TREK GEOTECHNICAL Quality Engineering | Valued Relationships

Engineered Recycled Rubber Aggregate

Tire Derived Aggregate (TDA) Testing Program
Final Report

Prepared for:
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Project Number: 0186 002 00

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RE: Tire Derived Aggregate (TDA) Testing Program – Final Report

As requested, TREK Geotechnical has carried out testing of Tire Derived Aggregate (TDA). The attached report provides our professional opinion in connection with this matter based on a review of background information, and laboratory testing.

Please contact the undersigned should you have any questions or require any clarification or additional information.

Sincerely,

TREK Geotechnical Inc.
Per:

Ken Skaftfeld, M.Sc., P.Eng.
Geotechnical Specialist

Encl.

Revision History

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0	Ken Skaftfeld	April 29, 2023	Draft Report
1	Ken Skaftfeld	May 17, 2023	Final Report

Authorization Signatures

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Appendices

1.0 Introduction and Background

This report summarizes the results of laboratory testing of Tire Derived Aggregate (TDA) carried out by TREK Geotechnical (TREK). The primary objective of the testing program was to provide technical support for future submissions to the City of Winnipeg for their acceptance of TDA as an approved alternate material to natural aggregate. A secondary objective was to assist in providing supporting technical information for potential National and Provincial code compliance assessments through the Canadian Construction Material Center (CCMC) or development of testing standards through the Canadian Standards Association (CSA). To aid in meeting these objectives, TREK proposed a testing program in a letter proposal to yourself dated October 5, 2021. Several steps were initially identified with the understanding that modifications would be made to the program based on material sources and availability of specialized shredders and shearing equipment.

Considerable literature is available on the engineering properties of TDA when used as a replacement for natural aggregate, for example, as retaining wall backfill. Numerous publications from private and public agencies who have performed similar studies on TDA were reviewed and compared with our results to aid in assessing expected project performance, specifically retaining or basement wall design and construction. TREK's testing program evaluated how the size of tire shreds and the particle size distribution (gradation) affects these engineering properties based on the shredded tire material you provided, with recognition given to the production cost and shredding equipment capabilities (with input from yourself). This report also includes commentary on placement/compaction techniques.

2.0 Engineering Properties of TDA

For the purposes of testing, TDA can be considered a coarse mineral aggregate (similar to crushed rock). However, considerable differences exist between mineral aggregates and TDA. In particular, individual TDA particles (or in bulk) are much more deformable than mineral aggregates. Another significant difference is unit weight, with that of TDA being much lower than natural aggregates. Other differences include thermal and drainage properties. Published data shows thermal conductivity of TDA can be up to three times lower than that of soil and hydraulic conductivity (permeability) can be orders of magnitude higher than for mineral aggregates (e.g., sand or gravel). The following sections provide the results of our testing with a commentary on how these results compare with published data.

Of particular relevance to the objectives of the testing program are potential uses as a backfill for retaining (basement) walls. It is recognized that the low unit weight of TDA can result in a significant reduction of lateral earth pressures when compared to walls backfilled with granular backfill. Similar to typical design with granular backfills, the lateral pressure of TDA on a wall can be estimated using the coefficient of lateral pressure multiplied by the unit weight of the backfill material. In the case of a (restrained) basement wall, this would be the at-rest coefficient of lateral earth pressure (K_o). For TDA, this parameter has been directly measured by others, including Rashwan (2018), from material properties (i.e., friction angle from strength testing), or obtained directly from laboratory constrained compression tests. Typical at-rest values of K_o that range from 0.26 to 0.47 (average vales) have been reported compared with values of about 0.3 to 0.4 for granular backfill (Harkins, 2008., Humphry, 2011., Oman, 2013). While the difference in K_o between TDA and natural aggregates is not significant (and in some cases, is comparable), the pressure on the wall backfilled with TDA (for an equivalent K_o) would be significantly lower since the unit weight of TDA can be less than half that of granular fill.

2.1 Testing Program

Laboratory testing was carried out at TREK's geotechnical testing laboratory in Winnipeg. Results of the testing are attached in Appendix A with excerpts contained within this report.

2.1.1 Sample Descriptions

Samples A and B – Two bulk samples of TDA were initially received for testing (Samples A and B). Upon visual examination, it was apparent that the exposed metal wires in both samples were significantly greater than would be typically expected or otherwise desirable for the intended use – metal wires from TDA can generate heat when they oxidize due to corrosion and/or exothermic reactions. Protruding wires were therefore trimmed off TDA particles producing three pails of Sample A and Sample B material for testing. Photo 1 shows the material before the wires were trimmed. Following sieve analysis of Samples A and B, the particle sizes ranging from 25 mm (1 inch) to 37.5 mm (1.5 inch) were separated for subsequent testing; this sample is referred to as Sample A-select.

Sample R22-639 – Three pails of a new sample (from a different source) were submitted for testing in November 2022. Wire protrusions were minimal on this sample as can be seen in Photo 3.

Photo 1 – Sample A (left) and **Photo 2 –** Sample B (right), before trimming protruding wires

Photo 3 – Sample R22-639

2.1.2 Particle Size Distribution

Samples A and B – There is little difference in the grain size distribution between Sample A (Figure 1) and Sample B (Figure 2). Particle sizes range from 50 mm (2 inch) to 10 mm (0.4 inch) with zero percent fines (less than 0.075 mm). As an aggregate, this material would be described as a poorly graded gravel. The portion of the grain size distribution curve used to prepare Sample A-select is also shown on Figure 1. The particle size distribution from Sample R22-639 is shown on Figure 3.

Figure 1 – Sample A particle size distribution

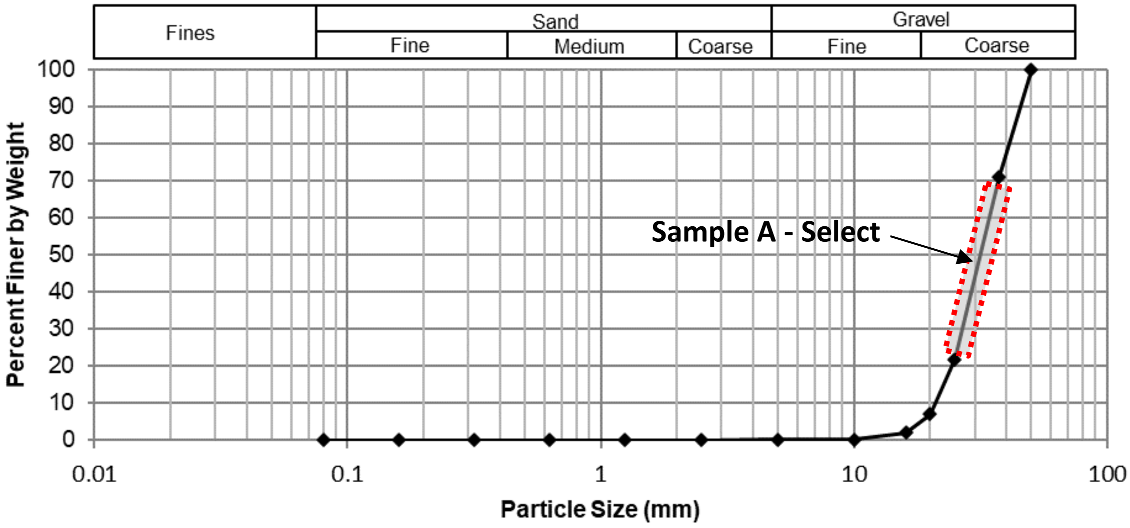


Figure 2 – Sample B particle size distribution

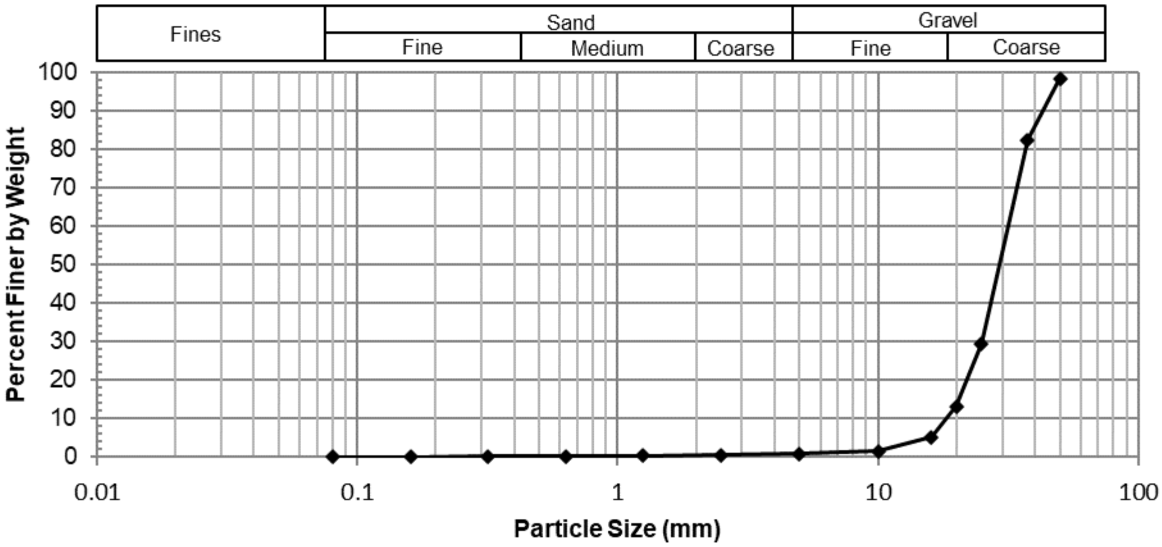
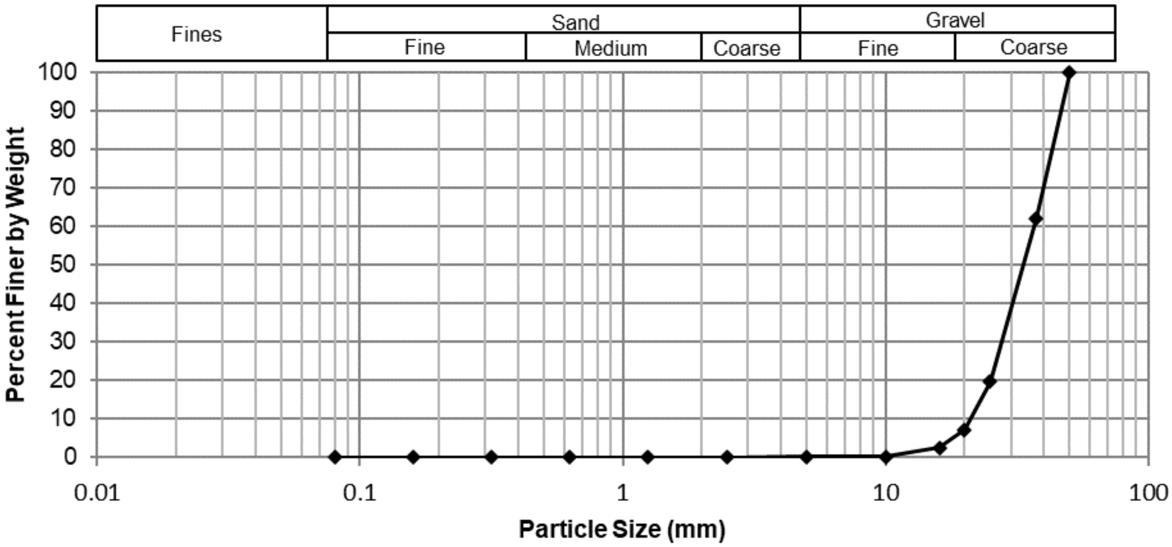
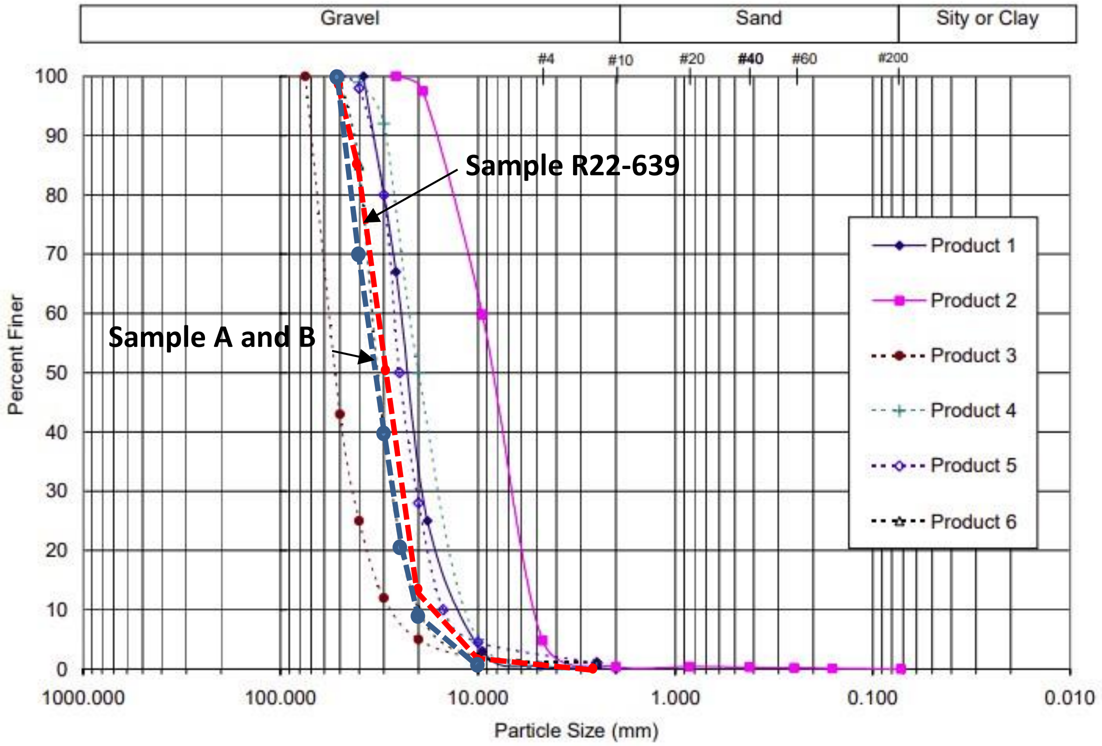


Figure 3 – Sample R22-639 particle size distribution



The grain size distribution for TDA reported in the literature is shown on Figure 4. For comparison, the results of our testing have been superimposed on the original figure. TREK's results for both Sample A, Sample B (which are essentially the same) and Sample R22-639 fall well within the reported range.

Figure 4 – Comparison of Particle Size Distribution between industry results and TREK laboratory testing, modified from Benda (1995) and Humphry et al. (1992)



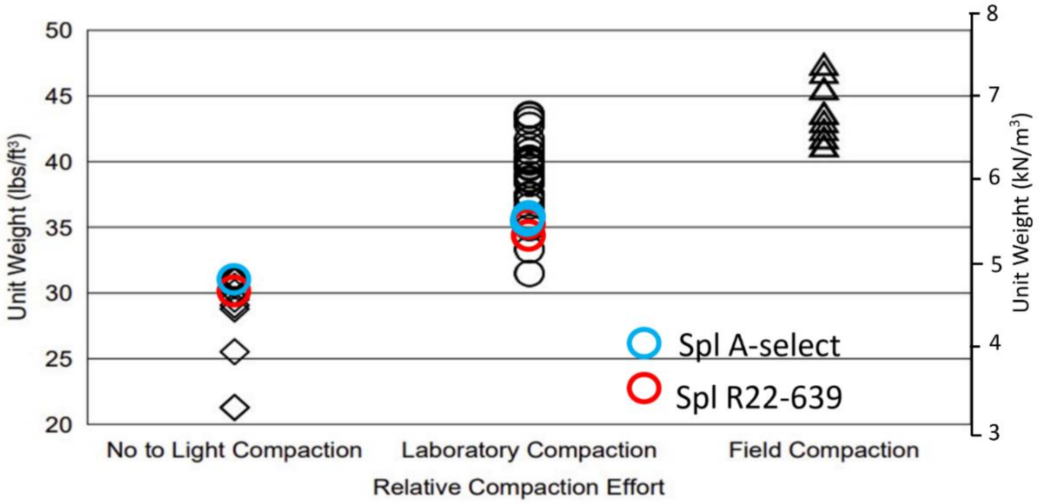
2.1.3 Unit Weight

The unit weight of compacted TDA with a maximum 75 mm (3 inch) particle size is typically about 6.3 kN/m^3 (40 lbs/ft^3). This is much lower than the unit weight of mineral aggregates which would typically range from 15.9 to 21.0 kN/m^3 (101 to 134 lbs/ft^3). With little to no compaction, unit weights of TDA typically range from about 3.3 to 4.9 kN/m^3 (21 to 31 lbs/ft^3). Laboratory compacted TDA unit weights typically range from about 5.0 to 6.9 kN/m^3 (32 to 44 lbs/ft^3).

ASTM C29/C29M-97 procedures for determining the laboratory bulk unit weight of aggregates were used to measure the density of the TDA samples in a loose state, after rodding, and after jigging. The latter two methods are intended to reproduce different levels and methods of compaction that may be representative of those utilized in the field. Rodding involves placing three layers of TDA into a cylindrical metal container and using a tamping rod to fully penetrate each layer 25 times. Jigging involves placing three layers in the metal container and compacting each layer by raising and dropping one edge of the container 25 times on opposite sides (50 per layer).

The results from TREK's testing are superimposed on data from industry (Harkins, 2008) on Figure 5. Our results show a unit weight of 4.9 kN/m^3 for both samples in a loose state and about 5.3 to 5.7 kN/m^3 for the two samples compacted in the laboratory (rodding and jigging). These values fall within the range of reported values although it is likely that industry testing may have used more rigorous compaction methods (e.g., vibrating table). There is little difference in the results from jigging and rodding although both methods yield results higher than the loose state.

