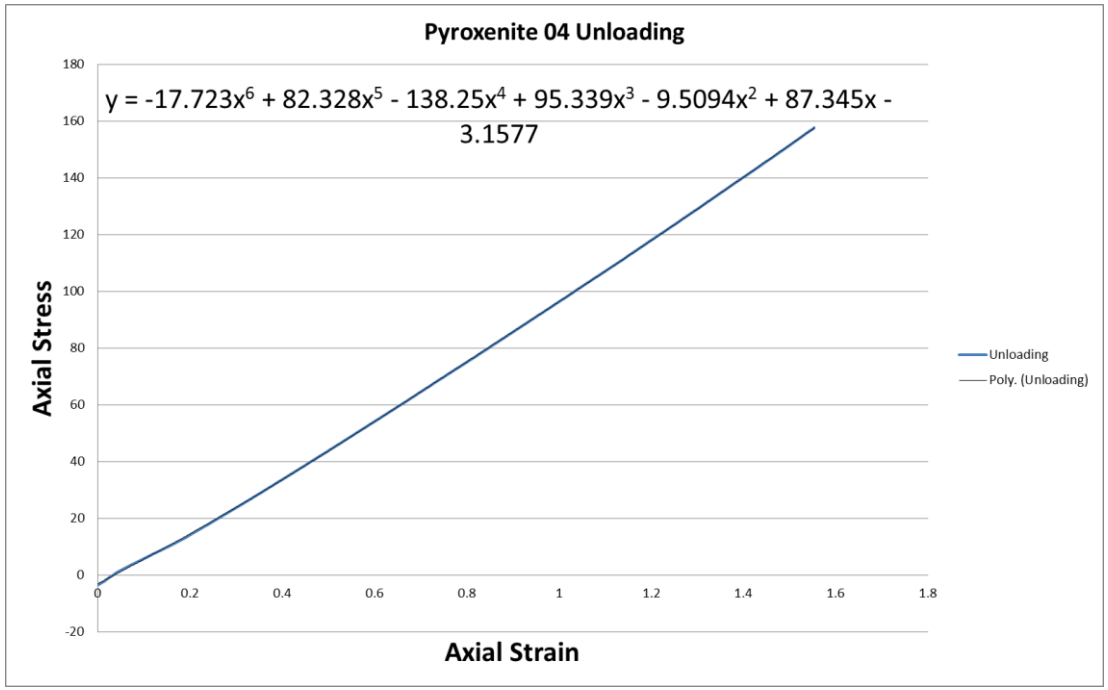

Pyroxenite 02 Loading
y = -27.504x^6 + 114.55x^5 - 178.27x^4 + 121.35x^3 - 28.694x^2 + 101.97x + 0.6373
Axial Stress
Axial Strain
Loading
Poly. (Loading)

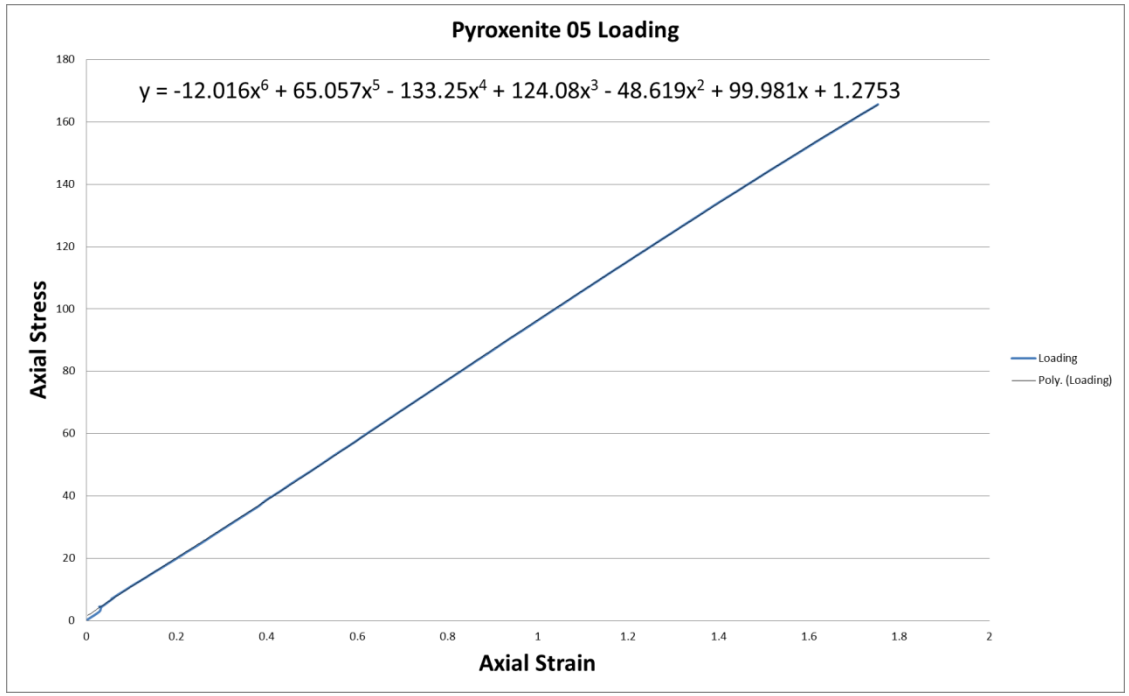

Pyroxenite 02 Unloading
y = -57.904x^6 + 221.95x^5 - 306.55x^4 + 170.27x^3 - 11.16x^2 + 84.827x + 0.351
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)

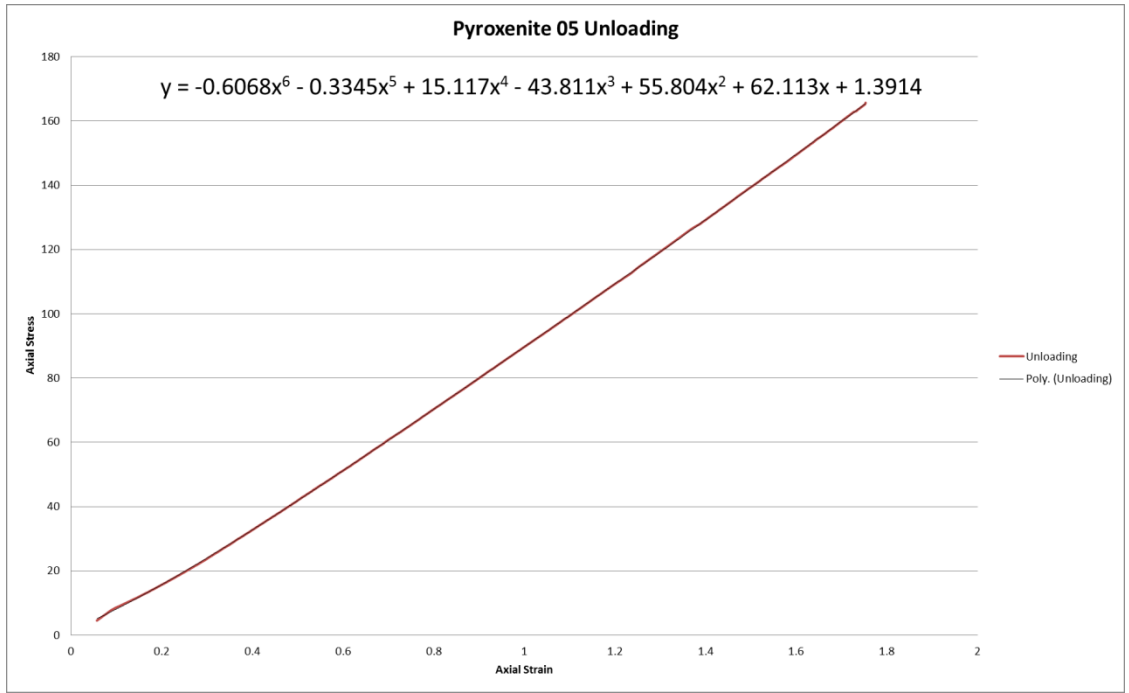

Pyroxenite 03 Loading
y = -18.987x^6 + 94.762x^5 - 181.68x^4 + 164.8x^3 - 70.361x^2 + 107.62x - 0.6656
Axial Stress
Axial Strain
Loading
Poly. (Loading)


Pyroxenite 03 Unloading
y = -40.077x^6 + 202.65x^5 - 390.33x^4 + 352.28x^3 - 139.68x^2 + 108.91x - 2.986
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)