Figure 5 – Comparison of unit weights (modified from Harkins, 2008)



2.1.4 *Void Ratio and Porosity*

The void ratio (e) is the ratio of the volume of voids to the volume of solids while porosity (n) is the volume of voids to the total volume (% void space in a unit volume). Both void ratio and porosity are used to characterize the open space within the TDA (or soil). The void ratio can be less than or greater than or equal to 1 while the porosity is always less than 1. These two engineering properties can be estimated using Equations 1 and 2.

$$Void\ Ratio\ (e) = \frac{G_s \gamma_w}{\gamma_d} - 1 \qquad \text{(Equation 1)}$$

where G_s is the specific gravity (measured at 1.26), γ_w is the unit weight of water (9.81 kN/m^3) and γ_d is the dry unit weight of TDA (kN/m^3). Note: 1 lb/ft^3 = 0.157 kN/m

$$Porosity\ (n) = \frac{e}{(1+e)} \qquad \text{(Equation 2)}$$

Table 1 shows the range reported by industry and the values from out testing program. Our results are in generally good agreement with industry data. Additional testing would be required to assess the statistical variability associated with these properties.

Table 1 – Unit weight, void ratio, and porosity of TDA

Sample	Unit Weight (kN/m^3)			Void Ratio (dimensionless)			Porosity (%)		
	Loose	Rodded	Jigged	Loose	Rodded	Jigged	Loose	Rodded	Jigged
Industry	3.3 – 4.9	5.0 - 6.9 (lab compacted)		1.5 – 2.5	0.9 – 1.2 (lab compacted)		60 – 70	45 – 55 (lab compacted)	
A	5.0	5.7	5.8	1.46	1.15	1.13	59	54	53
B	4.8	5.7	5.6	1.58	1.16	1.20	61	54	55
R22-639	4.7	5.5	5.4	1.60	1.25	1.30	62	56	56

2.1.5 Compressibility

Individual particles of TDA are significantly more deformable than mineral aggregate particles. TDA can undergo significant vertical deformation under applied loads as a result of i) bending and rearrangement of particles and ii) compression of individual particles. Bending and particle rearrangement occur during compaction and initial loading and these deformations are permanent. Compression of individual particles is largely recoverable (i.e., the material will rebound). Constrained compression tests were performed on the two samples – the test set-up is shown in Photos 4 and 5. Stress-strain (or compression) curves obtained from the tests are summarized on Figure 6 (Sample A-select) and Figure 7 (Sample R22-639).

Photo 4 – Constrained compression test set-up

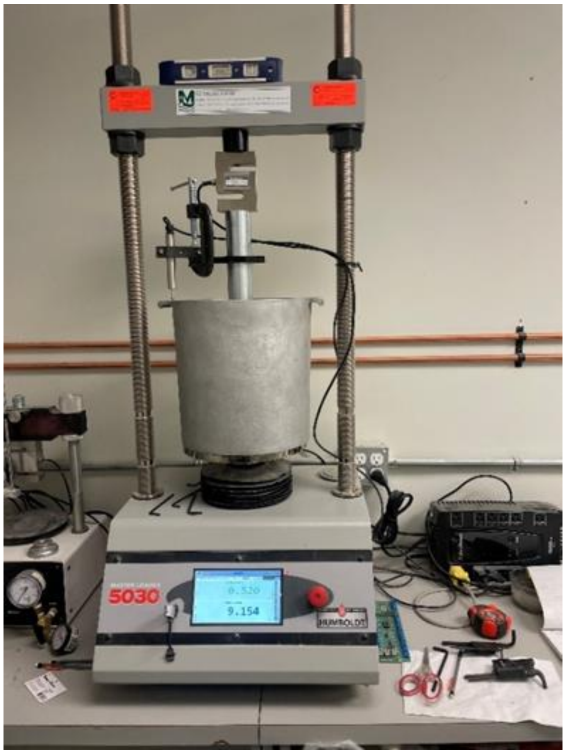


Photo 5 – Load transfer plate

Figure 6 – Constrained compression test results – Sample A-select

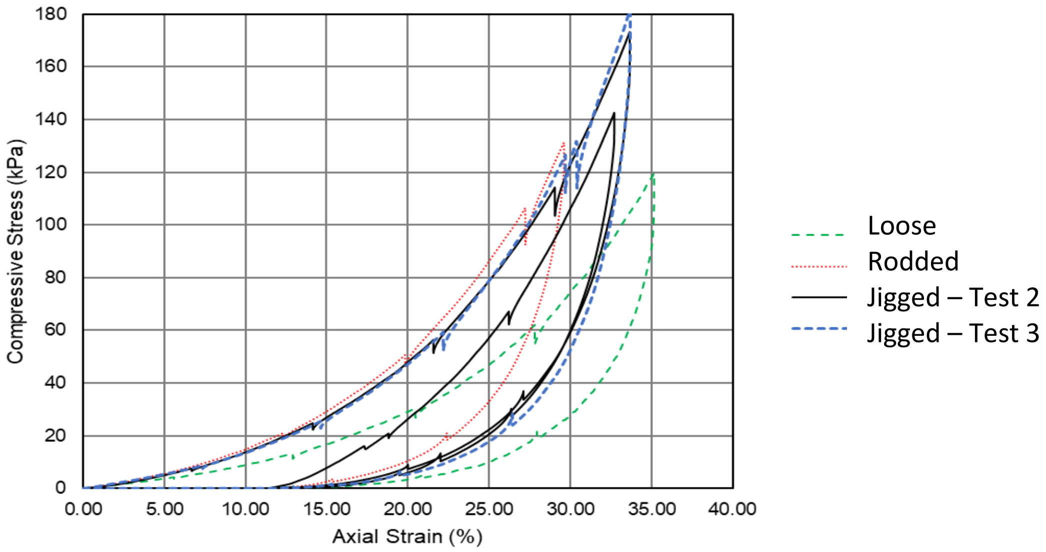
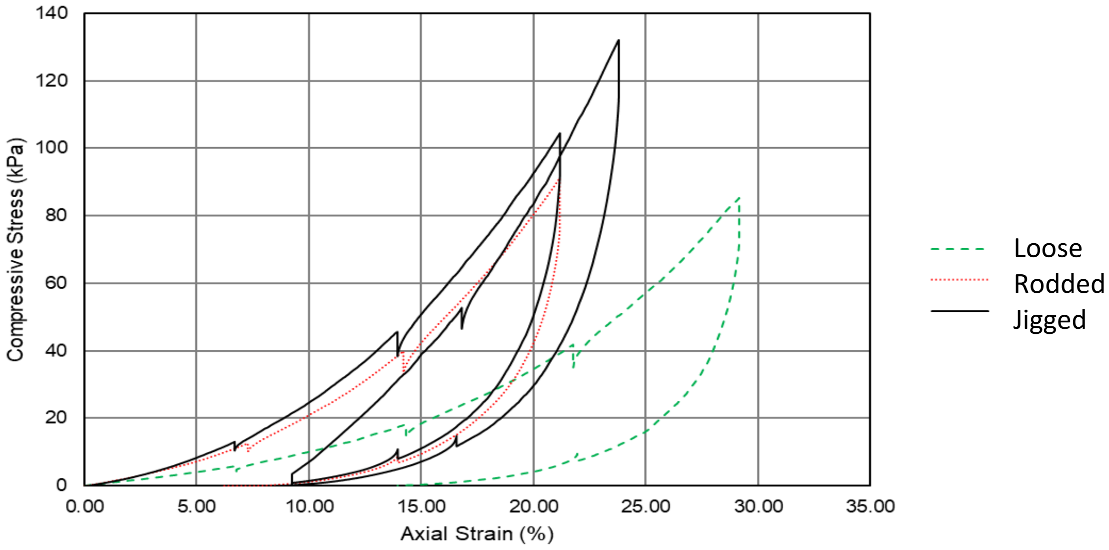


Figure 7 – Constrained compression test results – Sample R22-639



A typical stress-strain compression curve from industry testing is shown on Figure 8. Our results from Sample R22-639 are superimposed on this figure. The range of values measured by industry which reflects different degrees of compaction (and material) is shown on Figure 9. Our results have also been superimposed.

Figure 8 – Typical Stress-strain curve for TDA constrained compression testing (modified from Manion and Humphry, 1992)

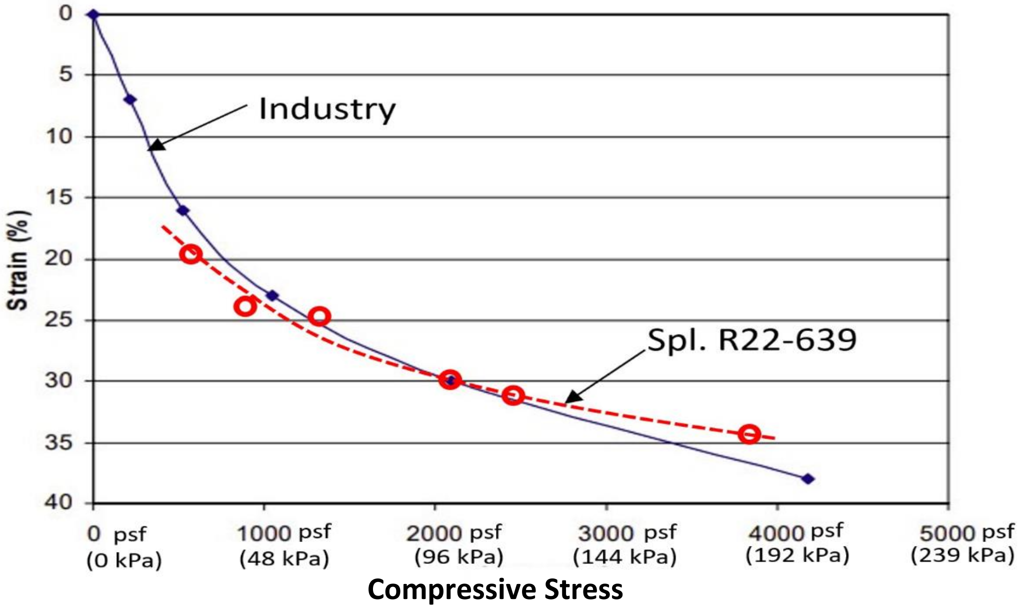
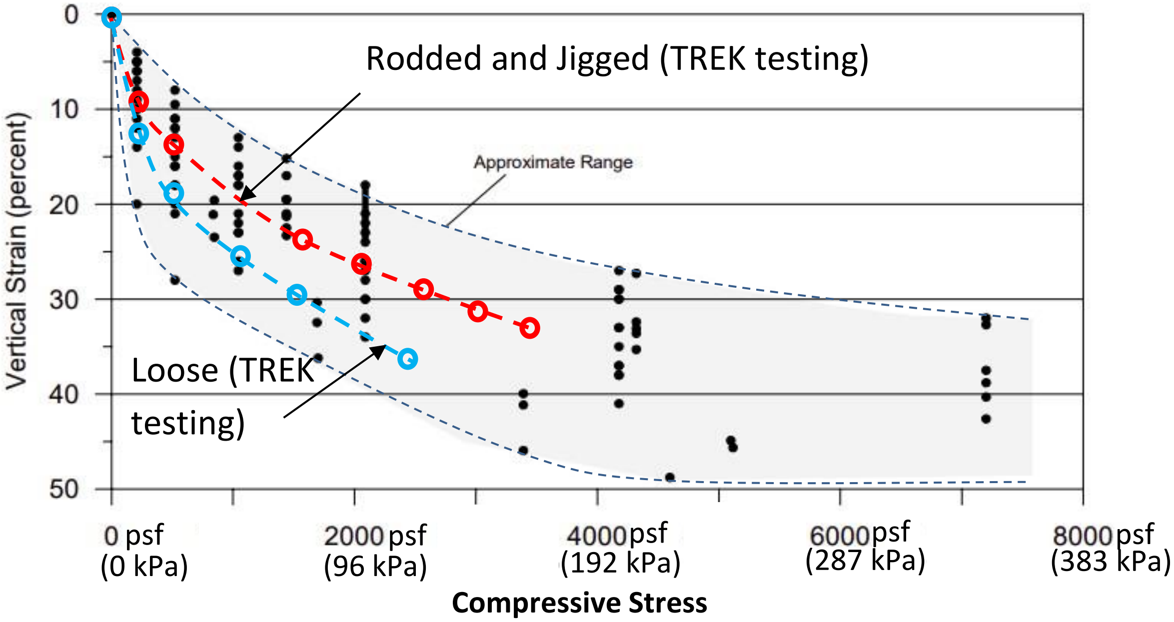


Figure 9 – Summary of constrained compression test results (modified from Harkins, 2008)



The initial portion of the stress-strain curves in Figure 8 is steep indicating high compressibility. As the applied stress increases, the curves flatten out. The initial (steep) portion is associated with nonrecoverable particle bending and rearrangement. This is supported by the results in Figure 6 and 7 where unloading has resulted in a permanent increase in measured axial strain from the initial condition.

The results of our constrained compression tests were used to estimate the constrained modulus, *D*. The lateral stress increment ($\Delta\sigma_x$) could not be measured directly with our test set-up, preventing the calculation of values for K_o (at-rest earth pressure coefficient), *E* (Young's modulus), and μ (Poisson's ratio). However, a favourable comparison of *D* and other (associated) parameters with industry test results provides confidence that preliminary estimates of these values can be obtained empirically.

The constrained modulus, *D*, can be calculated as the slope of the stress-strain curve using the loading-unloading portion of the curve (i.e., the recoverable deformation) as:

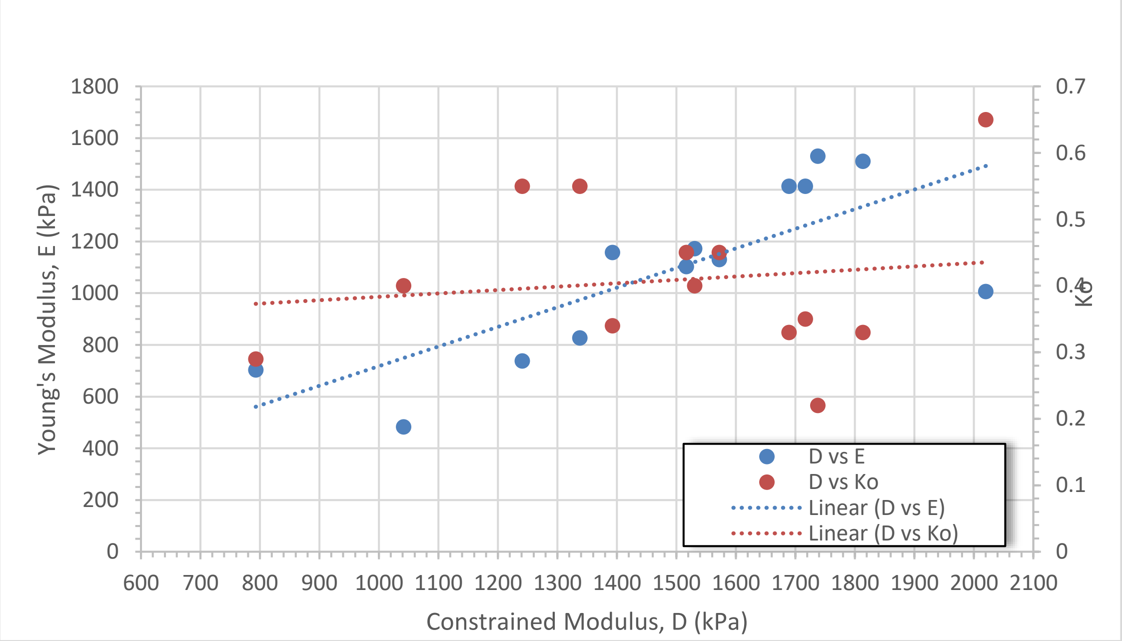
$$D = \frac{\Delta\sigma_y}{\Delta\varepsilon_y} \qquad \text{(Equation 3)}$$

where $\Delta\sigma_y$ is the vertical stress increment applied to the sample and $\Delta\varepsilon_y$ is the calculated vertical strain increment.

The results from industry testing are shown on Figure 10 as *D* vs *E* and *D* vs K_o. Young's modulus values (*E*) range from 703 to 1,510 kPa with an average of 1,092 kPa. For comparison, the *E* for mineral aggregates ranges from about 10,000 for loose sand) to 320,000 kPa for dense sand/gravel (Kezdi, 1974) illustrating how much more compressible TDA is compared to natural aggregate. There is a reasonably good linear trendline for *D* vs *E* showing increasing *E* with increasing *D* (Figure 10).

The K_o values range from industry tests range from 0.26 to 0.47 with an average of 0.41. In comparison, K_o values for mineral aggregates range from about 0.35 to 0.50 (Holtz and Kovacs, 1981). No clear relationship is apparent between *D* and K_o plotted on Figure 10.

Figure 10 – Relationship between *D* and *E* and *D* and K_0 (data from Harkins, 2008)



The constrained modulus values were calculated using Equation 3 at stress ranges greater than 70 kPa and where stress-strain behaviour is near-linear; results for Sample A-select and R22-639 are summarized in Table 1. Using these values, apparent values of Young's modulus (*E*) and the horizontal earth pressure coefficient (K_o) were extracted using the best fit lines on Figure 10; these results are also summarized in Table 1.

Table 2 – Summary of Elastic Properties

Sample	Condition	Calculated Constrained Modulus, *D* (kPa)	Estimated Young's Modulus, *E* from Fig. 11 (kPa)	Estimated K_o from Figure 11
A-select	Loose	694	500	0.38
A-select	Rodded	844	610	0.38
A-select	Jigged	1388	970	0.40
R22-639	Loose	930	670	0.38
R22-639	Rodded	1600	1170	0.42
R22-639	Jigged	1394 (avg)	1000	0.40
Industry	Unknown	369 - 2544	480 - 1530	

In comparison, Young's modulus values reported by industry ranges from about 480 to 1530 kPa and K_o values range from about 0.22 to 0.55 (Harkins, 2008). TREK's results generally fall within both ranges.

2.1.6 Hydraulic Properties

TDA has a much higher hydraulic conductivity (permeability) compared to most mineral aggregates (sand and gravel). In TDA however, the hydraulic conductivity is more sensitive to changes in applied overburden pressure (or any applied load) whereas, in general, the hydraulic conductivity of mineral aggregates is not significantly affected (reduced) with changes (increases) in overburden pressure. The flow (which is a function of voids ratio described earlier) is estimated using the general Equation 3:

$$Q=kiA \qquad \text{(Equation 4)}$$

where Q is the flow, k is the hydraulic conductivity (permeability), i is the hydraulic gradient, and A is the cross-sectional area of the specimen.

Because of equipment limitations necessary to satisfy the requirements in ASTM D76760-12 (Measurement of Hydraulic Conductivity of Tire Derived Aggregates Using a Rigid Wall permeameter), TREK conducted hydraulic conductivity testing in general accordance with ASTM D2434-19 (Standard Test Method for Permeability of Granular Soils (Constant Head). The test set-up is shown on Figure 11. Testing proved difficult due in part to high flow velocities; similar experience has been reported in industry results. The TDA was loosely placed in the cell; it was not possible to compact (rod or jig) the sample. A test on Sample A-select indicated a k value of 27 cm/sec. An average k value of about 6 cm/sec was measured on Sample R22-639. These values that fall within the very wide range reported by industry (Figure 12).

Figure 11 – Constant head test set-up

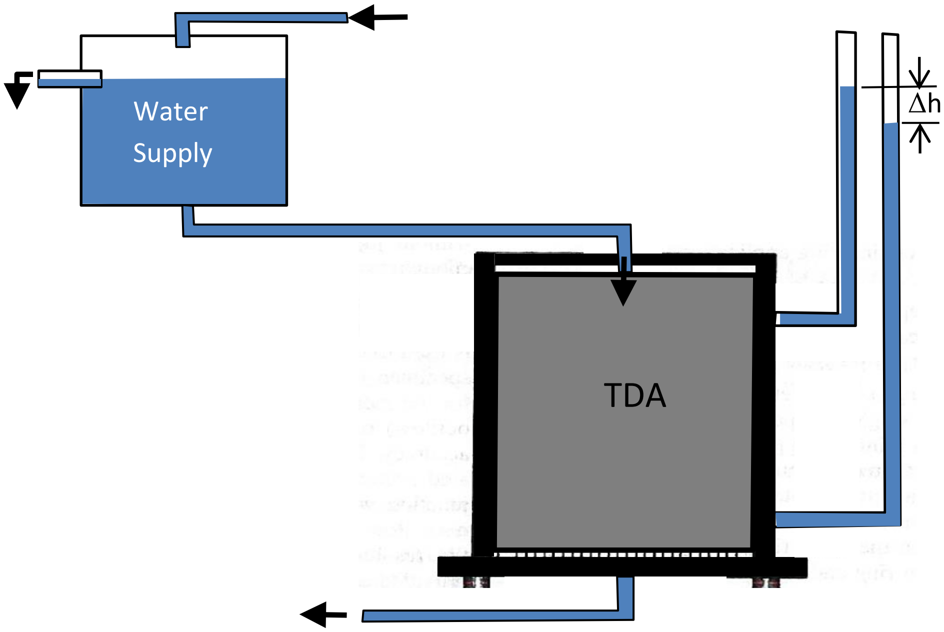
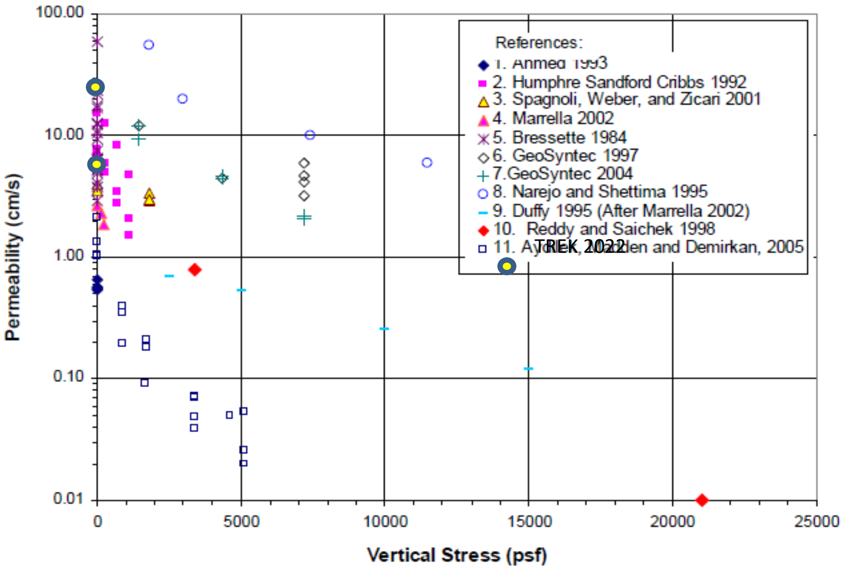


Figure 12 – Summary of Hydraulic conductivity tests (modified from Harkins, 2008)



2.1.7 *Thermal Conductivity and Heat Capacity*

Thermal conductivity is an expression of the amount of heat that flows through a one cubic metre cube of material within one second when the temperature gradient is exactly 1K between opposite sides. Every material has a unique thermal conductivity, a temperature dependent property which can be related to the ability of the material to conduct heat. The higher the thermal conductivity, the higher the rate of heat transfer and this is why materials with a lower thermal conductivity are used for insulation. The thermal conductivity of rubber (and hence TDA) is reported to be 2 to 3 times lower than that of mineral aggregate making it a potential candidate for insulation (Harkins 2008).

Another parameter used to characterize the thermal properties of a material is specific heat capacity (commonly referred to as specific heat) which is the amount of heat (energy) required to change the temperature of a material by one degree C. TREK's testing program was limited to determining the relative change in heat capacity for Sample A-select and Sample R22-639 in a loose state, after jigging, and after rodding. Comparisons between the two samples and between the compaction condition for each sample were made by first determining the heat capacity for each case and then expressing the comparisons as a heat transfer coefficient ratio (with a baseline of 1.0). In thermodynamics, the heat transfer coefficient is a constant used to calculate heat transfer. A lower coefficient ratio indicates lower heat transfer from one case to another while a higher ratio indicates a higher heat transfer. Direct measurements of thermal conductivity were not possible; this would have required a much more sophisticated set-up, however, the thermal conductivity for TDA has been well researched and typical values are available for use.

The test set-up with is shown in Figure 13. Loose, jigged, and rodded TDA was placed in an aluminum vessel and left in a freezer until stabilized temperatures were achieved. The container was then removed from the freezer and measurements taken until temperatures again stabilized. Thermistors embedded in the TDA, in the freezer, and outside of the freezer measured the temperatures which were stored in a data logger. Sample plots from tests on Sample R22-639 are shown on Figure 14 (cooling) and Figure 15 (heating) for loose material. All plots from the testing program are provided in Appendix A.

Figure 13 – Thermal testing set-up

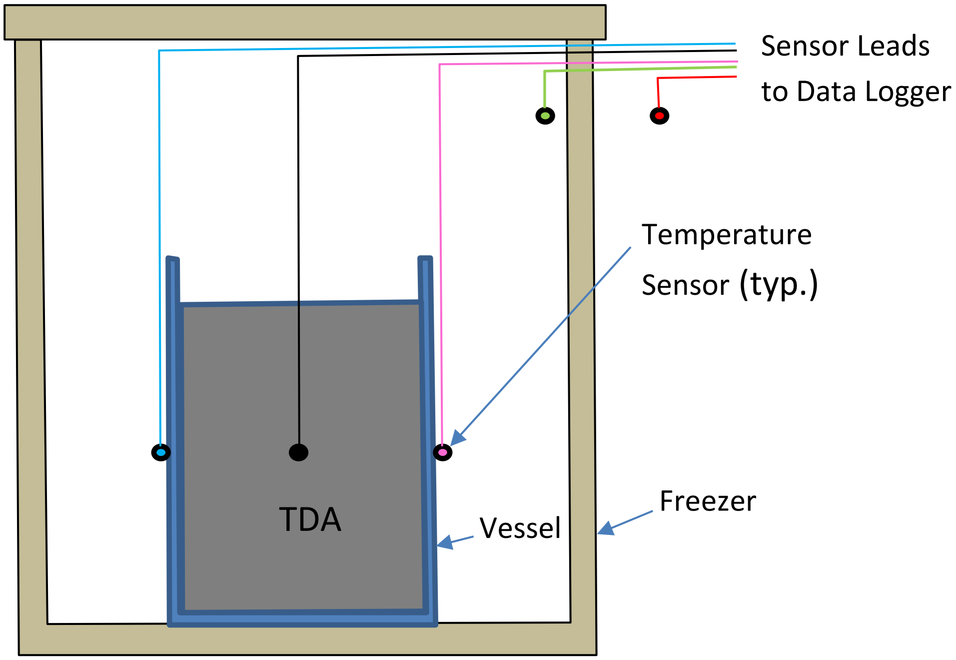


Figure 14 – Thermal testing (cooling) – loose TDA Sample R22-639

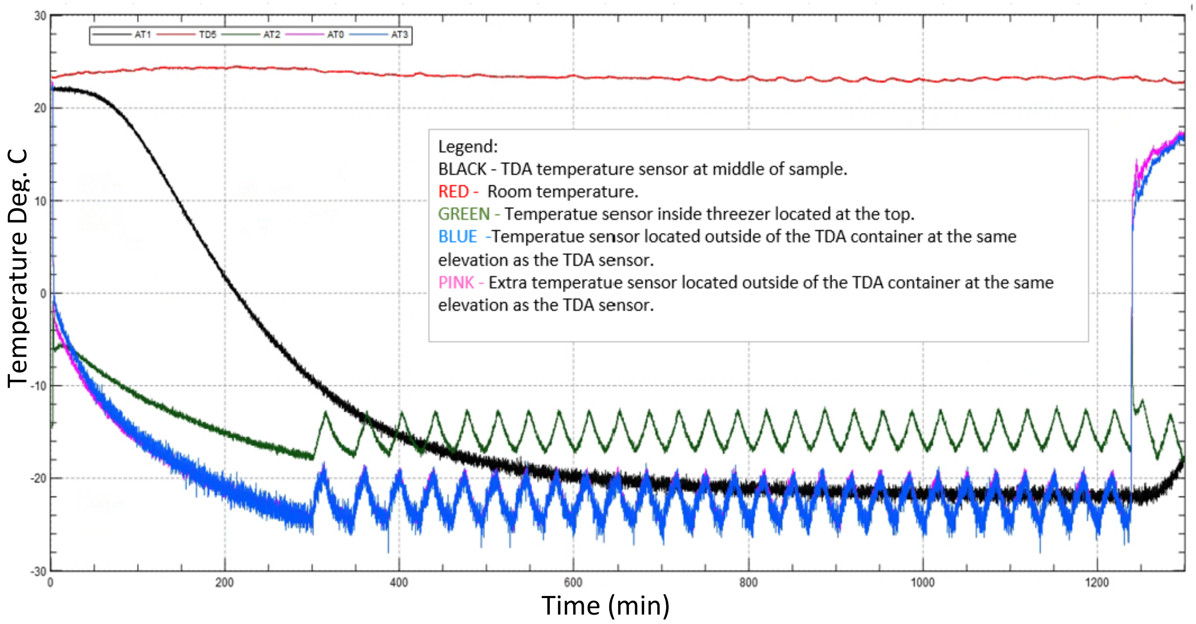


Figure 15 – Thermal testing (heating) – loose TDA Sample R22-639

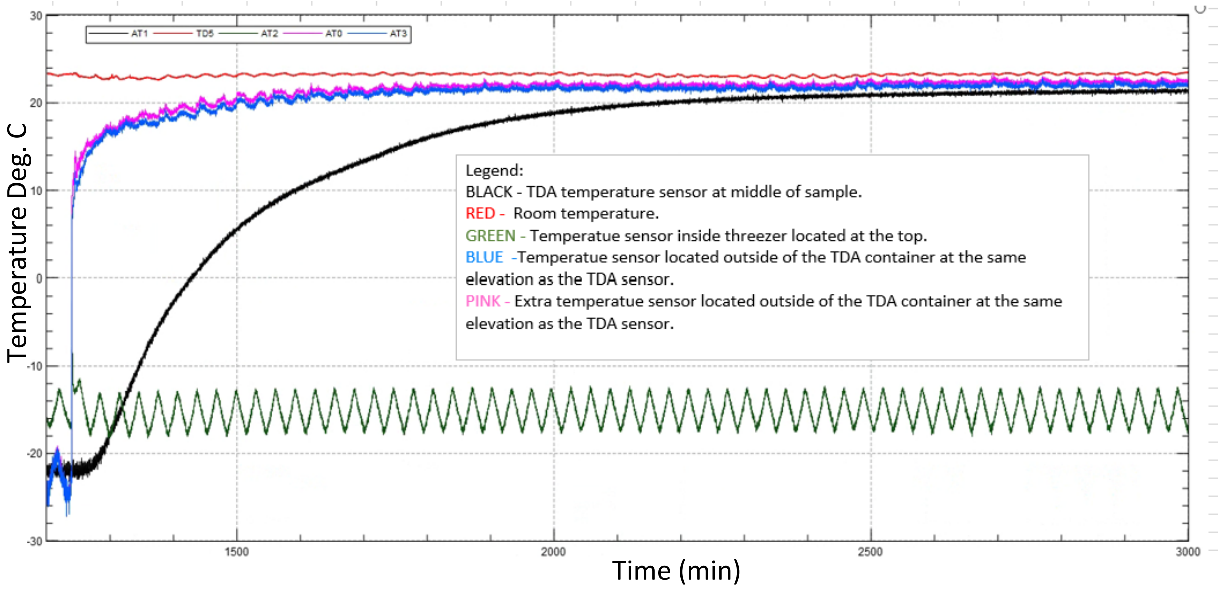
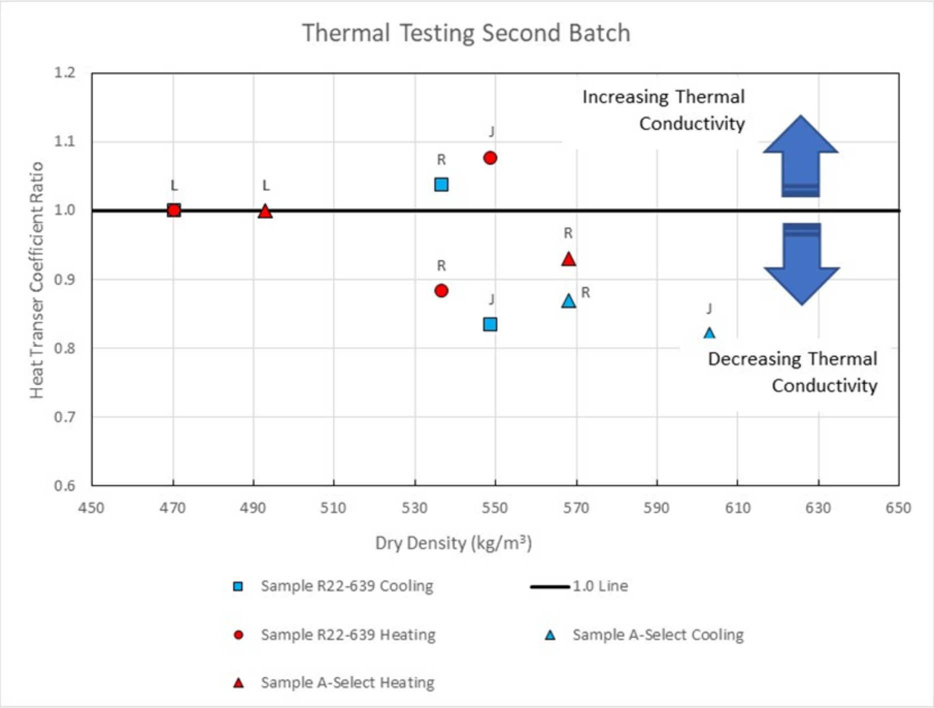


Table 3 shows an example of one set of calculations used to calculate the heat transfer coefficient ratio (Sample R22-639), comparing the jigged and rodded material to loose material, with the ratio for loose material is set at 1.0. The results for this example are inconclusive, both with respect to the test type (heating or cooling) and the method of sample preparation. The results for all tests, including those for sample A-select were plotted on Figure 16. These overall results tend to support this observation, with no well-defined trends. Most literature shows an increase in thermal conductivity with increased unit weight; however, this observation was not clearly evident.

Table 3 – Thermal testing (heating) – loose TDA Sample R22

Condition	Volume (m^3)	Mass (kg)	Density (kg/m^3)	Cycle	Start Temperature (°C)	End Temperature (°C)	Temperature Difference (°C)	Time to Reach Equilibrium (min)	Heat transfer Coefficient Ratio
Loose	0.0142	6.6810	470	Cooling	17.6	-21.5	39.1	1000	1.0
Loose	0.0142	6.6810	470	Heating	-21.5	21	42.5	1200	1.0
Rodded	0.0142	7.7942	549	Cooling	21.8	-21.2	43	1400	0.8
Rodded	0.0142	7.7942	549	Heating	-21.2	20.7	41.9	1300	1.1
Jigged	0.0142	7.6190	537	Cooling	20.5	-21.2	41.7	1100	1.0
Jigged	0.0142	7.6190	537	Heating	-21.2	21	42.2	1550	0.9

Figure 16 – Thermal testing summary plot (heating and cooling)



3.0 Potential Use as Retaining Wall Backfill

3.1 Engineering Considerations

Although there are some measurable differences between the samples tested, in our opinion, the performance expectations for the intended use would be similar. The submitted samples are expected to provide several advantages over the mineral aggregate conventionally used as backfill for retaining (including basement) walls. Exclusions would include situations where the backfill must provide adequate (external) lateral support to the wall, for example, where post-tensioned tie-back anchors are used. Discussion in this report focuses on typical applications where a retaining wall is designed to resist external loads.