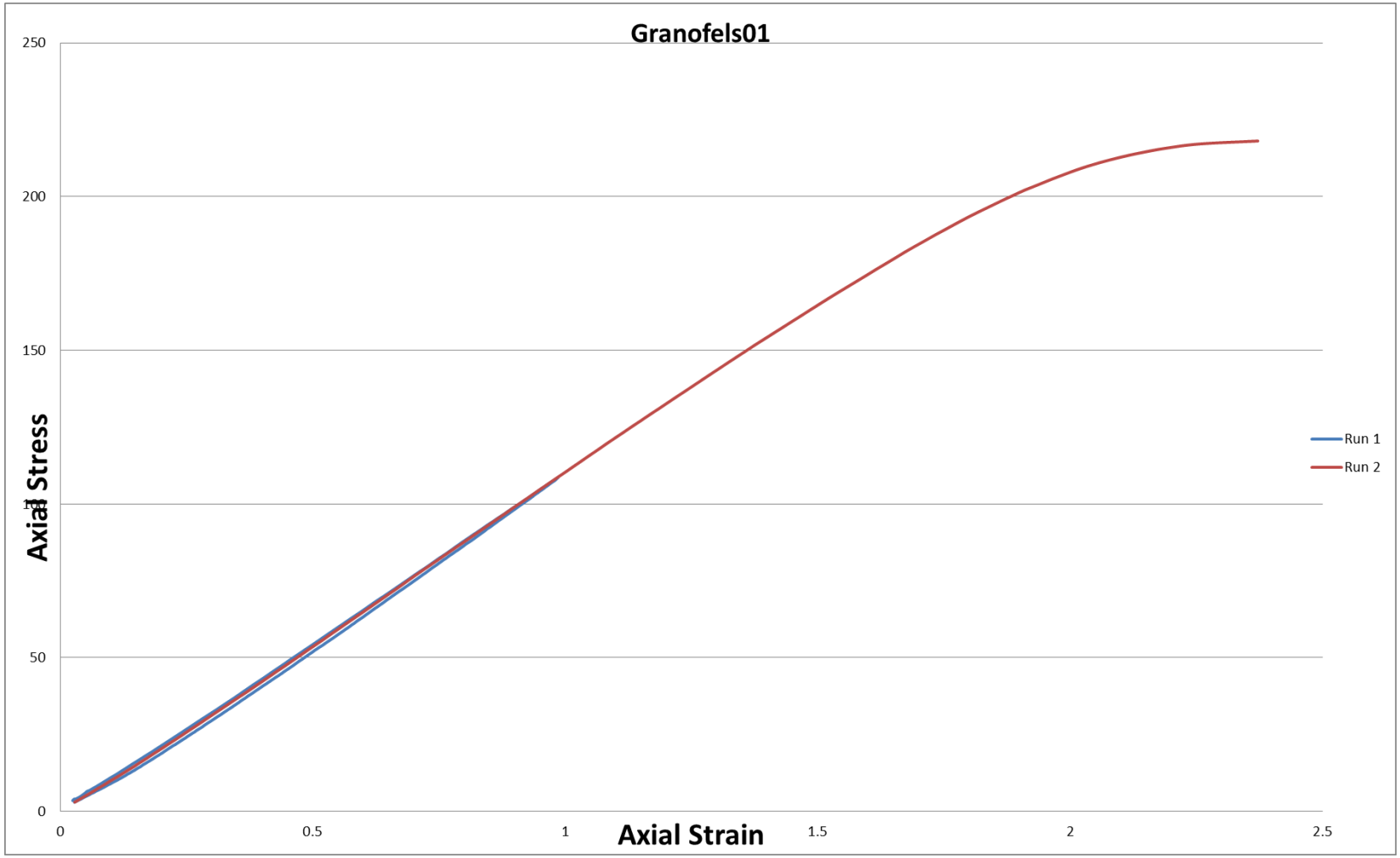

Pyroxenite 04 Loading
y = -3.9756x6 + 17.162x5 - 23.815x4 + 3.5901x3 + 15.837x2 + 93.585x + 0.0085
Axial Stress
Axial Strain
Loading
Poly. (Loading)

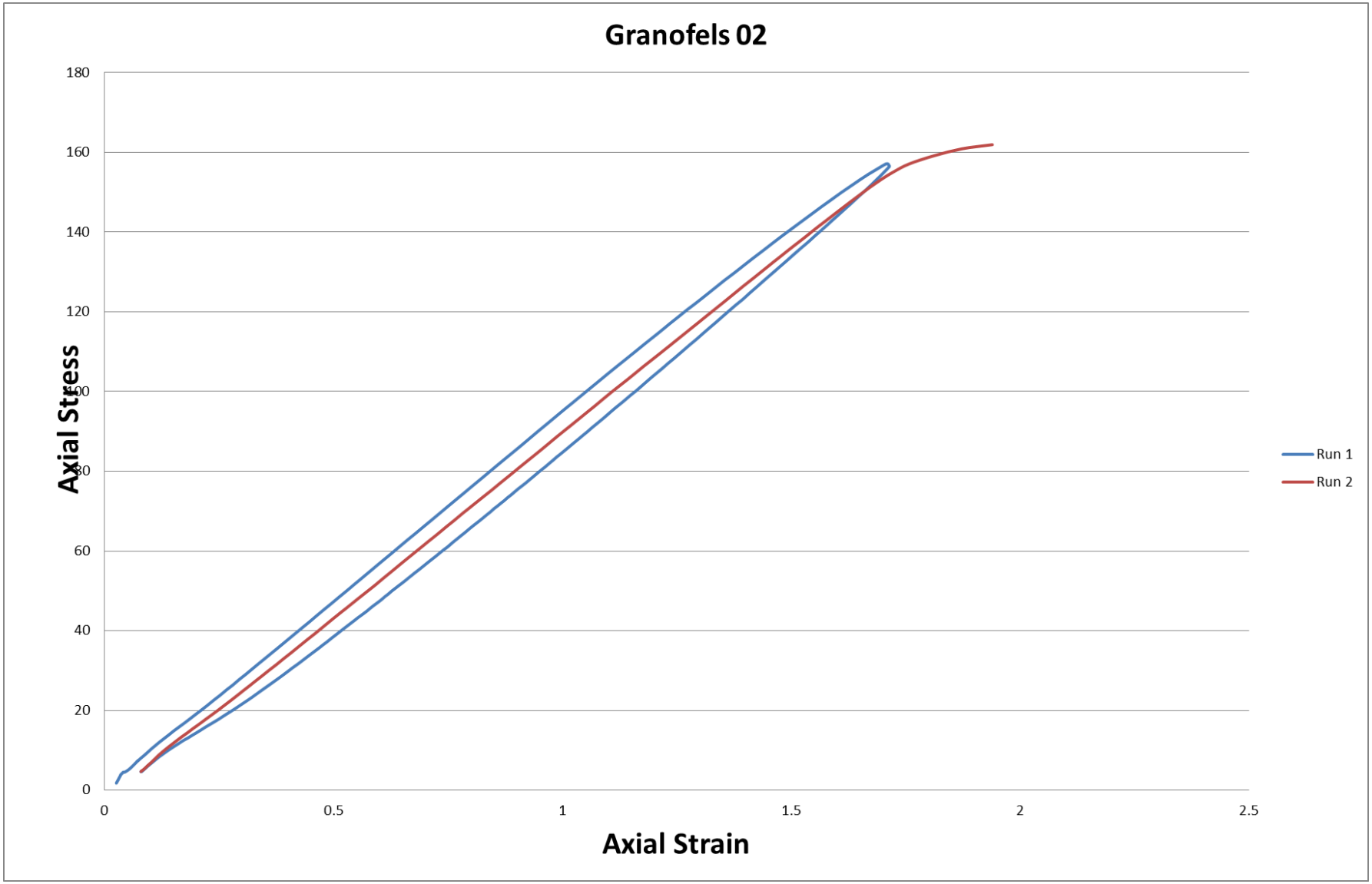

Pyroxenite 04 Unloading
y = -17.723x6 + 82.328x5 - 138.25x4 + 95.339x3 - 9.5094x2 + 87.345x - 3.1577
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)

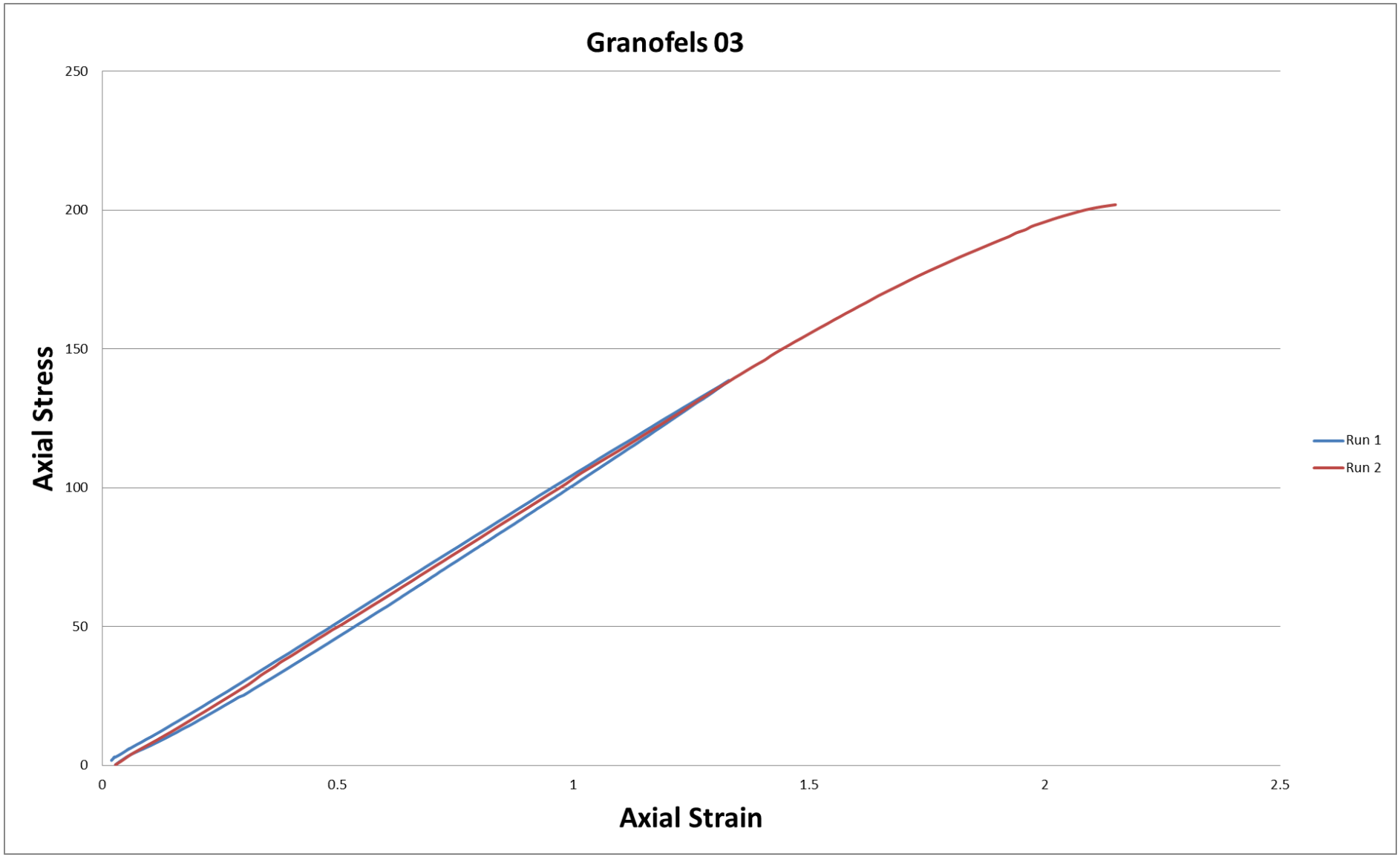

Pyroxenite 05 Loading
y = -12.016x^6 + 65.057x^5 - 133.25x^4 + 124.08x^3 - 48.619x^2 + 99.981x + 1.2753
Axial Stress
Axial Strain
Loading
Poly. (Loading)