In general, good performance of retaining walls requires backfill with good drainage characteristics and low susceptibility to internal erosion and volume change. This is why aggregates (sand and gravel) are generally preferred over cohesive soils (e.g., clay) although they are not exclusively used. Above the perimeter drain and granular fill (often pea gravel) at the footing level, perimeter excavations for residential house construction are often backfilled partially or entirely with loosely placed clay often leading to long term settlement and (undesirable) ponding against the structure unless the situation is remedied by regrading. Compacting the clay backfill is generally not advised as this process can generate large excess horizontal pressures against the wall. In some cases, a drainage media (e.g., sheet of dimpled rigid plastic) is used on the outside wall (in addition to a waterproofing membrane on the wall) to drain water to the base of the wall and into the drainage system.

3.1.1 Hydraulic Properties

Retaining wall designs typically assume that the backfill behind the wall will be free-draining, meaning that water infiltrating into the backfill will rapidly drain out of the system. This is to prevent the buildup of hydrostatic pressure. Both TDA samples tested far exceeded the hydraulic requirements necessary to be considered a free-draining backfill material. Testing by Rashwan (2018) and others has shown that the hydraulic conductivity of TDA (as a drainage media) remains high, even under large vertical loads. However, measures should be provided to minimize the potential for physical clogging from sediments filling in void spaces – the most likely source would be the sides or base of an excavation. Adequate filtration and separation should be used where needed to guard against clogging.

3.1.2 Volume Change Susceptibility

Cohesive soils (e.g., clay) have the potential to swell upon wetting (and conversely shrink upon drying). Mineral aggregates such as sand and gravel are generally not susceptible to volume change with changes in water content. Although TDA will absorb some water, there is no potential for volume change making it an excellent replacement for cohesive soil – this observation applies to both TDA samples tested.

3.1.3 Lateral Earth Pressure

It is the low unit weight of TDA, rather than a low horizontal earth pressure coefficient, that leads to a significant reduction in lateral pressures against a wall compared to mineral aggregates or clay. The unit weight of both TDA samples loosely placed and with laboratory compaction (rodding and jigging) was about 4.9 and 5.5 kN/m^3 respectively, or about 30% that of cohesive or granular backfill which ranges from say 15 kN/m^3 (loosely compacted clay) to 20 kN/m^3 for a granular backfill.

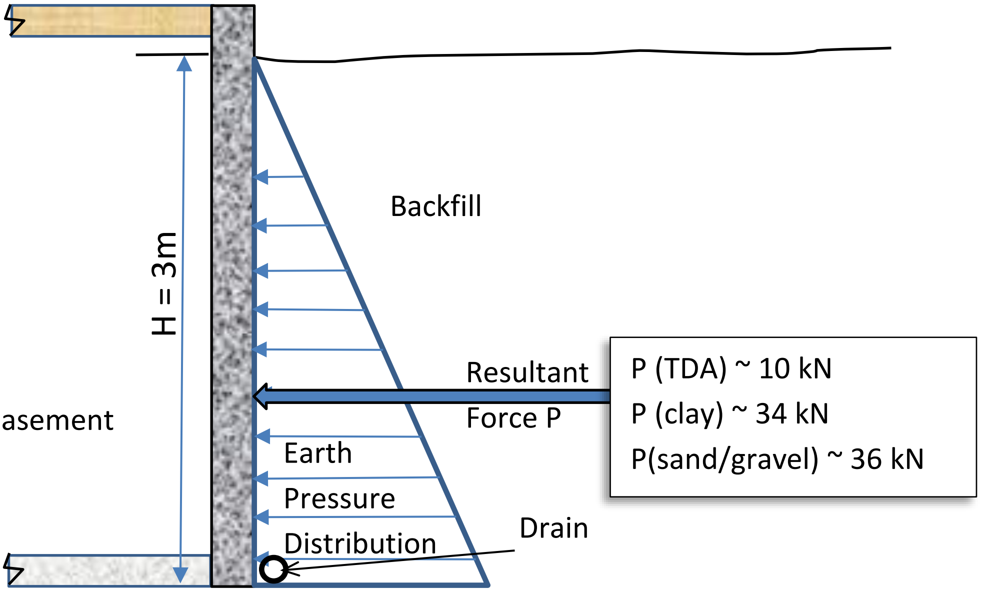
The lateral earth pressure on an unyielding (e.g., basement) wall is a triangular distribution (similar to hydrostatic pressure) based on the product of the unit weight of the backfill and at rest earth pressure coefficient. The resultant force on the wall, acts on the wall one third of the wall height from the bottom and is calculated using Equation 5.

$$P = \frac{1}{2} K_o \gamma H^2 \qquad \text{(Equation 5)}$$

Where P is the resultant force, K_o is the horizontal earth pressure coefficient, γ is the bulk unit weight of the backfill, and H is the wall height.

The apparent horizontal earth pressure coefficient for the TDA tested is estimated to be about 0.4 which is the average for both samples with laboratory compaction. Numerous agencies, including the Texas Department of Transportation recommends an at-rest coefficient of earth pressure of 0.4 be used for design. In comparison, the K_o for cohesive and granular soils would be in the order of 0.5 and 0.4 respectively. Without the benefit of more extensive testing, we suggest a K_o value of 0.4 be assumed for the TDA samples tested. If active conditions are reached (e.g., a retaining wall that can lean), Tweedie et al (1998) recommended an active earth pressure coefficient, K_a of 0.25 can be used for design. Based on the above, a hypothetical comparison of the resultant force (P) on a 3 m high restrained basement wall for TDA, cohesive, and granular backfill is illustrated on Figure 17.

Figure 17 – Comparison of Resultant Force, P, per m of wall



3.1.4 Thermal Properties

Although the thermal conductivity, *K*, of the TDA samples could not be measured directly with our test set-up, the behaviour during cooling and heating cycles was as expected. The thermal conductivity of TDA is reported to be in the order of 2 to 3 times that of soil and based on similarities between other engineering properties and industry results, the two TDA samples would be expected to provide a similar insulation value. In general, the thermal conductivity would be expected to increase with increasing particle size and with higher degrees of compaction, due in part to the reduced volume of voids (air pockets) between particles. The heat transfer coefficient ratio from our testing provided inconclusive results with both increasing and decreasing thermal conductivity with increasing density.

3.1.5 Potential for Internal Heating and Combustion

Design guidelines for minimizing heat potential due to oxidation of exposed steel belts and rubber are provided in ASTM D6270-08 Standard Practice for Use of Scrap Tires in Civil Engineering Applications. Factors thought to contribute to conditions favourable to oxidation include free access to air, free access to water, retention of heat caused by the high insulating value of TDA in combination with large fill heights, large amounts of exposed steel belts, small TDA particles, and the presence of inorganic or organic nutrients.

The ASTM design guidelines account favourable performance for projects where TDA thicknesses are less than 4 m and are divided into two classes: Class I Fills with TDA layers less than 1 m thick, and Class II Fills with TDA fills ranging from 1 to 3 m thick. Two shred sizes are identified – Type A (tire chips) and Type B (tire shred). TDA fill thicknesses greater than 3 m are not recommended. It is envisaged that for the applications under consideration and studied in this report, the TDA for retaining wall backfill would fall into Class II. By definition in the Standard, Class II material shall meet the requirements for Type B TDA given as follows:

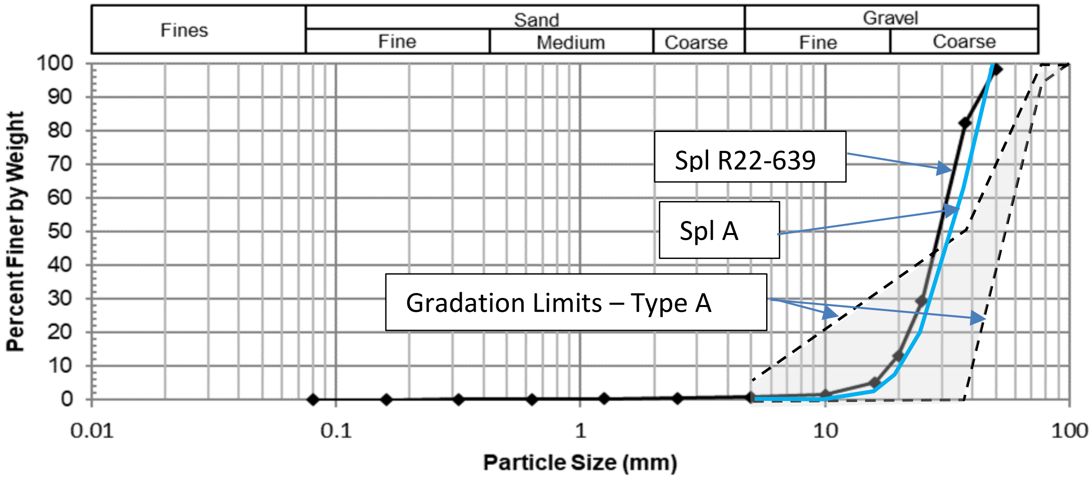
- Minimum 90% (by weight) with a maximum dimension, measured in any direction, of 300 mm and 100% with a maximum dimension measured in any direction, of 450 mm.

However, the TDA samples tested would fall into Type A given as follows:

- Maximum dimension, measured in any direction, of 200 mm and the following grain size distribution:
    - 100% passing the 100 mm sieve,
    - Minimum 95% (by weight) passing the 75 mm sieve,
    - Maximum 50% (by weight) passing the 38 mm sieve, and
    - Maximum 5% (by weight) passing the 4.75 mm sieve.

The gradation limits for Type A TDA are shown with the gradation results from Sample A and R22-639 on Figure 18.

Figure 18 – Comparison of Grain Size Distributions



Both samples tested by TREK fall outside of the gradation envelope above a particle size greater than 35 mm which means the overall material is somewhat finer overall. However, the shape of the curves also indicate that the material tested is more uniformly graded, which would tend to decrease unit weight and increase hydraulic conductivity. In comparison, the Type A gradation indicates a more well-graded material which would tend to have a higher unit weight and hence, lower hydraulic conductivity.

Further testing is recommended to confirm that the samples tested have the same (or lower) potential to ignite as the Type A material.

3.1.6 *Environmental Considerations*

Based on available information, including the work done at Red River College (Rashwan 2018), the impact of TDA on groundwater quality are considered small to negligible (Harkins 2008). For project sites with unique groundwater chemistry, for example low pH, additional testing may be warranted. Harkins (2008) also suggests aesthetic concerns should be evaluated if TDA is placed below the water table in accordance with ASTM D 6270-08.

4.0 Construction Considerations

Industry experience shows that compaction effort beyond about 50 to 60% of the Standard Proctor energy has little benefit in reaching higher unit weights (Oman 2013). Unlike mineral soils, the water content also has little effect on the degree of compaction that can be attained. Edil (1994) reports that vibration also has negligible effect unless sand is added to the TDA. Based on the testing carried out by TREK, an increase in unit weight was achieved by rodding and jigging but likely this was more related to redistributing the particles in a more consistent orientation (pieces tended to lie flatter). This observation does however support the benefit of field compaction.

Compaction of TDA in the field is generally achieved using the movement of tracked equipment (track packing), sheepsfoot rollers, or smooth drum rollers. Lift thicknesses ranged from 150 to 1000 mm

(Harkins 2008). It is considered good practice to only lightly compact backfill immediately adjacent to a retaining wall to reduce the compaction-induced horizontal pressure (which is additive to the earth pressure). However, some compaction of the TDA would be preferred to reduce compressibility and post-construction settlement. We are unaware of any data showing the degree of compaction achieved by free-fall from say an excavator bucket or material pushed into a trench.

Given the unique gradation of the material, we recommend a compaction trial be undertaken to determine the relationship between compaction methods/effort and density. This would help establish compaction guidelines including lift thickness, static weight of equipment, duration of compaction, etc. Similar work was done by the author in the late 1990s in Winnipeg when developing construction techniques for rock-filled trenches. At the same time, temperature probes could be installed to measure any buildup and maximum value of internal temperatures; this data can be compared with the combustion limit for TDA. Total stress cells could be installed on the trench base and wall(s) to directly measure the vertical and horizontal earth pressures.

5.0 Closure

The geotechnical information provided in this report is in accordance with current engineering principles and practices (Standard of Practice). The findings of this report were based on information provided (field investigation and laboratory testing).

All information provided in this report is subject to our standard terms and conditions for engineering services, a copy of which is provided to each of our clients with the original scope of work or standard engineering services agreement. If these conditions are not attached, and you are not already in possession of such terms and conditions, contact our office and you will be promptly provided with a copy.

This report has been prepared by TREK Geotechnical Inc. (the Consultant) for the exclusive use of Engineered Recycled Rubber Aggregate (the Client) and their agents for the work product presented in the report. Any findings or recommendations provided in this report are not to be used or relied upon by any third parties, except as agreed to in writing by the Client and Consultant prior to use.

List of References

Harkins, J.M., Wilson, T. (2008). Guidance Manual for Engineering Uses of Scrap Tires. Geosyntec Consultants Project No. ME0012-11, Prepared for Maryland Dept. of the Environment and Maryland Environmental Service.

Humphry, D. (2011). Civil Engineering Applications Using Tire Derived Aggregate. Presentation sponsored by California Integrated Waste Management Board, Publication # DRRR-2011-038.

Rashwan, S. (2018). Final Report - Demonstration of the Viability of Using Tire Derived Aggregate (TDA) to Replace Natural Material (NM) in Residential Home Basement Construction.

Appendix A-1

Grain Size Distribution Testing

TREK GEOTECHNICAL Quality Engineering | Valued Relationships

MEMORANDUM

Date	March 29, 2022
To	Ken Skaftfeld, TREK Geotechnical
From	Angela Fidler-Kliewer, TREK Geotechnical
Project No.	0186-002-00
Project	TDA Testing
Subject	Laboratory Testing Results – Lab Req. R22-052
Distribution	Ken Skaftfeld

Attached are the grain size distribution (Mechanical sieve method) for the above noted project.

Regards,

Angela Fidler-Kliewer, C.Tech.

Attach.

Review Control:

Prepared By: PM	*Reviewed By:* AFK	*Checked By:* NJF

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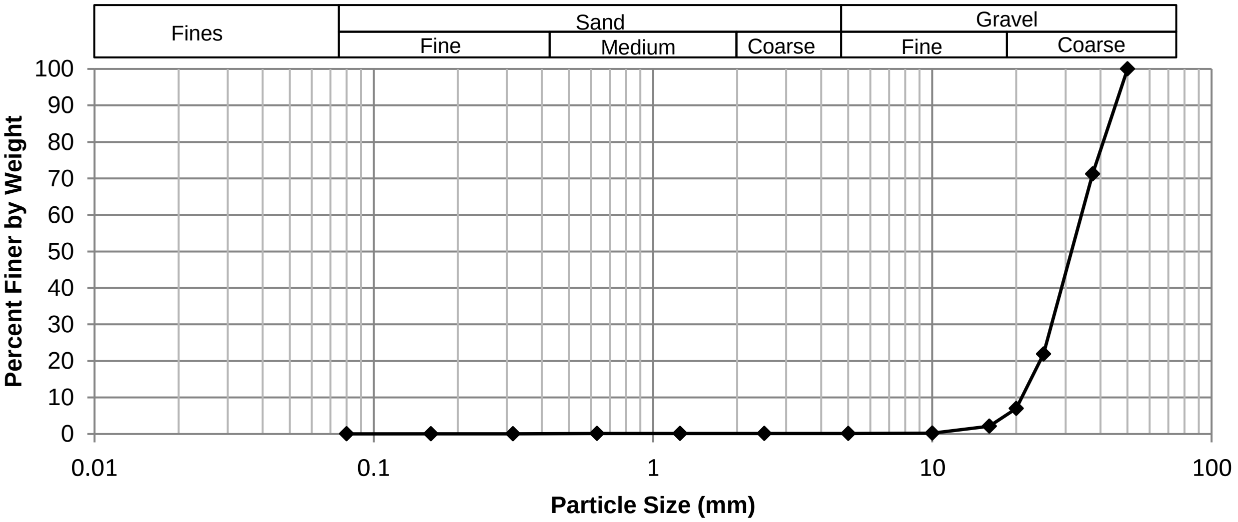
Grain Size Analysis (Sieve Method)
ASTM C136-06

Project No.	0186-002-00
Client	Peter Schroedter
Project	TDA Testing
Source	-
Sample #	R22-052-A
Depth	N/A
Date Sampled	7-Mar-22
Date Tested	28-Mar-22
Technician	PM

Total Weight (g)	19741.2
Gravel %	99.8
Sand %	0.1
Fines %	0.0

Particle Size Distribution Curve



Sieve Opening (mm)	Percent Passing	Specification (Min-Max)
50.0	100	-
37.5	71	-
25.0	22	-
20.0	7	-
16.0	2	-
10.0	0	-
5.0	0	-
2.50	0	-
1.25	0	-
0.630	0	-
0.315	0	-
0.160	0	-
0.080	0	-

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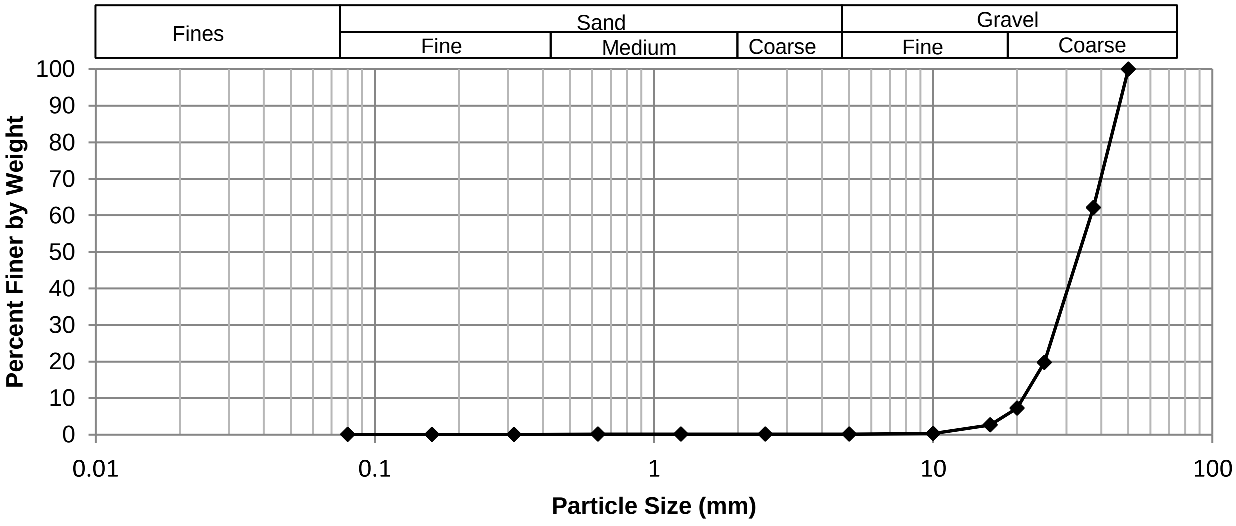
Grain Size Analysis (Sieve Method)
ASTM C136-06

Project No.	0186-002-00
Client	Peter Schroedter
Project	TDA Testing
Source	-
Sample #	R22-052-B
Depth	N/A
Date Sampled	7-Mar-22
Date Tested	28-Mar-22
Technician	PM

Total Weight (g)	21844.4
Gravel %	99.8
Sand %	0.1
Fines %	0.0

Particle Size Distribution Curve



Sieve Opening (mm)	Percent Passing	Specification (Min-Max)
50.0	100	-
37.5	62	-
25.0	20	-
20.0	7	-
16.0	3	-
10.0	0	-
5.0	0	-
2.50	0	-
1.25	0	-
0.630	0	-
0.315	0	-
0.160	0	-
0.080	0	-

TREK GEOTECHNICAL Quality Engineering | Valued Relationships

MEMORANDUM

Date	November 14, 2022
To	Ken Skaftfeld, TREK Geotechnical
From	Angela Fidler-Kliewer, TREK Geotechnical
Project No.	0186-002-00
Project	TDA Testing
Subject	Laboratory Testing Results – Lab Req. R22-639
Distribution	Ken Skaftfeld

Attached are the grain size distribution (Mechanical sieve method), Bulk density and Stress–strain curve for the above noted project.

Regards,

Angela Fidler-Kliewer, C.Tech.

Attach.

Review Control:

Prepared By: TN	*Reviewed By:* AFK	*Checked By:* NJF

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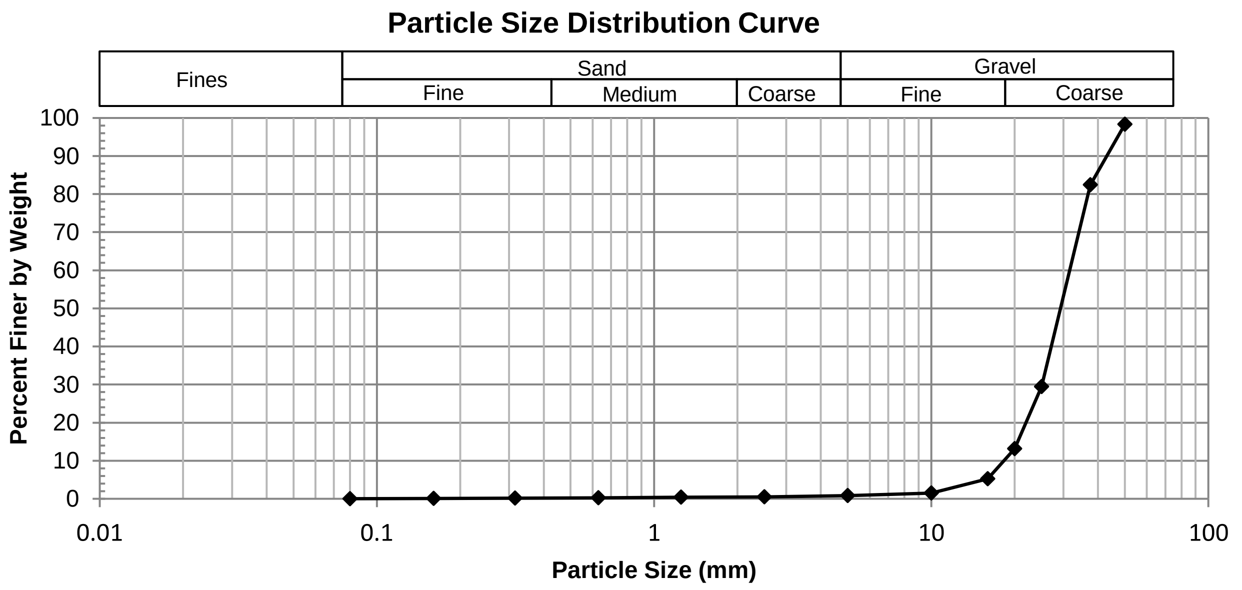
Grain Size Analysis (Sieve Method)
ASTM C136-06

CERTIFIED BY CCIL
Canadian Council of Independent Laboratories
For specific tests as listed on www.ccil.com

Project No. 0186-002-00
Client OTR Recylcing
Project TDA Testing

Sample # R22-639
Source -
Soil Desc. Tire Shred
Date Sampled 9-Nov-22
Date Tested 10-Nov-22
Technician TN

Total Weight (g)	26483
Gravel %	99.2
Sand %	0.8
Fines %	0.0



	Sieve Opening (mm)	Percent Passing	Specification (Min-Max)
-	50.0	98	-
-	37.5	82	-
-	25.0	29	-
-	20.0	13	-
-	16.0	5	-
-	10.0	1	-
-	5.00	1	-
-	2.50	0	-
-	1.250	0	-
-	0.630	0	-
-	0.315	0	-
-	0.160	0	-
-	0.080	0	-

Appendix A-2

Relative Density and Absorption Testing

Relative Density (Specific Gravity) and Absorption of Coarse Aggregate
CSA A23.2-12A

CERTIFIED BY CCIL
Canadian Council of Independent Laboratories
For specific tests as listed on www.ccil.com

Project No.	0186-002-00
Client	
Project	TDA Testing
Sample #	R23-031
Source	
Material	Tire Shred
Sample Date	16-Jan-23
Test Date	7-Feb-23
Technician	I. Araquil

Fraction #	**1**
Oven Dry Mass (g)	2007.00
Saturated Surface Dry Mass (g)	2119.50
Apparent SSD Mass (g)	531.50

Specific Gravity (OD)	1.26
Specific Gravity (SSD)	1.33
Absorption %	5.61

Comments:

Above values were determined by (without / first drying the aggregate.)

Appendix A-3

Bulk Density Testing

VOLUME OF THE VESSEL

METHOD A - By Measurement

	Diameter (mm)	Average height (mm)	Volume (mm^3)
Trial 1	253.07	278.63	14014941.62
Trial 2	254.50	278.00	14141981.04
Trial 3	253.45	278.00	14025529.58
Trial 4	253.66	277.75	14036147.56
Trial 5	253.03	277.75	13966512.68

Average vessel volume by measurement = **0.0140** m^3 or **14.037** L

METHOD B - By Mass of Water

Mass of empty vessel = 5681.5 g

Mass of cover plate = 2182.8 g

Total mass of the equipment = 7864.3 g

Total mass (with water) = 22016.9 g

Mass of occupied water = 14152.6 g

Water temperature	20.0	^{o}C
Density of water	998.23	kg/m^3

Volume of the vessel by mass of water = **0.0142** m^3 or **14.178** L

1/V FACTOR = 70.53332956

BULK DENSITY OF AGGREGATE - SAMPLE A (25mm - 1")

A) RODDING PROCEDURE

Total mass (with vessel) = 13987.4 g

Net mass of the material = 8305.9 g or 8.3059 kg

Bulk Density - Rodding procedure = **586** **kg/m^3**

B) JIGGING PROCEDURE

Total mass (with vessel) = 14062.3 g

Net mass of the material = 8380.8 g or 8.3808 kg

Bulk Density - Jigging procedure = **591** **kg/m^3**

C) LOOSE AGGREGATE PROCEDURE

Total mass (with vessel) = 12946.4 g

Net mass of the material = 7264.9 g or 7.2649 kg

Bulk Density - Loose aggregate procedure = **512** **kg/m^3**

BULK DENSITY OF AGGREGATE - SAMPLE B (BLENDED MATERIAL)

A) RODDING PROCEDURE

Total mass (with vessel) = 13933.5 g

Net mass of the material = 8252.0 g or 8.252 kg

Bulk Density - Rodding procedure = 582 kg/m^3

B) JIGGING PROCEDURE

Total mass (with vessel) = 13809.9 g

Net mass of the material = 8128.4 g or 8.1284 kg

Bulk Density - Jigging procedure = 573 kg/m^3

C) LOOSE AGGREGATE PROCEDURE

Total mass (with vessel) = 12596.6 g

Net mass of the material = 6915.1 g or 6.9151 kg

Bulk Density - Loose aggregate procedure = 488 kg/m^3

SAMPLE B (BLENDED MATERIAL) COMPONENT

Seive Opening (mm)	Mass Retained (g)
37.5	8283.2
25.0	9266.6
20.0	2734.7
16.0	1013.2
10.0	511.2

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Bulk Density of Aggregate
CSA A23.2-10A

Project No.	0186-002-00
Client	OTR Recylcing
Project	TDA Testing
Sample #	R22-639
Source	N/A
Material	Tire Shred
Sample Date	9-Nov-22
Test Date	10-Nov-22
Technician	TN

Test	Rodding Procedure	Jigging Procedure	Loose Aggregate Procedure
Mass of sample and mold (kg)	13.58	13.43	12.51
Mass of mold (Kg)	5.68	5.68	5.68
Volume of Mold (m^3)	0.0141	0.0141	0.0141
Bulk Density (kg/m^3)	**560**	**549**	**484**
Average Bulk Density (kg/m^3)		**531**	

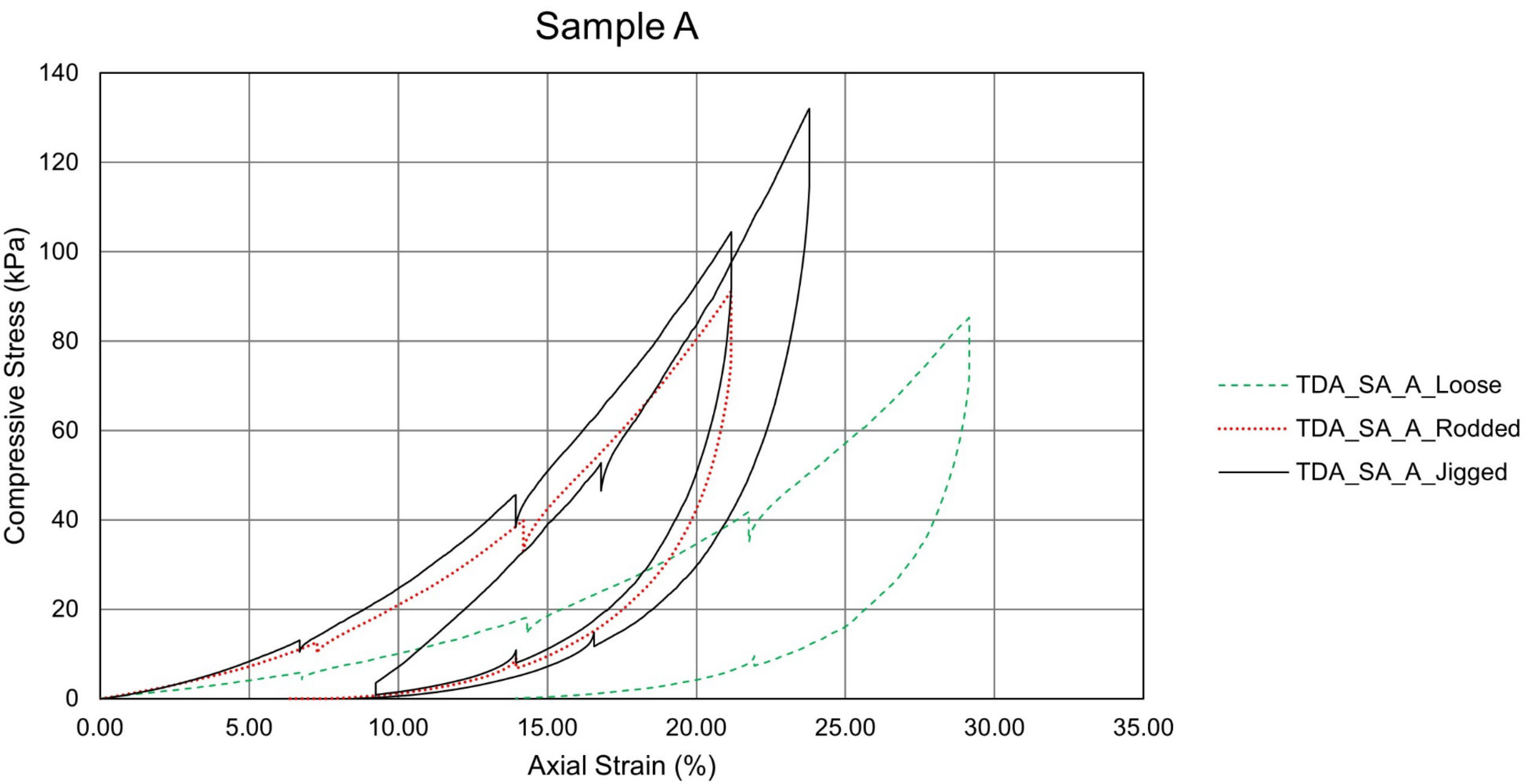
Comments:

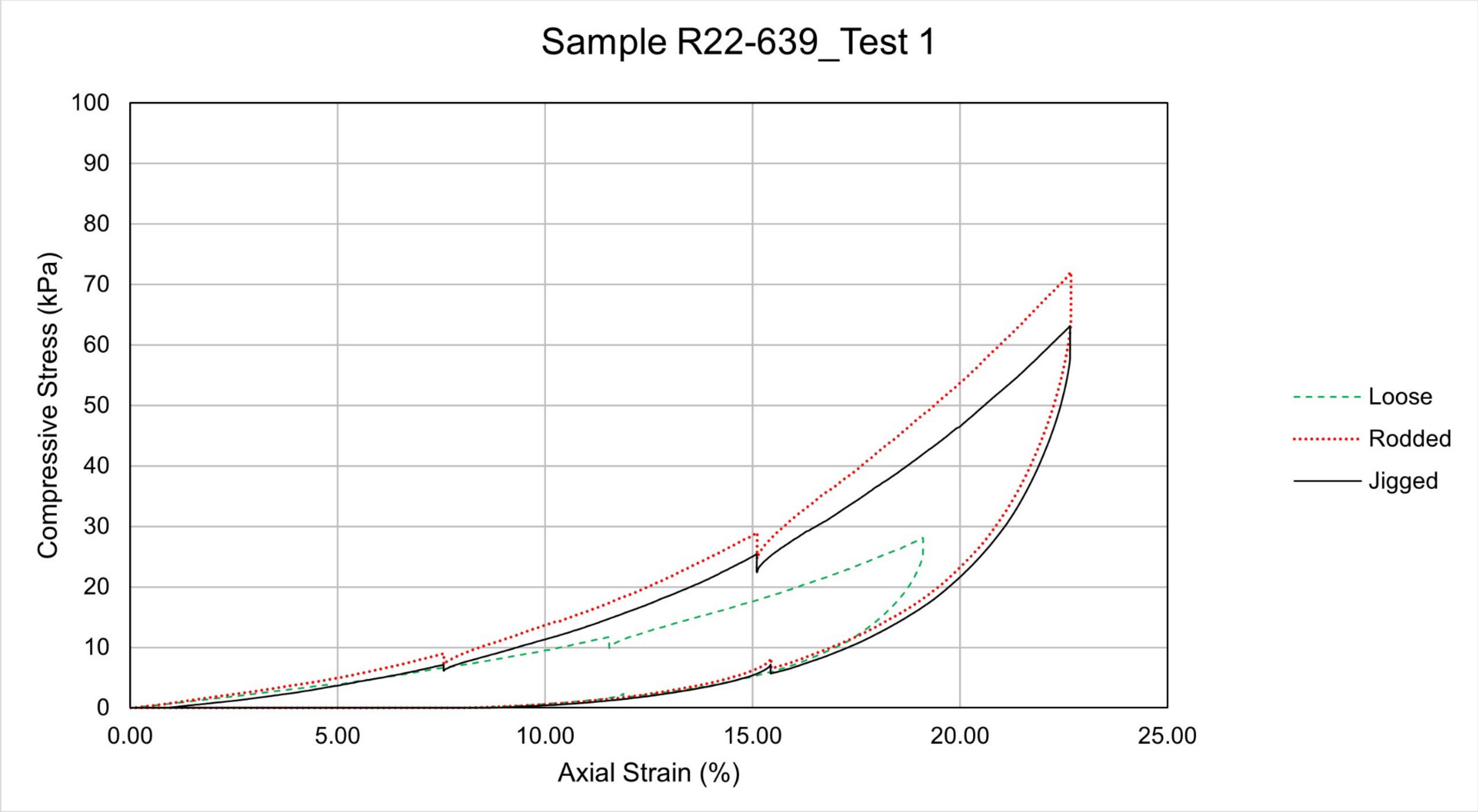
Reviewed by: ______________________

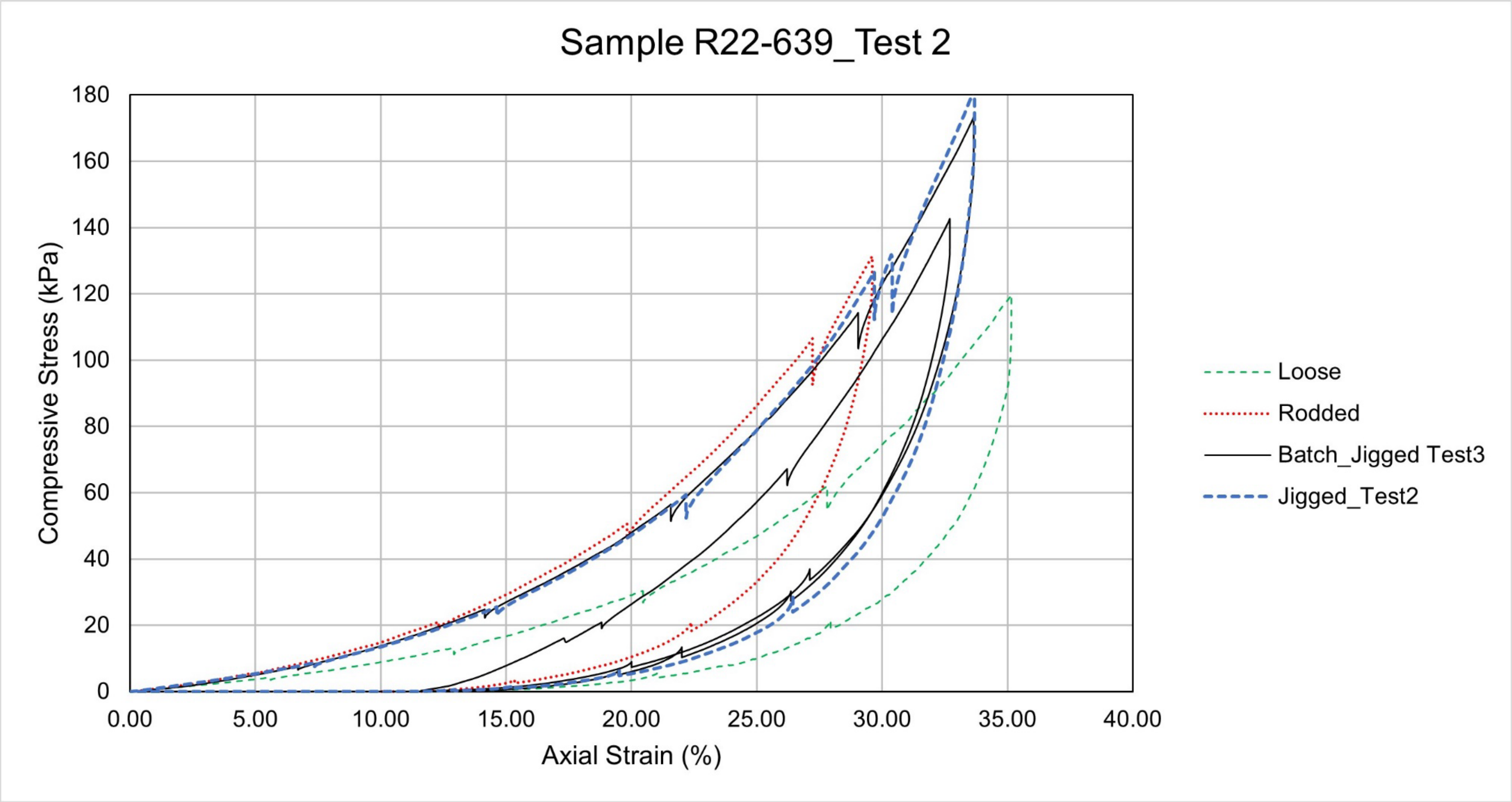
Signature: ______________________

Appendix A-4

Constrained Compression Testing

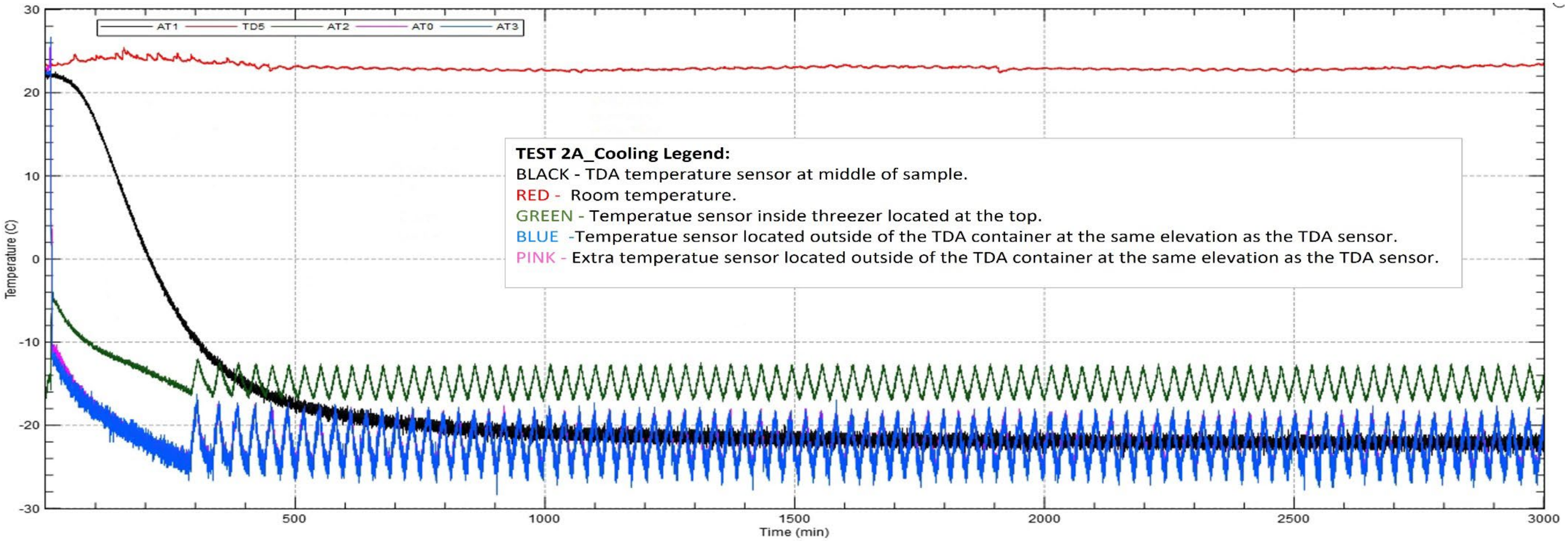

Sample A
Compressive Stress (kPa)
140
120
100
80
60
40
20
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
Axial Strain (%)
TDA_SA_A_Loose
TDA_SA_A_Rodded
TDA_SA_A_Jigged

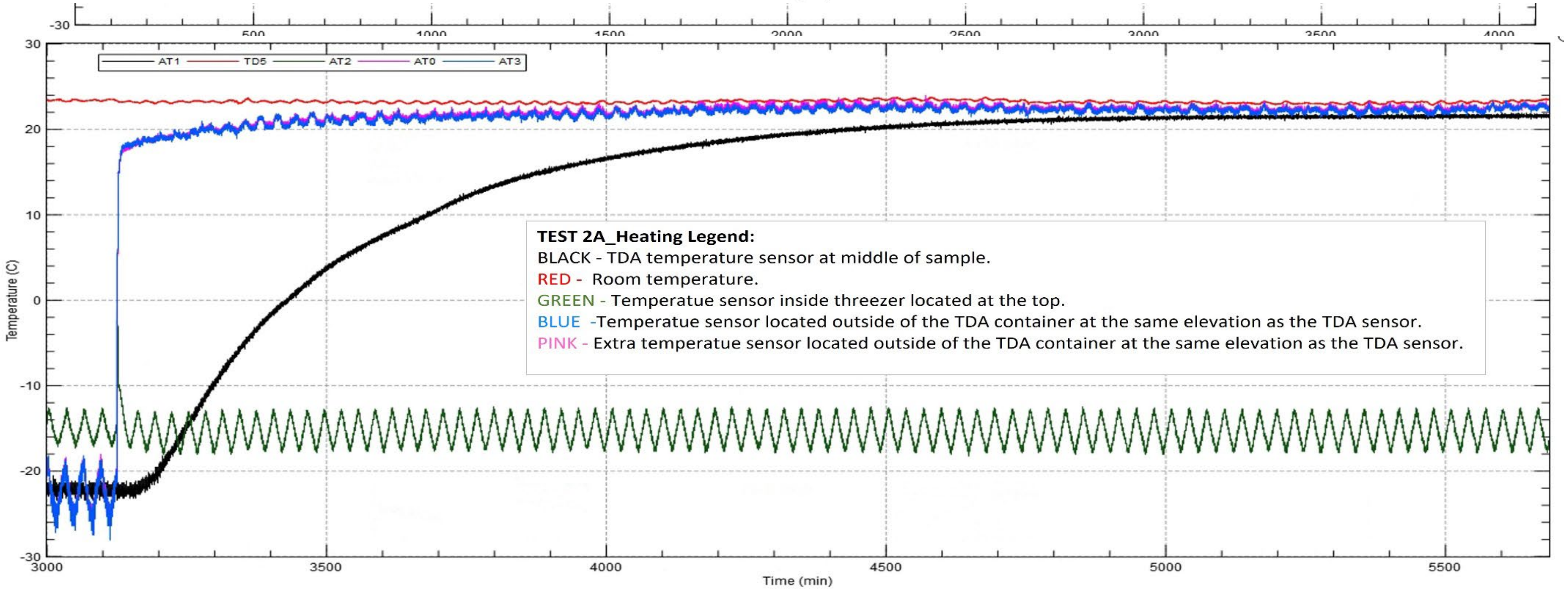

Sample R22-639_Test 1
Compressive Stress (kPa)
100
90
80
70
60
50
40
30
20
10
0
0.00
5.00
10.00
15.00
20.00
25.00
Axial Strain (%)
Loose
Rodded
Jigged

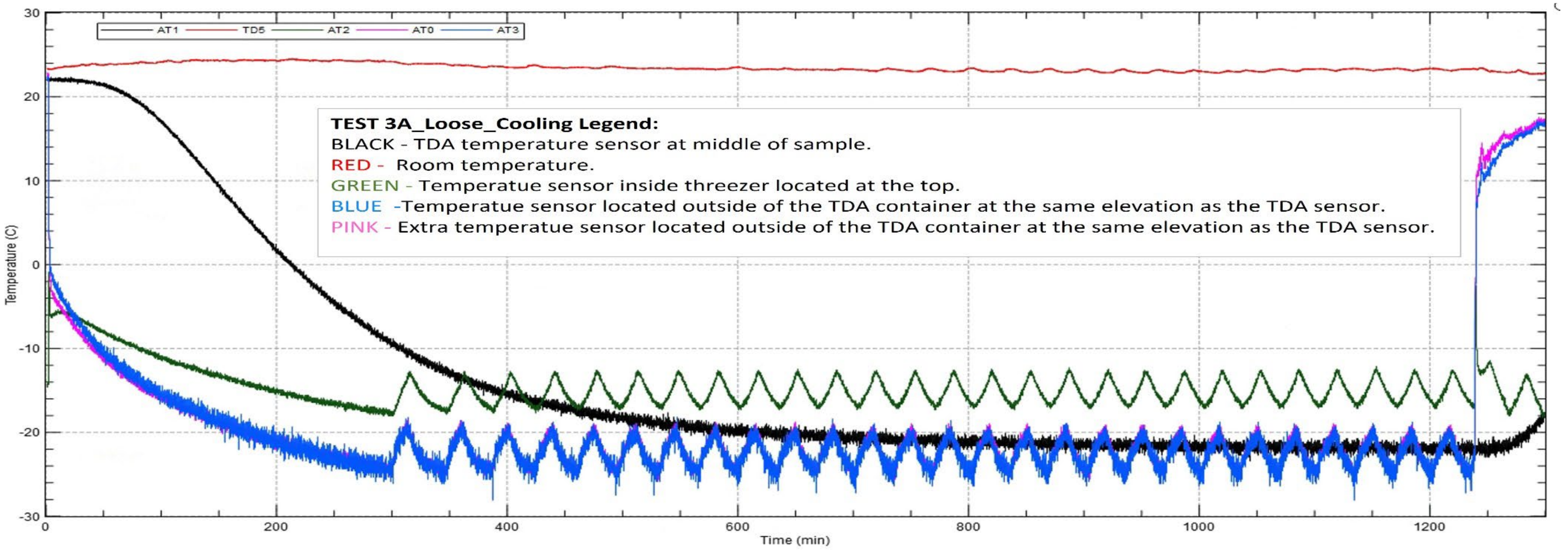

Sample R22-639_Test 2
Compressive Stress (kPa)
180
160
140
120
100
80
60
40
20
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
Axial Strain (%)
Loose
Rodded
Batch_Jigged Test3
Jigged_Test2

Appendix A-5

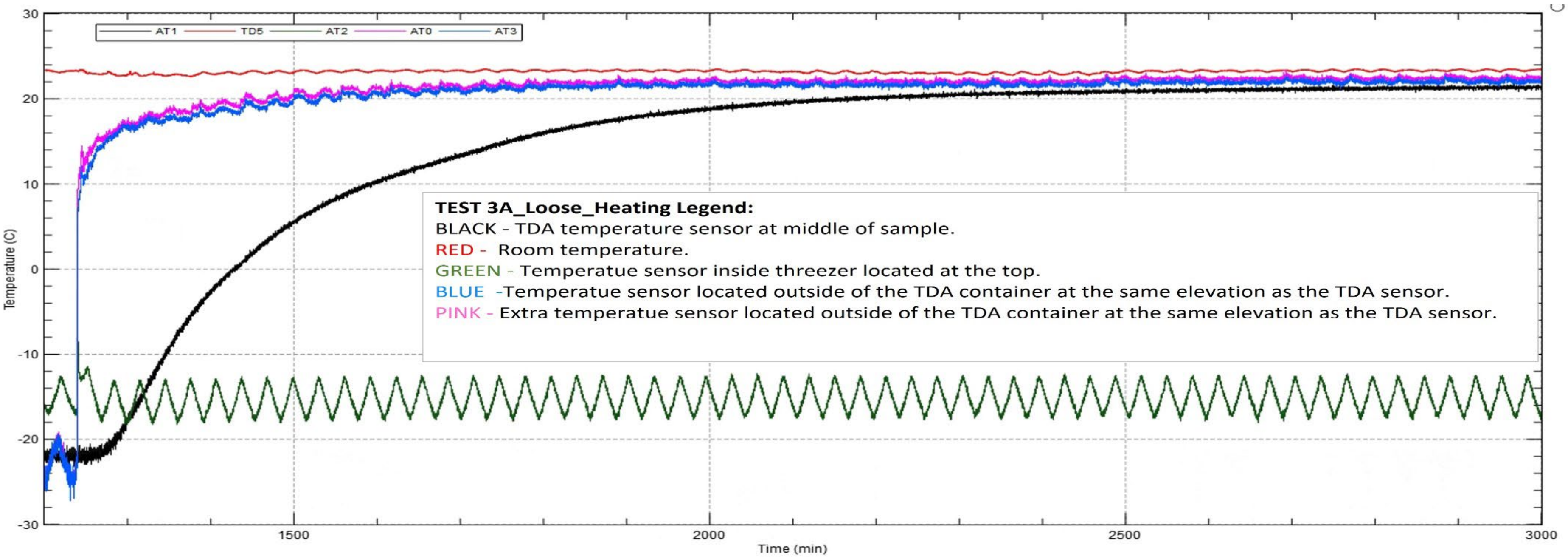
Thermal Testing


AT1
TD5
AT2
AT0
AT3
TEST 2A_Cooling Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
Temperature (C)
30
20
10
0
-10
-20
-30
500
1000
1500
2000
2500
3000
Time (min)

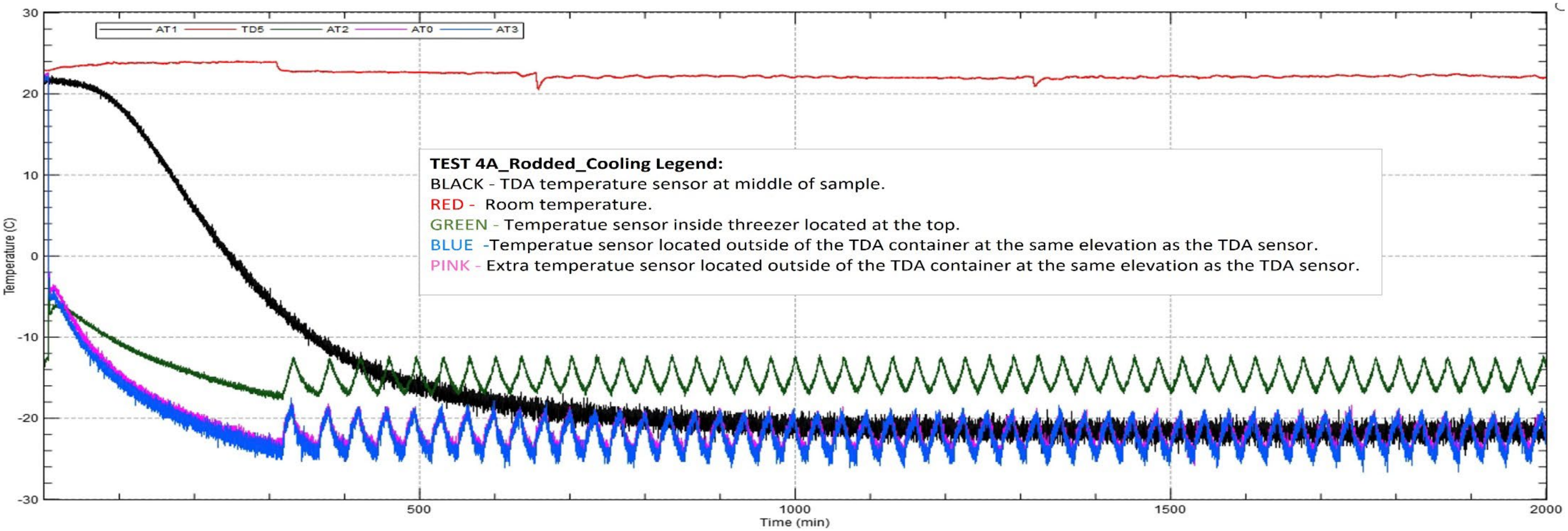

-30
500
1000
1500
2000
2500
3000
3500
4000
AT1
TD5
AT2
AT0
AT3
TEST 2A_Heating Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
Temperature (C)
30
20
10
0
-10
-20
-30
3000
3500
4000
4500
5000
5500
Time (min)



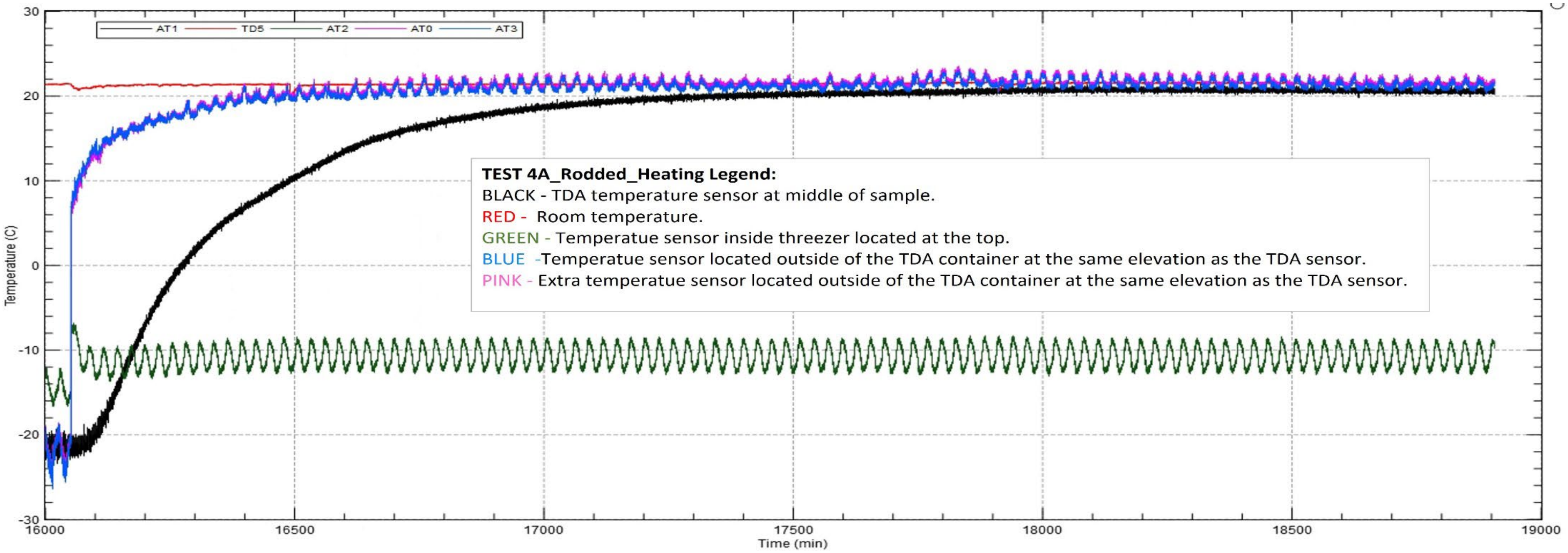
TEST 3A_Loose_Cooling Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.