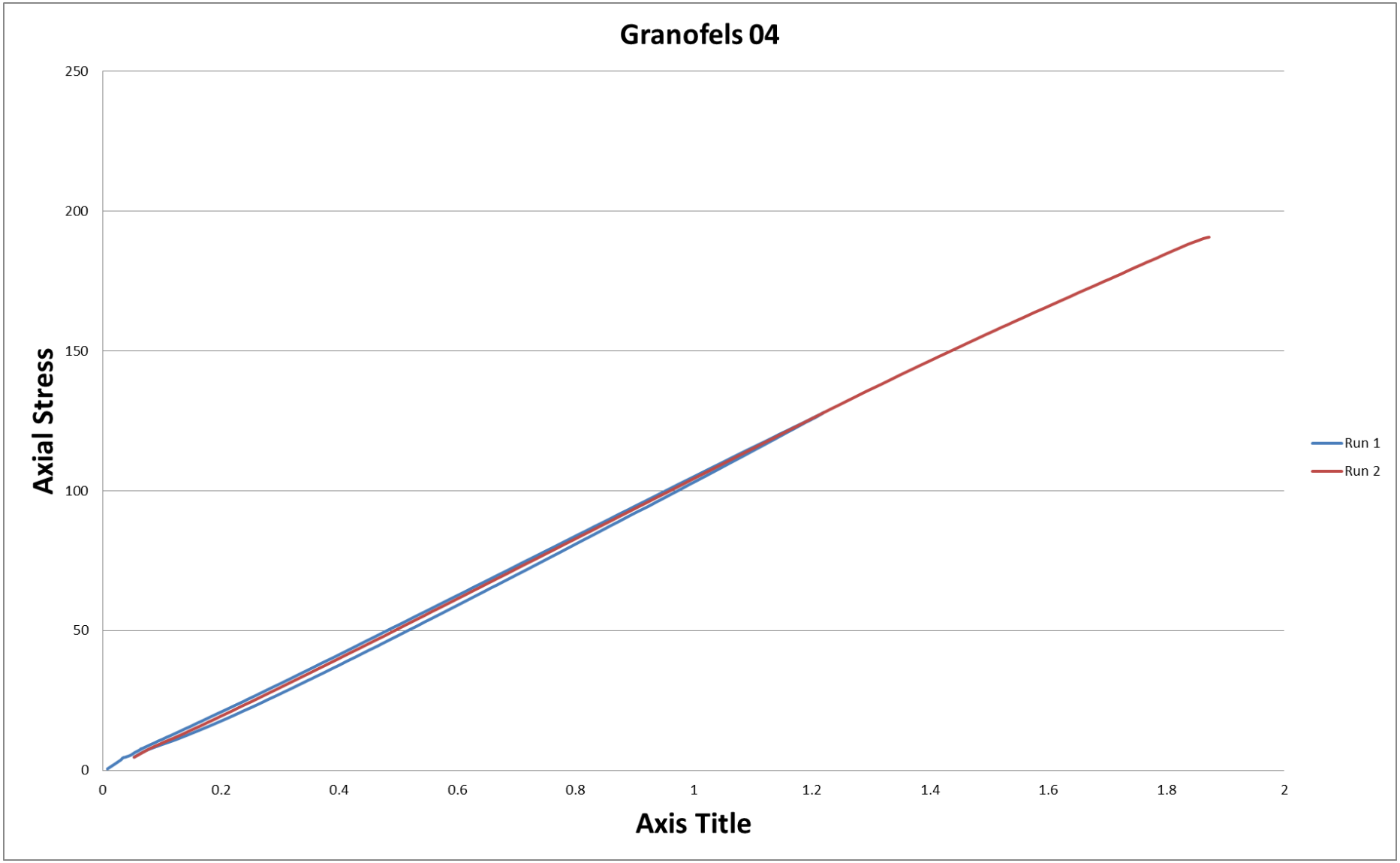

Pyroxenite 05 Unloading
y = -0.6068x^6 - 0.3345x^5 + 15.117x^4 - 43.811x^3 + 55.804x^2 + 62.113x + 1.3914
Axial Stress
Axial Strain
Unloading
Poly. (Unloading)