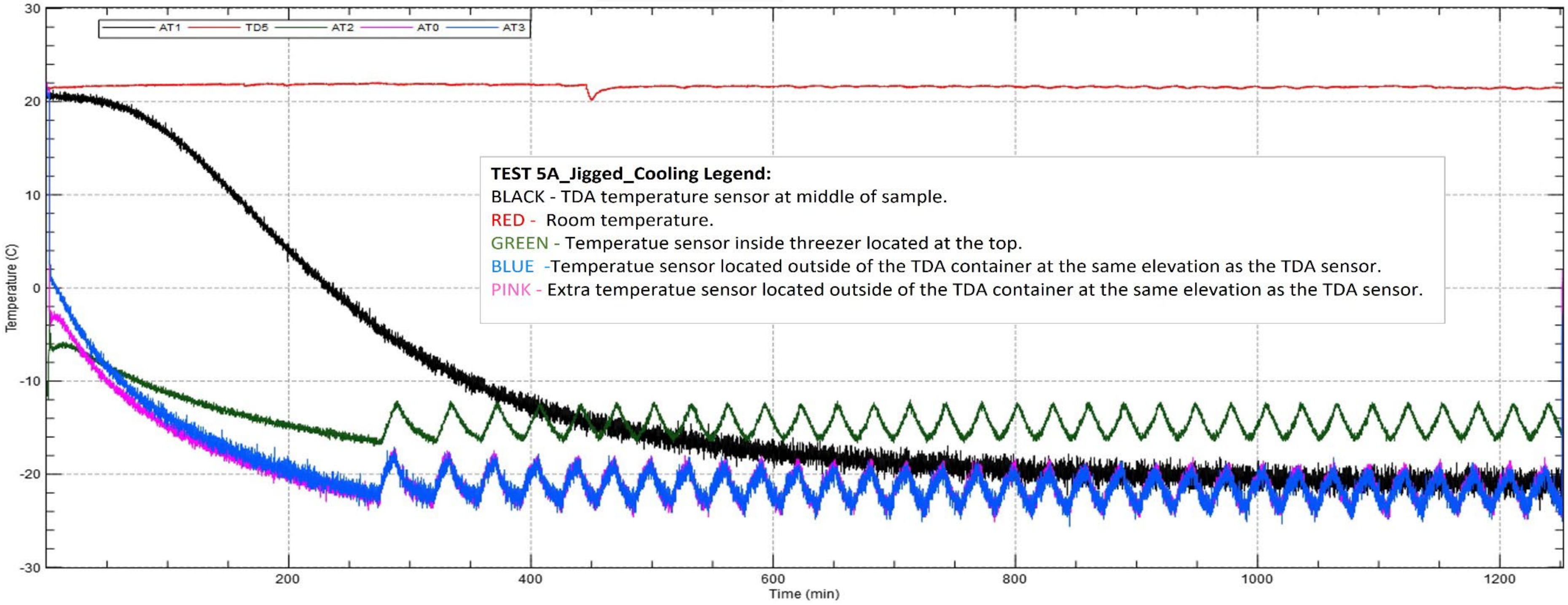
TEST 3A_Loose_Heating Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.

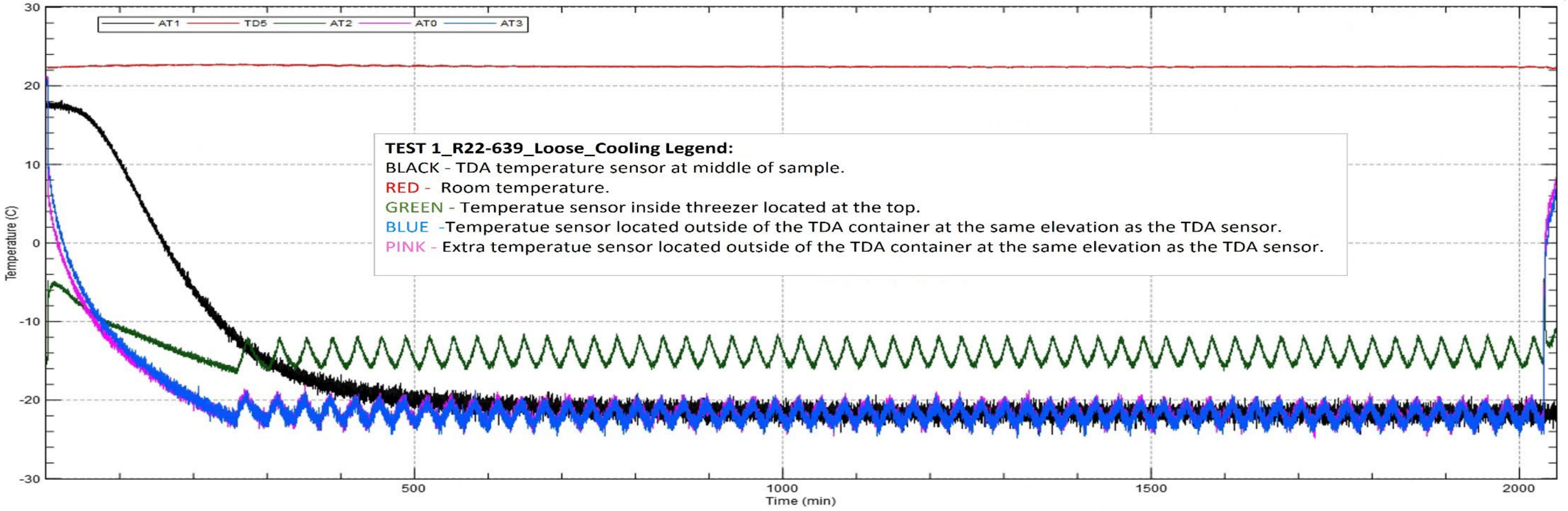


TEST 4A_Rodded_Cooling Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.



TEST 4A_Rodded_Heating Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.


AT1
TD5
AT2
AT0
AT3
TEST 5A_Jigged_Cooling Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
30
20
10
0
-10
-20
-30
Temperature (C)
200
400
600
800
1000
1200
Time (min)



TEST 1_R22-639_Loose_Cooling Legend:

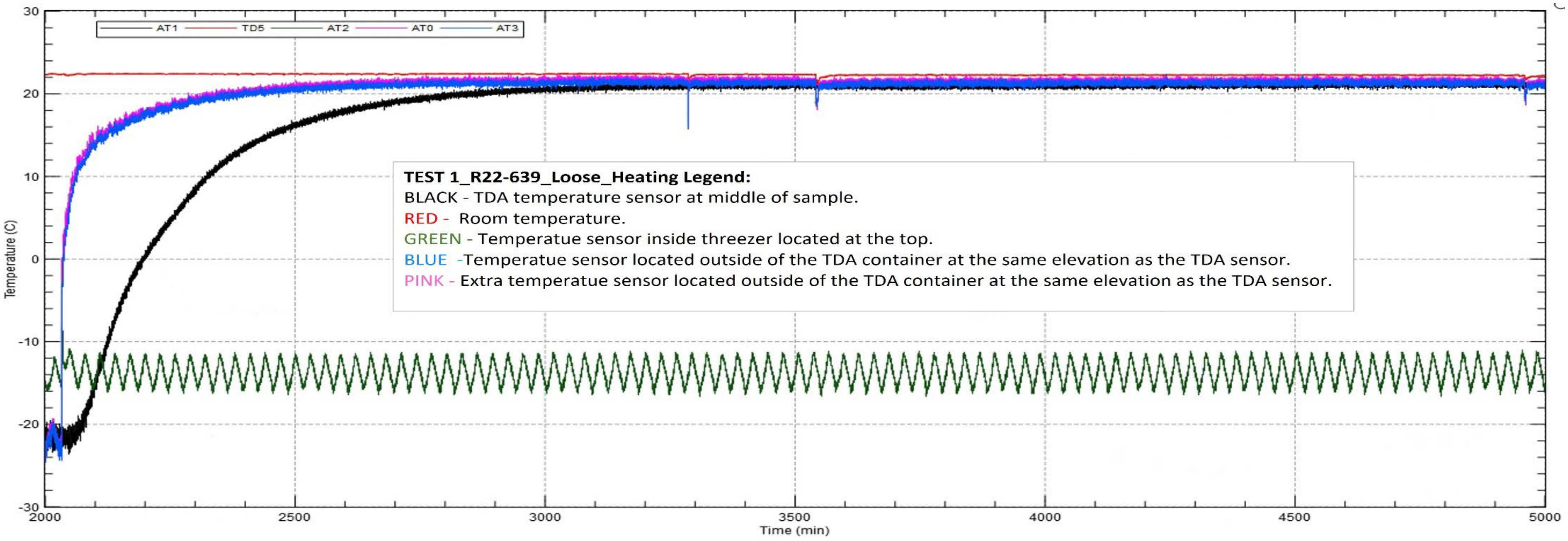
BLACK - TDA temperature sensor at middle of sample.

RED - Room temperature.

GREEN - Temperatue sensor inside threezer located at the top.

BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.

PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.



TEST 1_R22-639_Loose_Heating Legend:

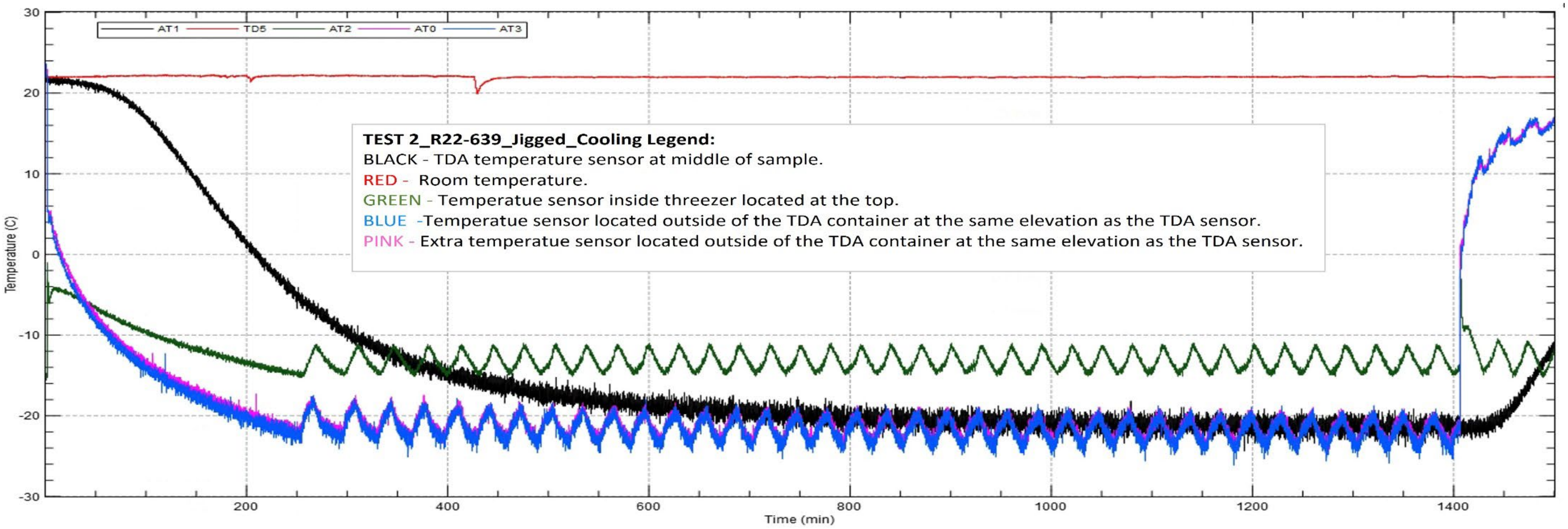
BLACK - TDA temperature sensor at middle of sample.

RED - Room temperature.

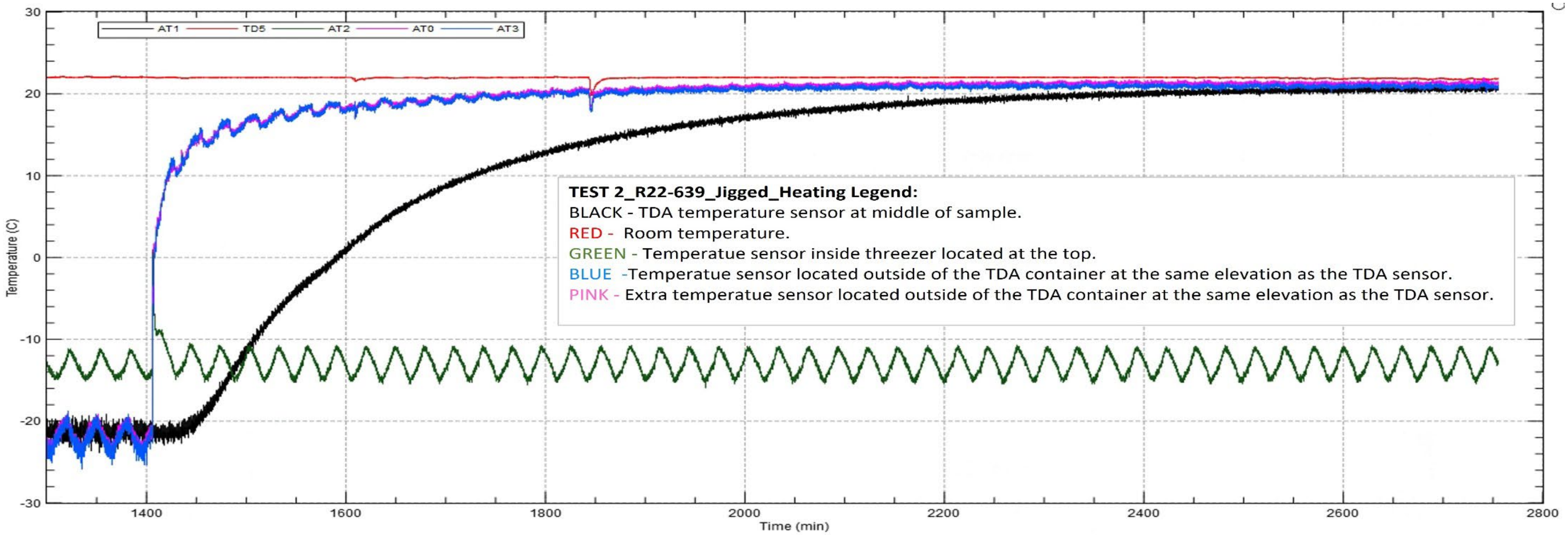
GREEN - Temperatue sensor inside threezer located at the top.

BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.