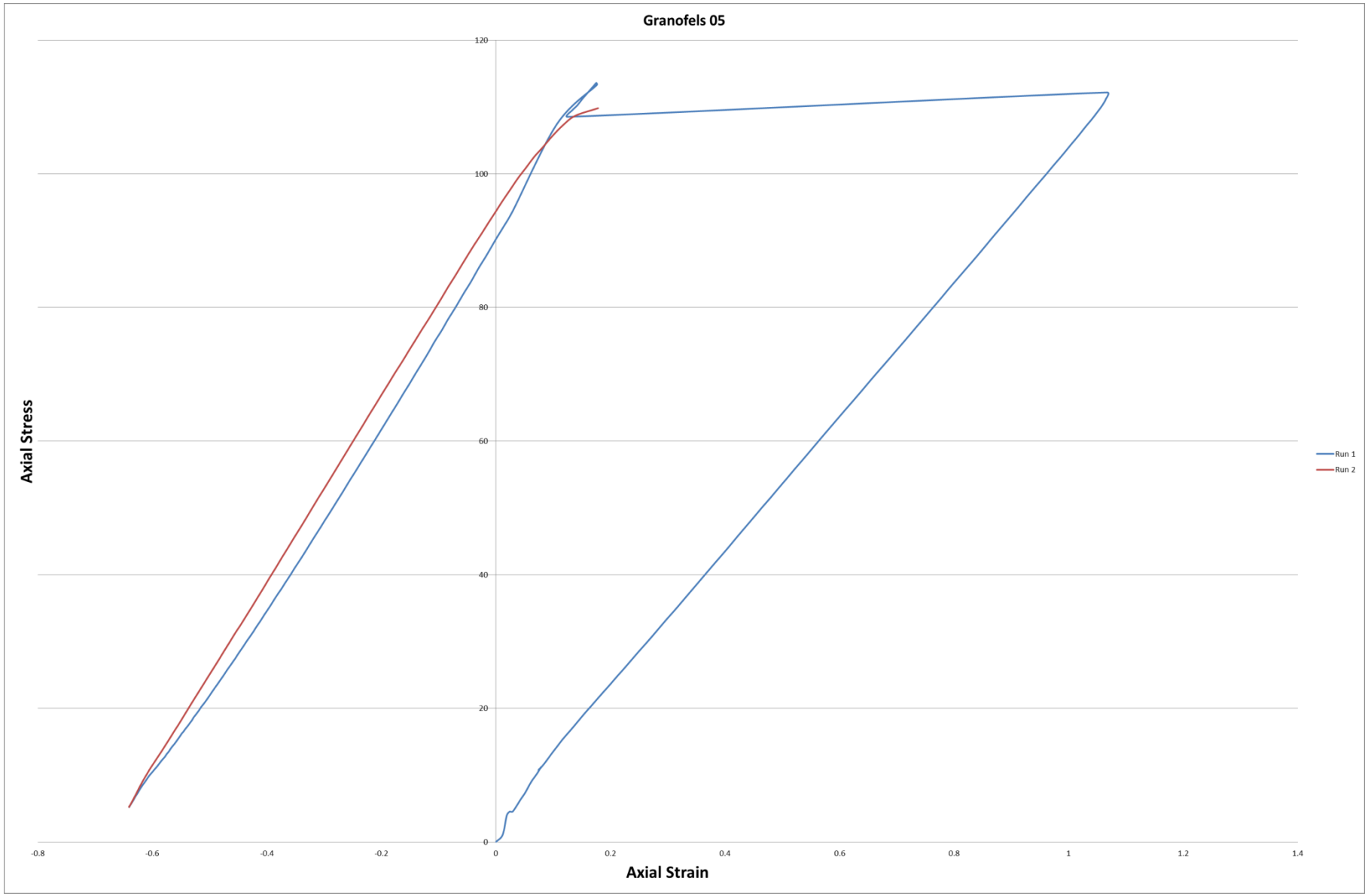
| | Term | x^7 | x^6 | x^5 | x^4 | x^3 | x^2 | x | X= (milli strain) | Energy density (MJ/m3) | COR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N1 | Loading | -9.21 | 42.623 | -76.43 | 64.4 | -24.65 | 51.15 | 0.8092 | 1.281368 | 79.19100785 | 0.912325 |
| | Unloading | -4.648 | 21.738 | -36.38 | 22.233 | 6.376 | 32.635 | 0.876 | 1.281368 | 72.24797348 | |
| | UCS | -0.008 | 0.0355 | -0.269 | -0.939 | 4.7893 | 41.298 | 0.2586 | 2.223035 | 221.7886074 | |
| N2 | Loading | -5.201 | 24.248 | -47.68 | 50.408 | -30.91 | 60.345 | -1.582 | 1.344183 | 88.97749481 | 0.913696 |
| | Unloading | 11.494 | -55.14 | 103.32 | -97.28 | 54.09 | 25.727 | 1.2857 | 1.344183 | 81.29840962 | |
| | UCS | 0.465 | -2.976 | 6.3518 | -5.968 | 3.4287 | 44.405 | -1.174 | 2.105446 | 197.9568639 | |
| N3 | Loading | -6.695 | 34.548 | -70.37 | 68.525 | -31.22 | 54.06 | 2.095 | 1.338505 | 89.56104015 | 0.910634 |
| | Unloading | 5.5306 | -34.2 | 83.17 | -104 | 75.9 | 13.688 | 4.1236 | 1.338505 | 81.55737082 | |
| | UCS | 0.4847 | -3.772 | 10.718 | -14.62 | 9.8067 | 44.249 | -0.282 | 2.273956 | 235.1642949 | |
| N4 | Loading | -2.774 | 14.552 | -29.66 | 27.898 | -11.06 | 46.895 | 0.0963 | 1.452327 | 96.37408202 | 0.917923 |
| | Unloading | 3.1453 | -19.13 | 49.544 | -70.98 | 62.15 | 12.396 | 2.8887 | 1.452327 | 88.46402604 | |
| | UCS | 0.516 | -4.408 | 13.974 | -22.27 | 19.762 | 35.817 | -1.409 | 2.089823 | 188.6487769 | |
| N5 | Loading | -1.436 | 7.782 | -15.85 | 13.343 | -2.75 | 44.251 | -0.393 | 1.661213 | 123.3783555 | 0.887156 |
| | Unloading | -1.055 | 6.9292 | -16.81 | 17.236 | -1.284 | 32.976 | -1.816 | 1.661213 | 109.455799 | |
| | UCS | -1.576 | 9.3757 | -21.84 | 24.699 | -12.76 | 45.303 | 3.9913 | 1.895656 | 164.1926161 | |
| G1 | Loading | -6.135 | 19.657 | -21.83 | 5.2988 | 8.9727 | 47.422 | 1.2662 | 0.985967 | 53.12105328 | 0.965146 |
| | Unloading | 19.759 | -79.76 | 134.01 | -122.9 | 69.92 | 30.585 | 1.2236 | 0.985967 | 51.26959768 | |
| | UCS | 0.2611 | -2.809 | 10.381 | -19.58 | 20.53 | 44.836 | 0.4344 | 2.371519 | 296.9206391 | |
| G2 | Loading | -2.625 | 15.444 | -35.93 | 40.618 | -21.92 | 51.805 | 0.0334 | 1.714931 | 138.6433661 | 0.903759 |
| | Unloading | -1.594 | 10.714 | -27.7 | 33.51 | -14.87 | 41.052 | -1.432 | 1.714931 | 125.3001562 | |
| | UCS | -3.241 | 19.672 | -47.22 | 56.103 | -33.21 | 54.535 | -3.357 | 1.939724 | 166.8859624 | |
| G3 | Loading | -0.047 | -0.623 | 4.1442 | -10.46 | 12.928 | 45.274 | 0.6341 | 1.32987 | 92.04028654 | 0.942799 |
| | Unloading | -4.444 | 22.115 | -41.16 | 32.61 | -3.364 | 43.278 | -1.721 | 1.32987 | 86.77544858 | |
| | UCS | 0.5935 | -4.717 | 13.708 | -19.78 | 15.536 | 46.803 | -2.238 | 2.149786 | 233.1369696 | |
| G4 | Loading | -11.88 | 53.83 | -96.04 | 83.508 | -33.99 | 56.36 | 0.5138 | 1.219624 | 77.89449841 | 0.958684 |
| | Unloading | -6.462 | 28.005 | -43.96 | 25.603 | 6.1707 | 39.096 | 0.8831 | 1.219624 | 74.67620021 | |
| | UCS | 0.6361 | -4.081 | 10.241 | -14.36 | 13.475 | 45.028 | 0.178 | 1.872604 | 181.3575888 | |
| P1 | Loading | 16.809 | -47 | 51.94 | -29.21 | 8.6707 | 47.778 | 30.589 | 0.802301 | 55.99834141 | 0.968348 |
| | Unloading | 25.316 | -69.41 | 78.184 | -47.33 | 18.067 | 45.634 | 27.719 | 0.802301 | 54.2258885 | |
| | UCS | -0.302 | 1.9372 | -4.716 | 4.402 | -1.279 | 49.476 | 29.17 | 2.260896 | 308.0466011 | |
| P2 | Loading | -3.929 | 19.092 | -35.65 | 30.338 | -9.565 | 50.985 | 0.6373 | 1.241452 | 80.02676048 | 0.960056 |
| | Unloading | -8.272 | 36.992 | -61.31 | 42.568 | -3.72 | 42.414 | 0.351 | 1.241452 | 76.83020173 | |
| | UCS | -0.214 | 1.6932 | -5.198 | 6.389 | -1.298 | 49.798 | -0.615 | 2.766601 | 378.0238468 | |
| P3 | Loading | -2.712 | 15.794 | -36.34 | 41.2 | -23.45 | 53.81 | -0.666 | 1.54282 | 113.2934105 | 0.944344 |
| | Unloading | -5.725 | 33.775 | -78.07 | 88.07 | -46.56 | 54.455 | -2.986 | 1.54282 | 106.987924 | |
| | UCS | -0.275 | 2.0418 | -6.351 | 9.785 | -7.09 | 49.888 | -2.878 | 2.367826 | 258.8266647 | |
| P4 | Loading | -0.568 | 2.8603 | -4.763 | 0.8975 | 5.279 | 46.793 | 0.0085 | 1.553358 | 122.6449603 | 0.936123 |
| | Unloading | -2.532 | 13.721 | -27.65 | 23.835 | -3.17 | 43.673 | -3.158 | 1.553358 | 114.8107095 | |
| | UCS | -0.011 | -0.151 | 0.9502 | -2.827 | 5.0063 | 47.616 | -3.099 | 2.441553 | 293.2315195 | |
| P5 | Loading | -1.717 | 10.843 | -26.65 | 31.02 | -16.21 | 49.991 | 1.2753 | 1.753249 | 147.6881475 | 0.939234 |
| | Unloading | -0.087 | -0.056 | 3.0234 | -10.95 | 18.601 | 31.057 | 1.3914 | 1.753249 | 138.7137422 | |
| | UCS | -0.29 | 1.4991 | -2.477 | 0.2602 | 3.5593 | 44.109 | -0.206 | 2.388314 | 265.3694524 | |

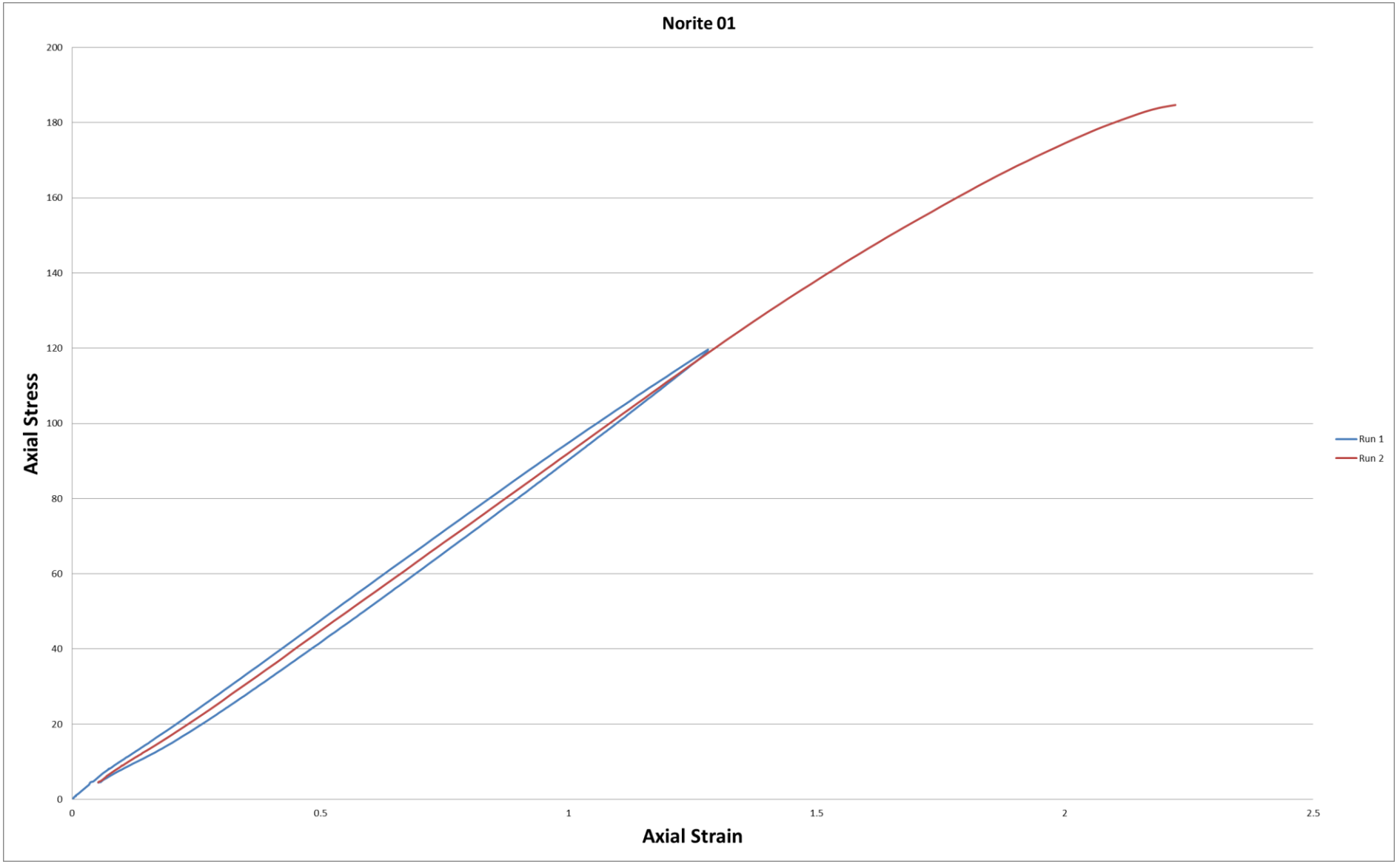

Granofels01
250
200
150
100
50
0
Axial Stress
0
0.5
1
1.5
2
2.5
Axial Strain
Run 1
Run 2

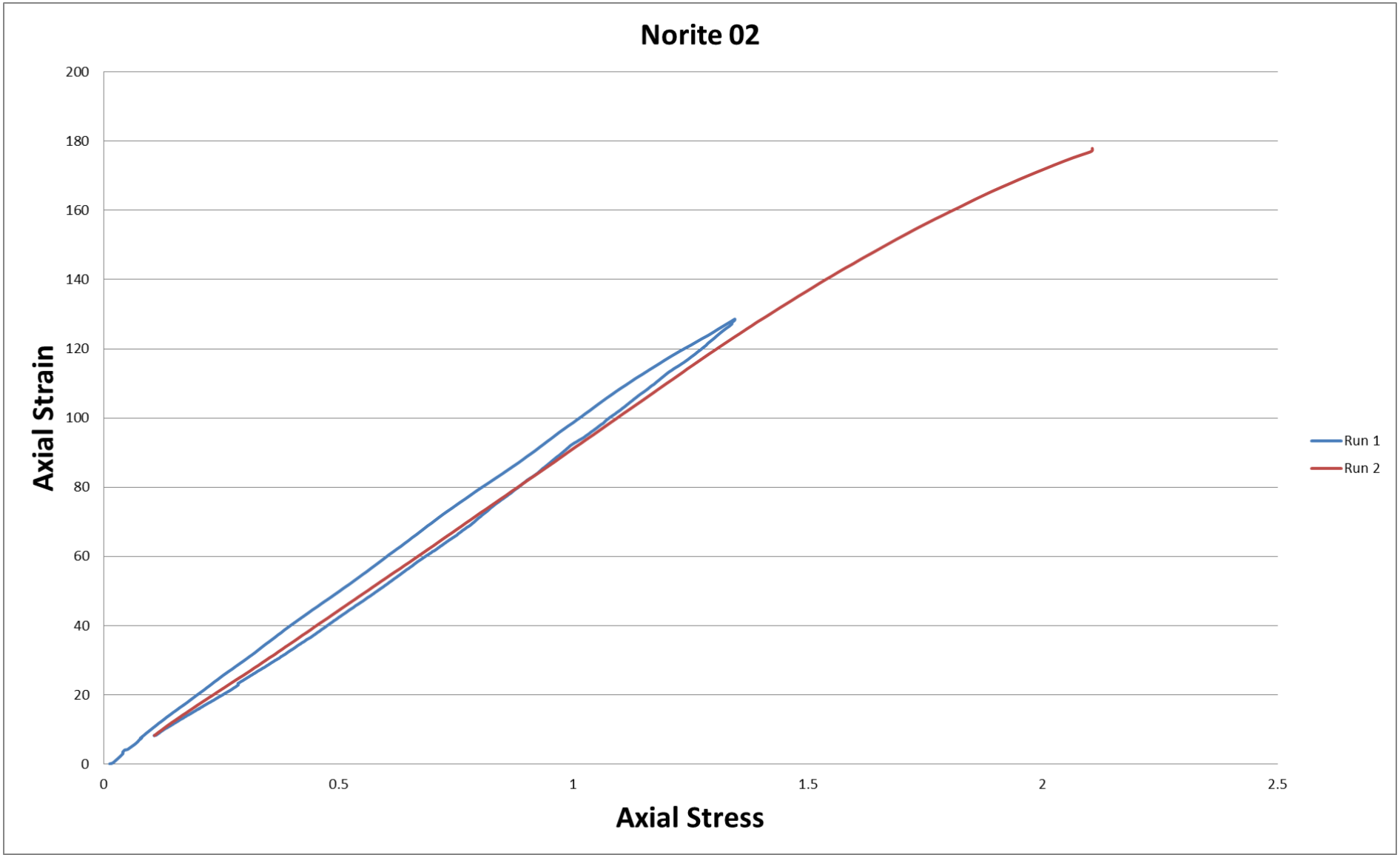

Granofels 02
Axial Stress
Axial Strain
180
160
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Run 1
Run 2

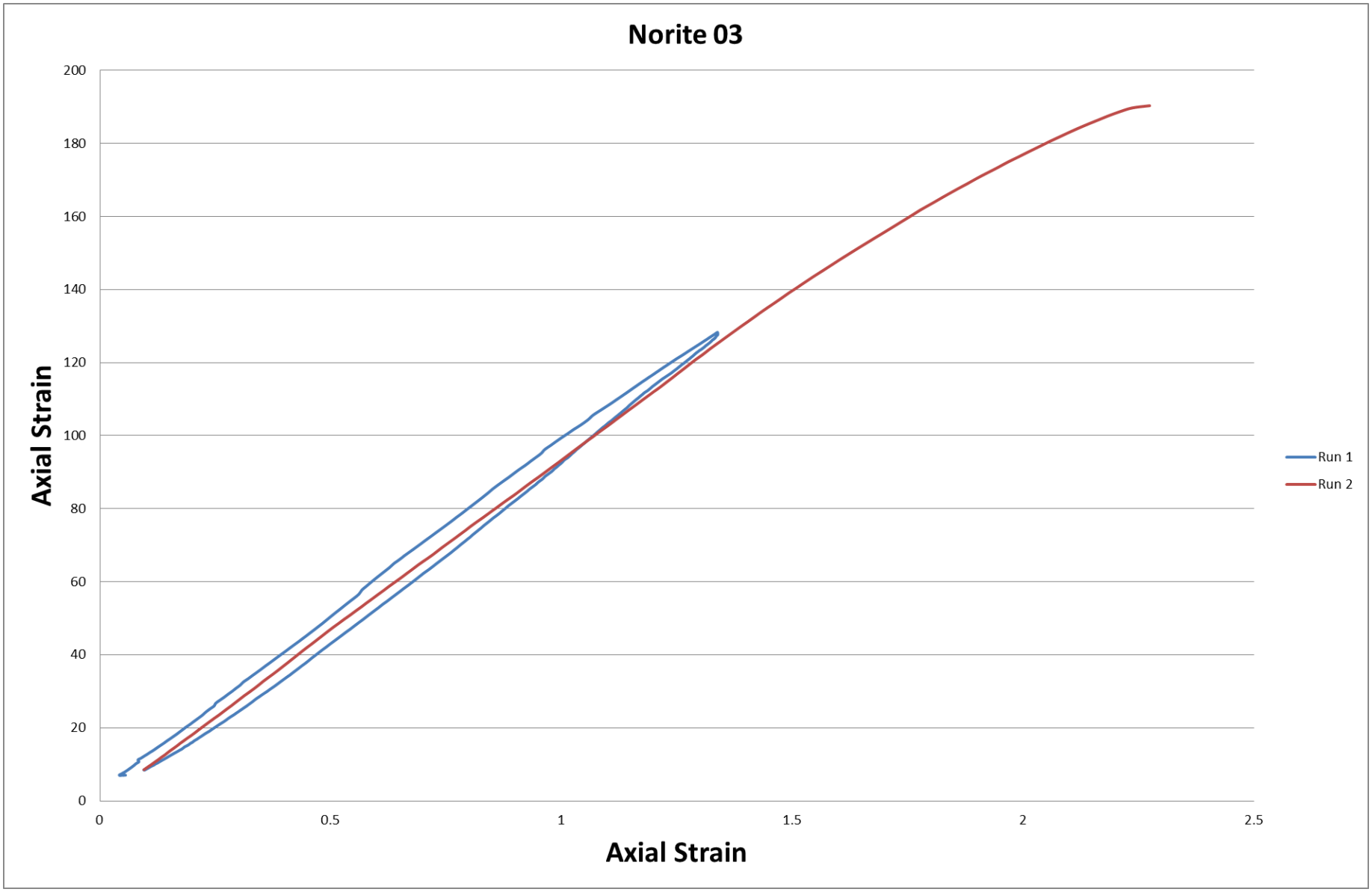

Granofels 03
250
200
150
100
50
0
Axial Stress
0
0.5
1
1.5
2
2.5
Axial Strain
Run 1
Run 2

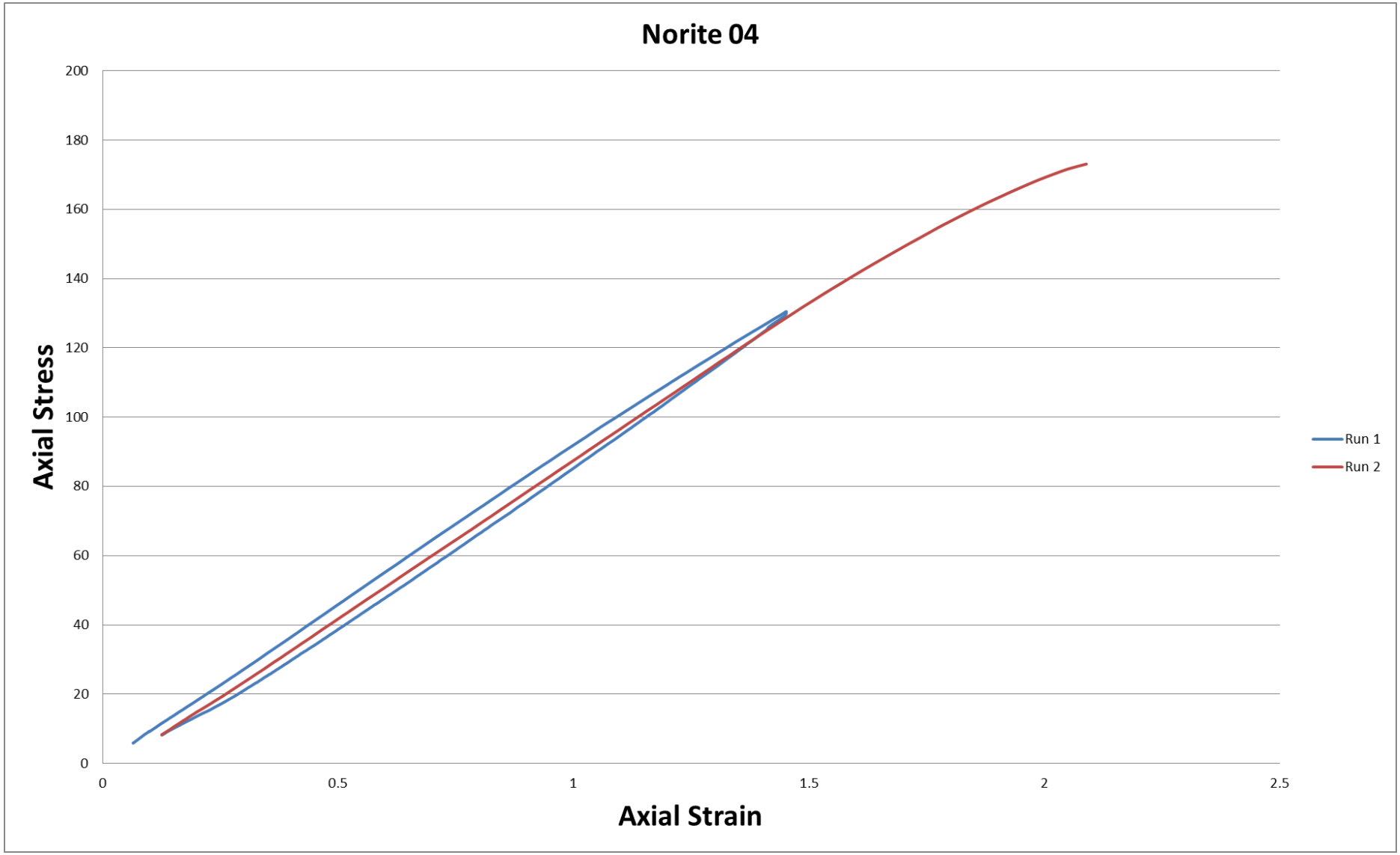

Granofels 04
250
200
150
100
50
0
Axial Stress
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Axis Title
Run 1
Run 2

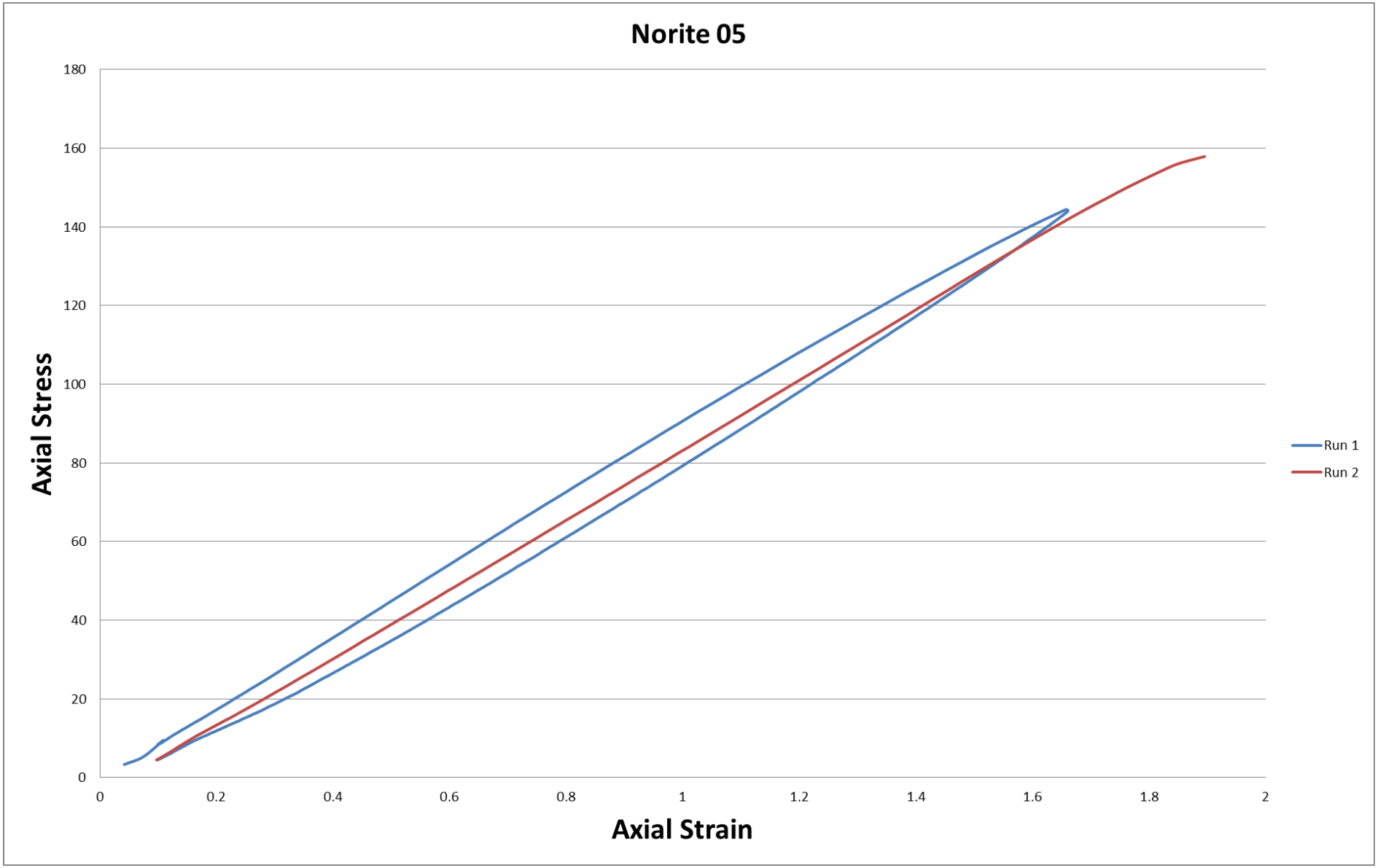

Granofels 05
Axial Stress
Axial Strain
120
100
80
60
40
20
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Run 1
Run 2

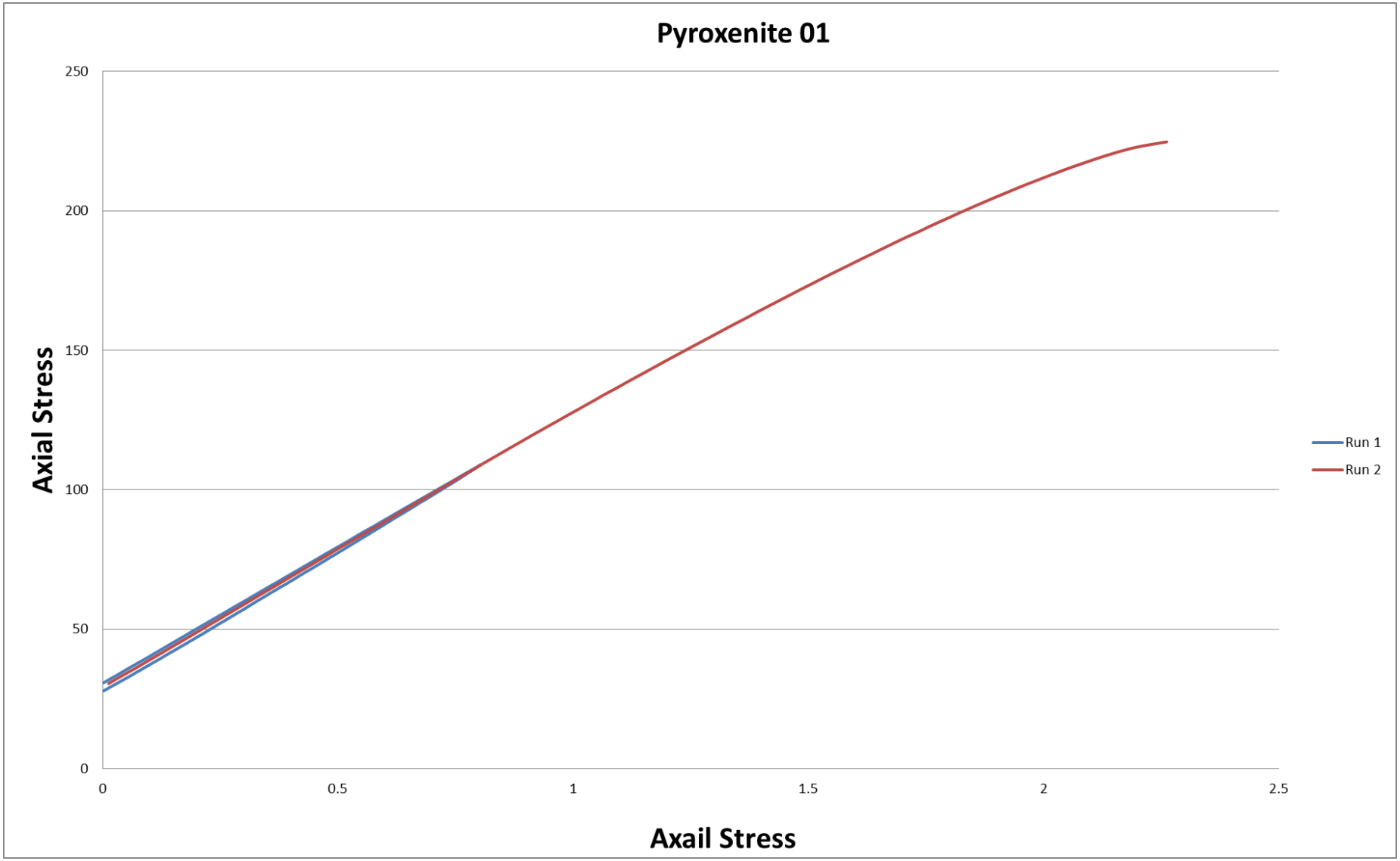

Norite 01
Axial Stress
Axial Strain
200
180
160
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Run 1
Run 2

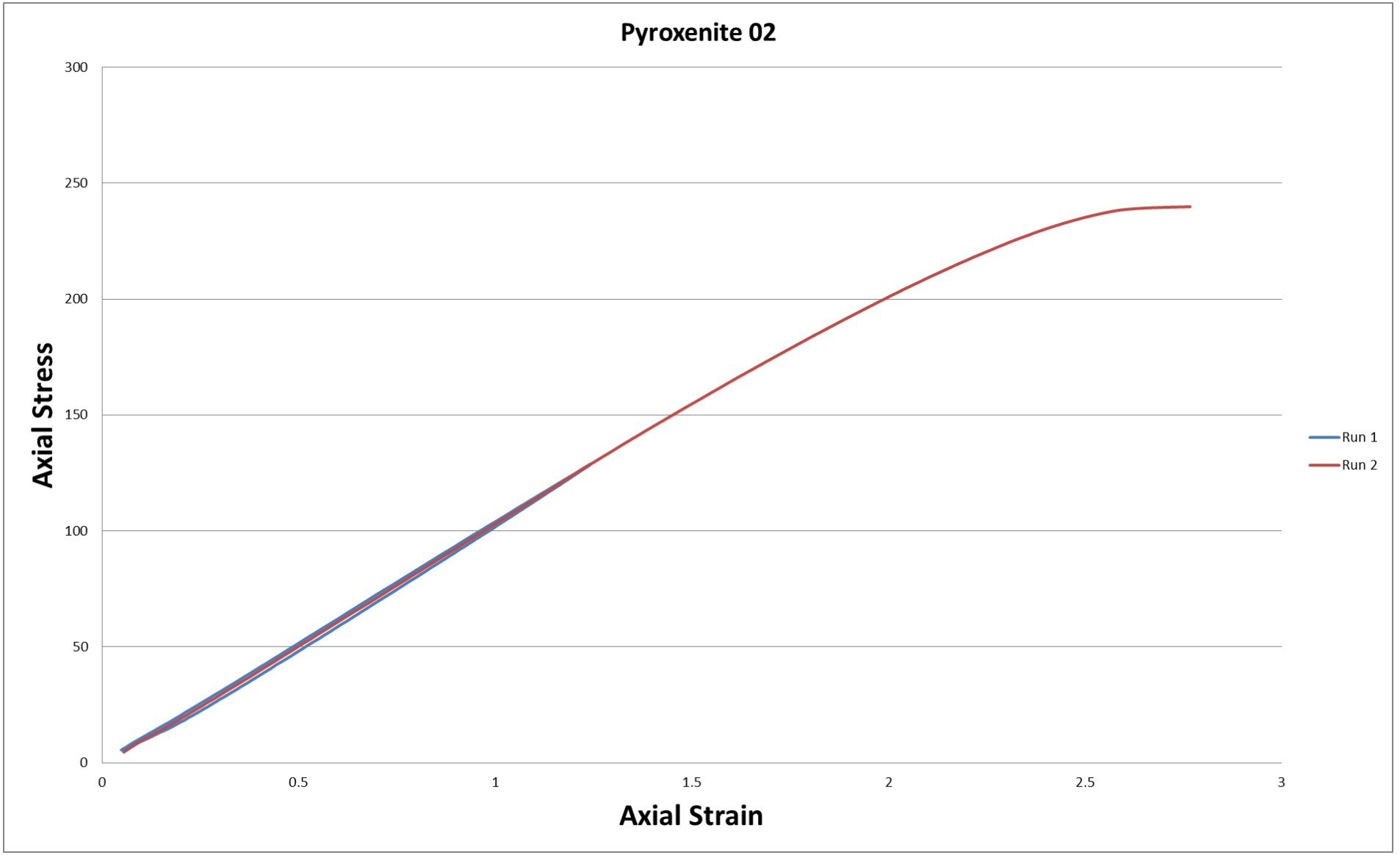

Norite 02
Axial Strain
Axial Stress
200
180
160
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Run 1
Run 2

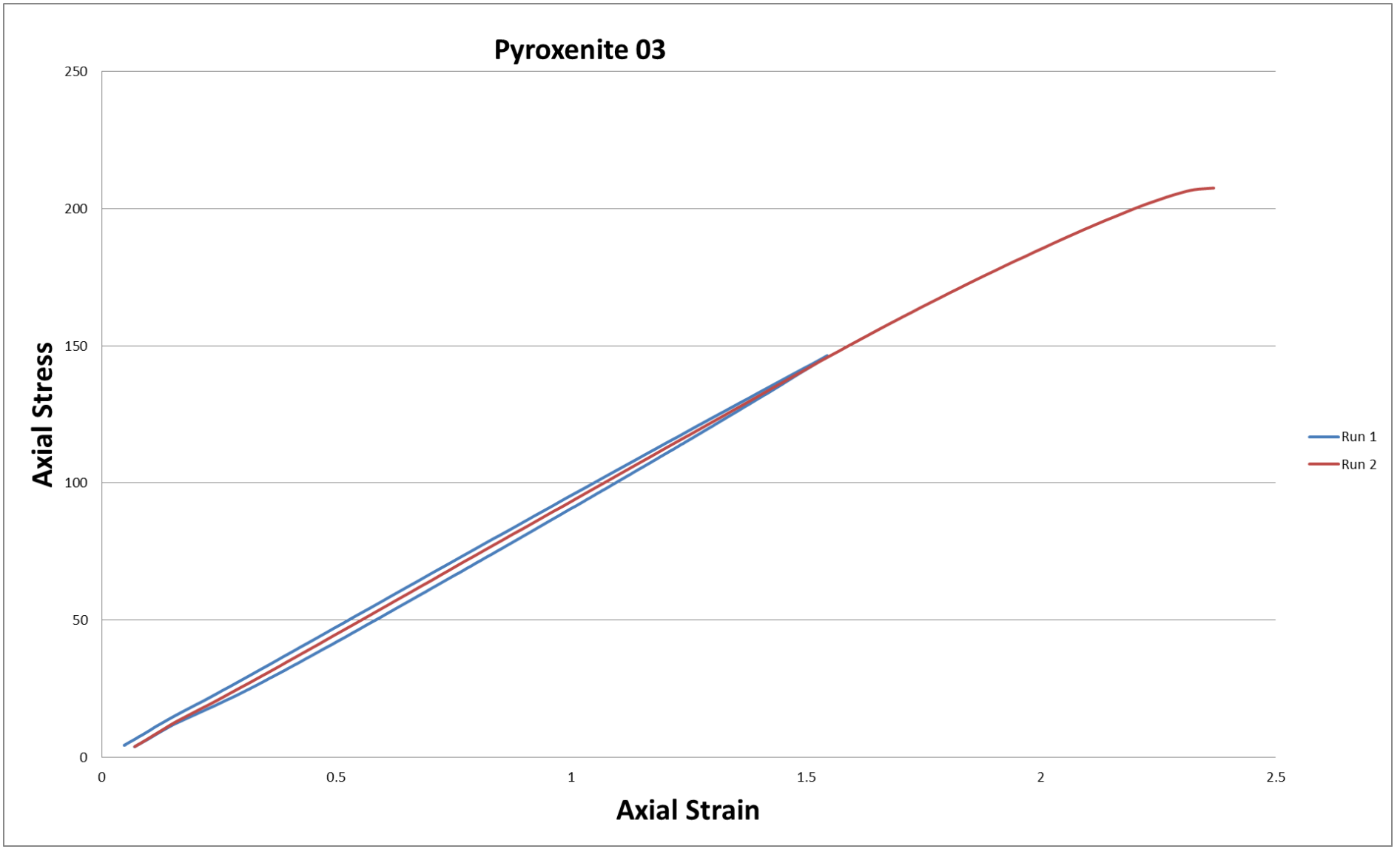

Norite 03
Axial Strain
200
180
160
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Axial Strain
Run 1
Run 2

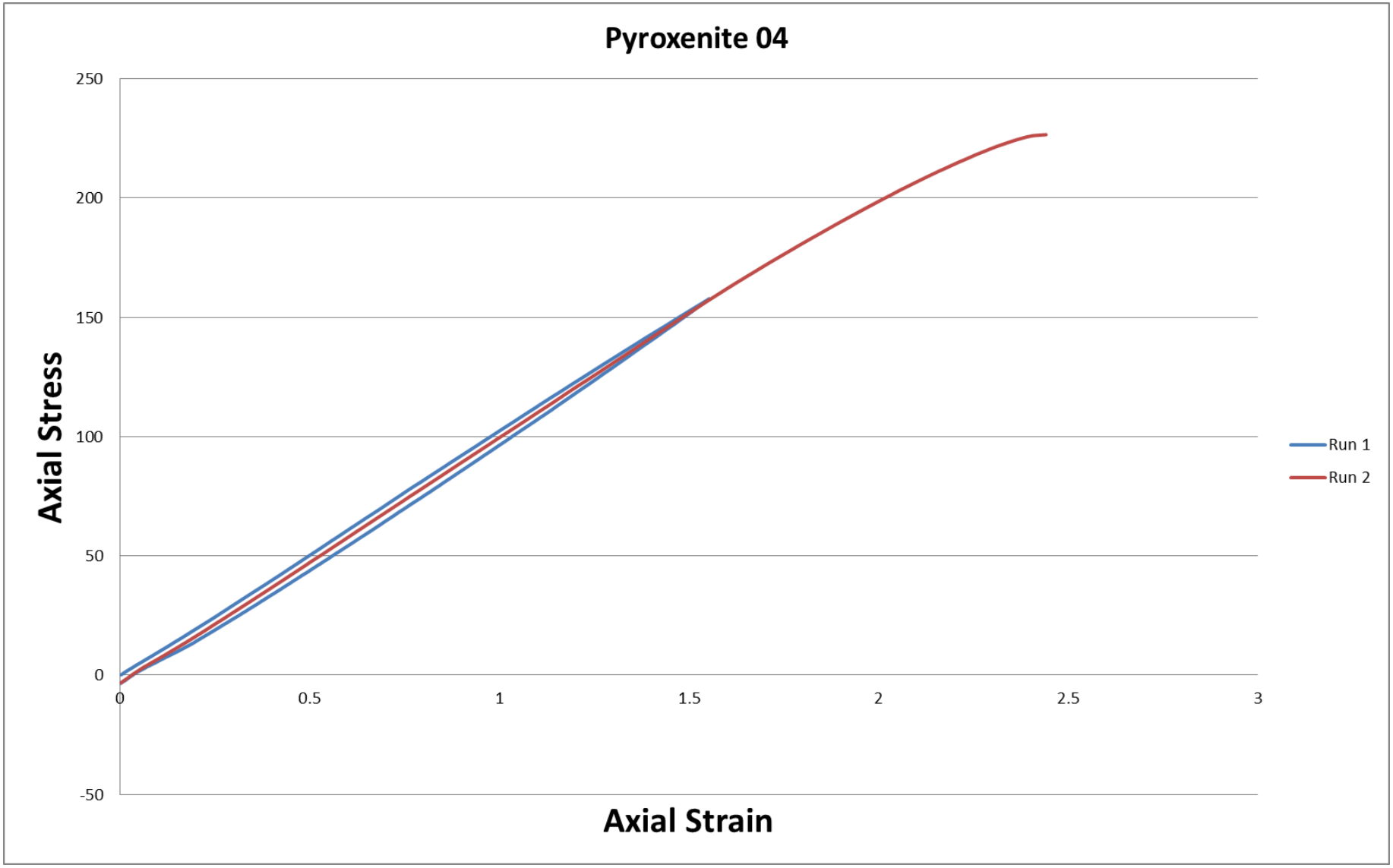

Norite 04
Axial Stress
200
180
160
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Axial Strain
Run 1
Run 2

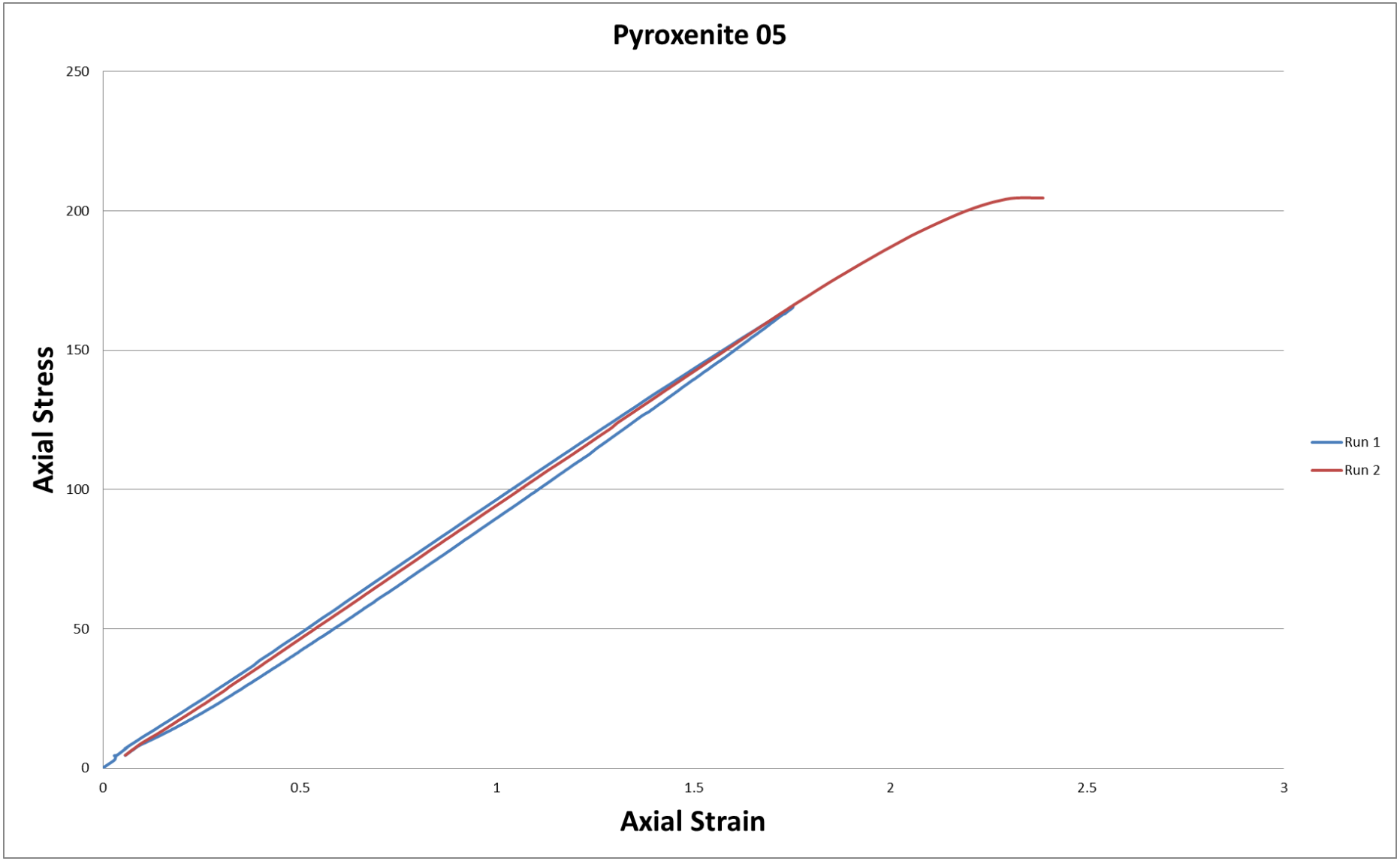

Norite 05
Axial Stress
180
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Axial Strain
Run 1
Run 2


Pyroxenite 01
250
200
150
100
50
0
Axial Stress
0
0.5
1
1.5
2
2.5
Axail Stress
Run 1
Run 2


Pyroxenite 02
Axial Stress
300
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
3
Axial Strain
Run 1
Run 2


Pyroxenite 03
Axial Stress
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
Axial Strain
Run 1
Run 2


Pyroxenite 04
Axial Stress
250
200
150
100
50
0
-50
0
0.5
1
1.5
2
2.5
3
Axial Strain
Run 1
Run 2


Pyroxenite 05
Axial Stress
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
3
Axial Strain
Run 1
Run 2

| Rock Type | Norite | Granofels | Pyroxenite |
|---|---|---|---|
| CoR | 0.91 | 0.94 | 0.95 |
| UCS (MPa) | 176.792 | 203.59 | 220.67 |
| Poisson's Ratio | 0.34 | 0.279 | 0.285 |
| Modulus of Elasticity (GPa) | 93.24 | 105.34 | 99.52 |
| Energy (MJ/m3) | 201.55 | 219.58 | 300.7 |

| | Norite | Granofels | Pyroxenite |
|---|---|---|---|
| 1 | 184.71 | 218.07 | 224.75 |
| 2 | 177.94 | | 239.85 |
| 3 | 190.32 | 201.98 | 207.52 |
| 4 | 173.1 | 190.72 | 226.6 |
| 5 | 157.89 | | 204.63 |
| **AVE** | 176.792 | 203.59 | 220.67 |
| **STD** | 12.4292 | 13.7459 | 14.5764176 |

| Rock Type | Sample Number | E (GPa) | v | UCS (MPa) | Notes |
|---|---|---|---|---|---|
| Granofels | G01 | 112.361 | 0.2784 | 218.07 | Shear failure |
| Granofels | G02 | 95.294 | 0.2765 | 161.91 | exclude, failure through joint |
| Granofels | G03 | 107.05 | 0.2867 | 201.98 | Shear failure |
| Granofels | G04 | 106.65 | 0.2755 | 190.72 | Shear failure |
| Granofels | G05 | 100.474 | 0.8953 | 113.62 | exclude, failure through joint |
| | AVE | 105.33875 | 0.279275 | 203.59 | |
| | | | | | |
| Pyroxenite | P01 | 98.477 | 0.2516 | 224.75 | Shear failure |
| Pyroxenite | P02 | 86.693 | 0.295 | 239.85 | Shear failure |
| Pyroxenite | P03 | 94.396 | 0.2981 | 207.52 | Shear failure |
| Pyroxenite | P04 | 104.559 | 0.2995 | 226.6 | Shear failure |
| Pyroxenite | P05 | 94.875 | 0.3029 | 204.63 | Shear failure |
| | AVE | 95.8 | 0.28942 | 220.67 | |
| | | | | | |
| Norite | N01 | 92.578 | 0.3366 | 184.71 | Shear failure |
| Norite | N02 | 95.403 | 0.3609 | 177.94 | Shear failure |
| Norite | N03 | 96.772 | 0.3162 | 190.32 | Shear failure |
| Norite | N04 | 91.211 | 0.3394 | 173.1 | Shear failure |
| Norite | N05 | 90.23 | 0.3472 | 157.89 | Shear failure |
| | AVE | 93.2388 | 0.34006 | 176.792 | |