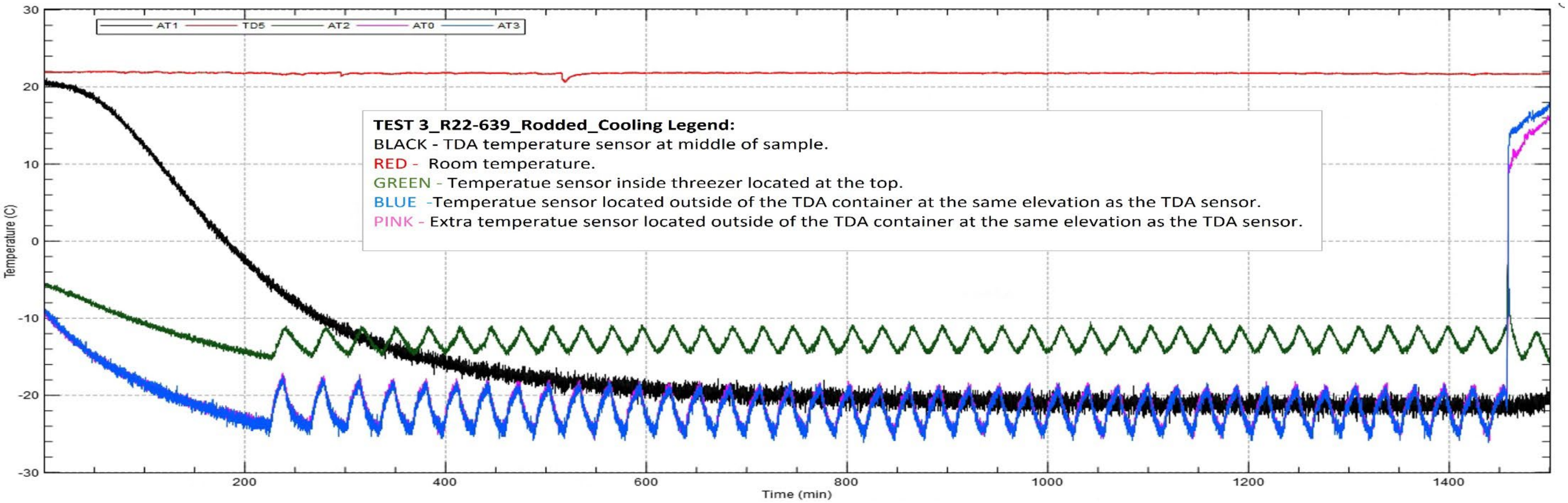
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.



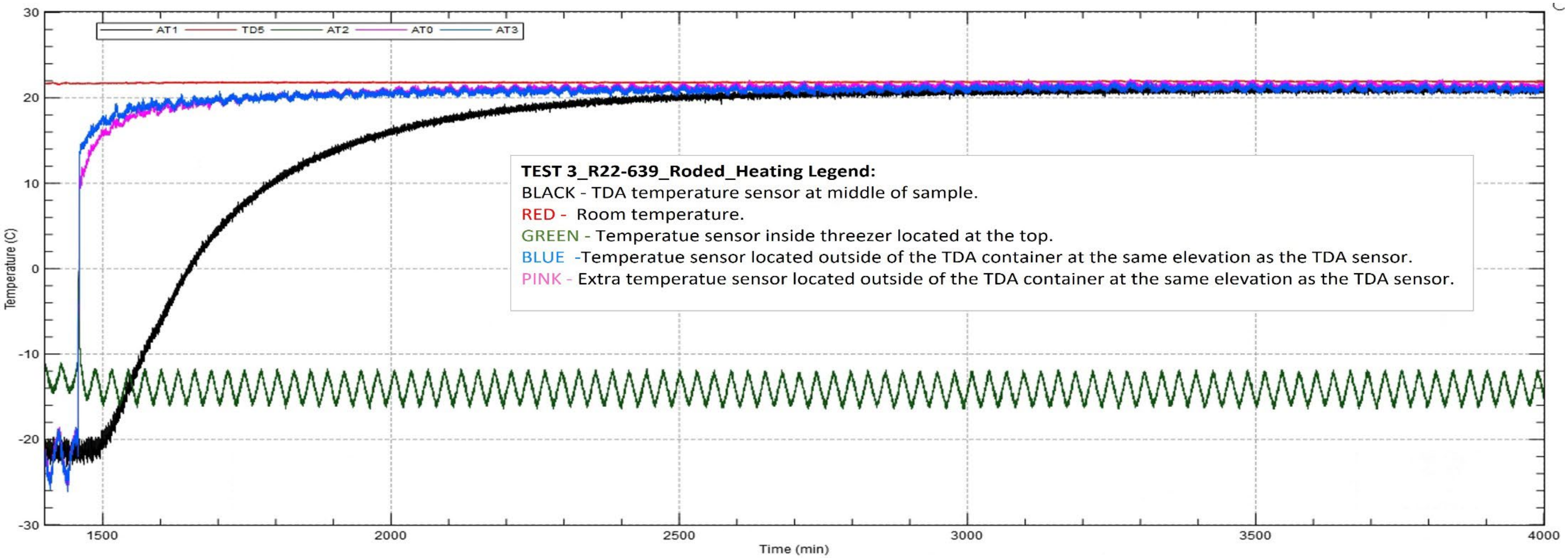
TEST 2_R22-639_Jigged_Cooling Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.



TEST 2_R22-639_Jigged_Heating Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.

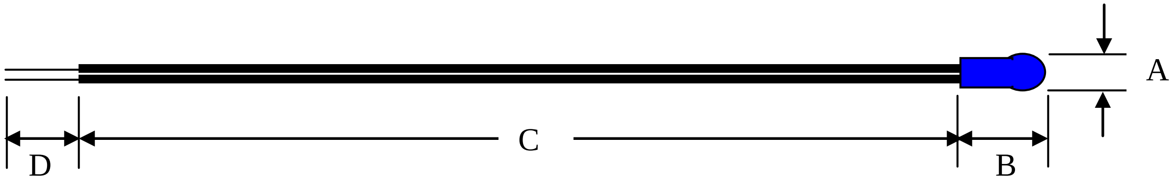


TEST 3_R22-639_Rodded_Cooling Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.



TEST 3_R22-639_Roded_Heating Legend:
BLACK - TDA temperature sensor at middle of sample.
RED - Room temperature.
GREEN - Temperatue sensor inside threezer located at the top.
BLUE -Temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.
PINK - Extra temperatue sensor located outside of the TDA container at the same elevation as the TDA sensor.

Part Number: PANE 103395



Electrical Specifications:

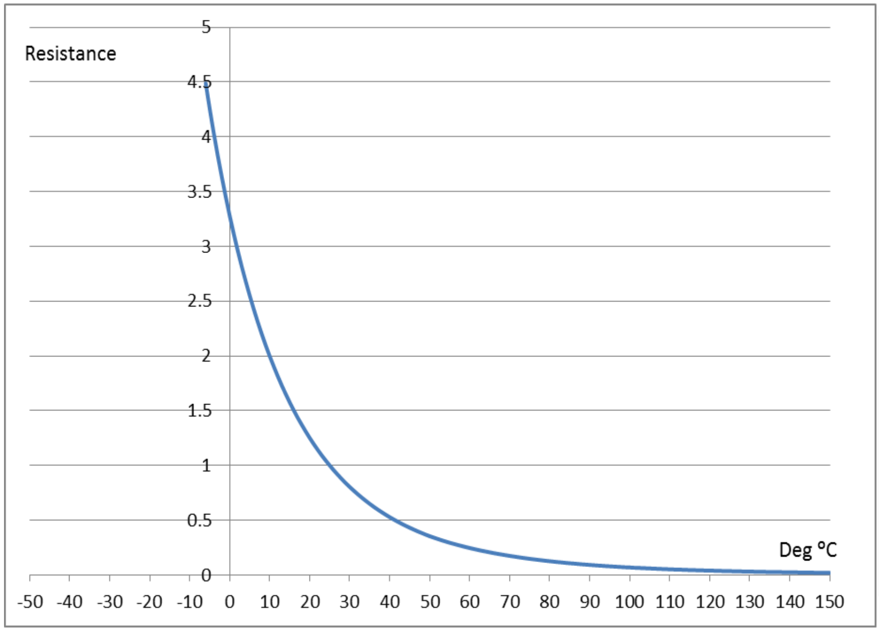
Resistance @ 25°c	**10kΩ ± 5%**
Temperature Coefficient of Resistance	**-4.43 % / °C**
Operating Temperature Range	**-50°C to + 150°C**
Dissipation Constant	**7.2mW/°C**
Thermal Time Constant	**6 seconds**
Material Constant (Beta)	**3950°K ± 1%**
MSL **(moisture sensitivity level)**	**#2**

Mechanical Specifications:

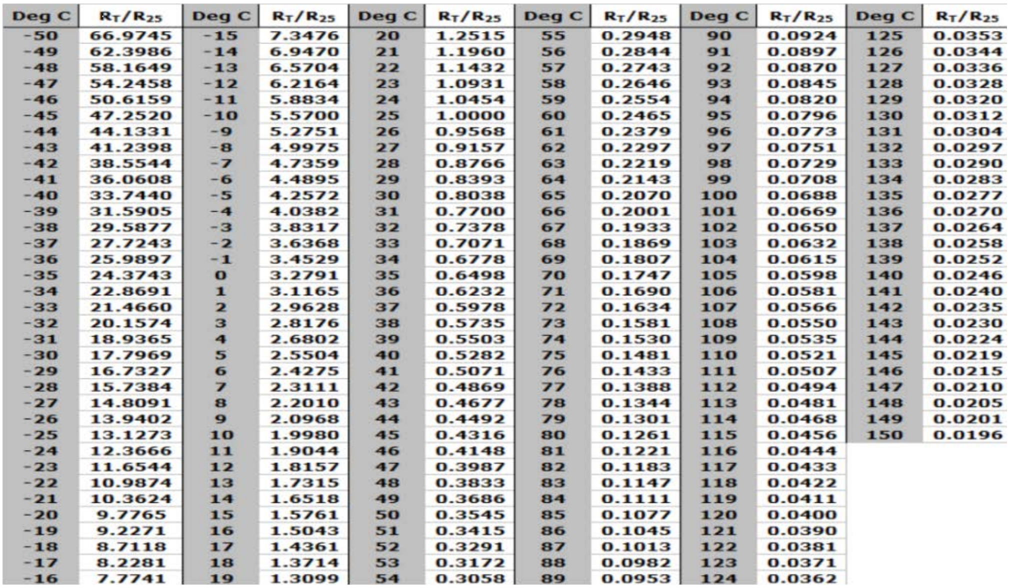
A	**3.5 mm Max**
B	**7.5 mm Max**
Lead Diameter	**24 AWG (0.5 mm)**
C	**150 mm**
D	**6.5 mm nom**

Rev:	Changes Made:
0	

DRAWN BY: C. Terry		AMETHERM Circuit Protection Thermistors
DATE: 4/6/16	REV: 0	
ORIG. M Samii	APPR: M Samii	NTC THERMISTOR PROBE
SHEET 1 of 2		PANE 103395



Temperature Vs Resistance Curve



Deg C	R_T/R_{25}	Deg C	R_T/R_{25}	Deg C	R_T/R_{25}	Deg C	R_T/R_{25}	Deg C	R_T/R_{25}	Deg C	R_T/R_{25}
-50	66.9745	-15	7.3476	20	1.2515	55	0.2948	90	0.0924	125	0.0353
-49	62.3986	-14	6.9470	21	1.1960	56	0.2844	91	0.0897	126	0.0344
-48	58.1649	-13	6.5704	22	1.1432	57	0.2743	92	0.0870	127	0.0336
-47	54.2458	-12	6.2164	23	1.0931	58	0.2646	93	0.0845	128	0.0328
-46	50.6159	-11	5.8834	24	1.0454	59	0.2554	94	0.0820	129	0.0320
-45	47.2520	-10	5.5700	25	1.0000	60	0.2465	95	0.0796	130	0.0312
-44	44.1331	-9	5.2751	26	0.9568	61	0.2379	96	0.0773	131	0.0304
-43	41.2398	-8	4.9975	27	0.9157	62	0.2297	97	0.0751	132	0.0297
-42	38.5544	-7	4.7359	28	0.8766	63	0.2219	98	0.0729	133	0.0290
-41	36.0608	-6	4.4895	29	0.8393	64	0.2143	99	0.0708	134	0.0283
-40	33.7440	-5	4.2572	30	0.8038	65	0.2070	100	0.0688	135	0.0277
-39	31.5905	-4	4.0382	31	0.7700	66	0.2001	101	0.0669	136	0.0270
-38	29.5877	-3	3.8317	32	0.7378	67	0.1933	102	0.0650	137	0.0264
-37	27.7243	-2	3.6368	33	0.7071	68	0.1869	103	0.0632	138	0.0258
-36	25.9897	-1	3.4529	34	0.6778	69	0.1807	104	0.0615	139	0.0252
-35	24.3743	0	3.2791	35	0.6498	70	0.1747	105	0.0598	140	0.0246
-34	22.8691	1	3.1165	36	0.6232	71	0.1690	106	0.0581	141	0.0240
-33	21.4660	2	2.9628	37	0.5978	72	0.1634	107	0.0566	142	0.0235
-32	20.1574	3	2.8176	38	0.5735	73	0.1581	108	0.0550	143	0.0230
-31	18.9365	4	2.6802	39	0.5503	74	0.1530	109	0.0535	144	0.0224
-30	17.7969	5	2.5504	40	0.5282	75	0.1481	110	0.0521	145	0.0219
-29	16.7327	6	2.4275	41	0.5071	76	0.1433	111	0.0507	146	0.0215
-28	15.7384	7	2.3111	42	0.4869	77	0.1388	112	0.0494	147	0.0210
-27	14.8091	8	2.2010	43	0.4677	78	0.1344	113	0.0481	148	0.0205
-26	13.9402	9	2.0968	44	0.4492	79	0.1301	114	0.0468	149	0.0201
-25	13.1273	10	1.9980	45	0.4316	80	0.1261	115	0.0456	150	0.0196
-24	12.3666	11	1.9044	46	0.4148	81	0.1221	116	0.0444		
-23	11.6544	12	1.8157	47	0.3987	82	0.1183	117	0.0433		
-22	10.9874	13	1.7315	48	0.3833	83	0.1147	118	0.0422		
-21	10.3624	14	1.6518	49	0.3686	84	0.1111	119	0.0411		
-20	9.7765	15	1.5761	50	0.3545	85	0.1077	120	0.0400		
-19	9.2271	16	1.5043	51	0.3415	86	0.1045	121	0.0390		
-18	8.7118	17	1.4361	52	0.3291	87	0.1013	122	0.0381		
-17	8.2281	18	1.3714	53	0.3172	88	0.0982	123	0.0371		
-16	7.7741	19	1.3099	54	0.3058	89	0.0953	124	0.0362		

The general equation for measurement to reduce error in Temperature by using Stein Hart & Hart equation.

$$T = 1 / a + b (\mathrm{Ln}\ R_T / R_{25}) + c\ b (\mathrm{Ln}\ R_T / R_{25})^2 + d (\mathrm{Ln}\ R_T / R_{25})^3$$

R_T / R_{25} Range	a	b	c	d
3.279 – 66.97	3.357296E-03	2.508334E-04	4.189372 E-06	-6.240867E-08
0.3507-3.363	3.354016E-0-3	2.541522 E-04	3.730922 E-06	-7.881561E-08
0.0637-0.3507	3.361395E-03	2.582266 E-04	5.885012 E-07	-2.823586 E-08
0.0169-0.0637	3.351295E-03	2.500181 E-04	-1.7255607 E-07	-4.356943 E-08

This equation is for Beta 3950 °K

R @0°C/ R@50°C = 9.20

R@25°C / R @125°C = 28.30

DRAWN BY: C. Terry	AMETHERM Circuit Protection Thermistors
DATE: 4/6/16 REV: 0	
ORIG. M Samii APPR: M Samii	NTC THERMISTOR PROBE
SHEET 2 of 2	PANE 103395

Appendix A-6

Hydraulic Conductivity Testing

TREK GEOTECHNICAL Quality Engineering | Valued Relationships

MEMORANDUM

Date	May 16, 2023
To	Ken Skaftfeld, TREK Geotechnical
From	Angela Fidler-Kliewer, TREK Geotechnical
Project No.	0186-002-00
Project	TDA Testing
Subject	Laboratory Testing Results – Lab Req. R23-031
Distribution	Ken Skaftfeld

Attached is the Constant Head report for the above noted project.

Regards,

Angela Fidler-Kliewer, C.Tech.

Attach.

Review Control:

Prepared By: *IA*	*Reviewed By:* AFK	*Checked By:* NJF

TREK GEOTECHNICAL
www.trekgeotechnical.ca
1712 St. James Street
Winnipeg, MB R3H 0L3
Tel: 204.975.9433 Fax: 204.975.9435

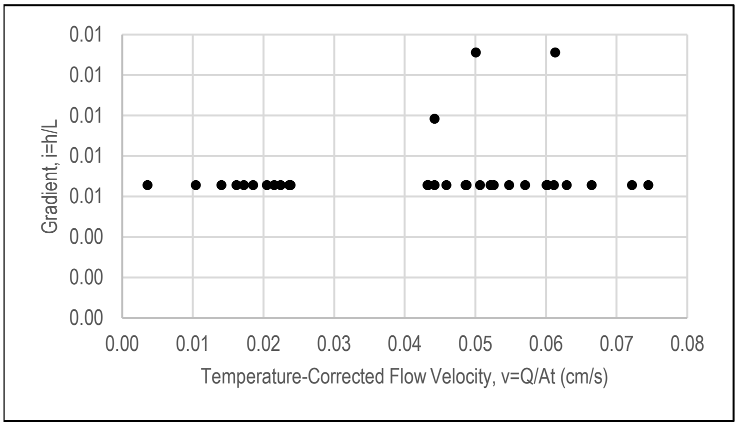
Permeability of Granular Soils (Constant Head)

ASTM D2434-19

Project No.	0186-002-00
Client	OTR Recycling
Project	TDA Testing
Technician	I. Araquil

Sample #	R23-031
Source	-
Material	Tire Shred
Sample Date	January 16, 2023
Test Date	February 7, 2023

Grain Size	
USCS Classification	-
Maximum Particle Size (mm)	75
Oversize Material not used	-



Density

Material Properties

SPMDD (kg/m^3)	560
Optimum Moisture Content	0.0%
Minimum Relative Dry Density (kg/m^3)	504
Maximum Relative Dry Density (kg/m^3)	N/A
Specific Gravity (Measured)	1.26

Test Sample

	Intial	Final
Density (kg/m^3)	504	543
Moisture Content	0.0%	5.3%
Dry Density (kg/m^3)	504	516
% SPMDD	90%	92%
% Relative Density	N/A	N/A
Void Ratio	1.50	1.44
Porosity	0.60	0.59

Notes

Linear laminar flow region used to determine average temperature corrected permeability. All tests (1 to 32) interpreted as laminar flow.

Average Temperature Corrected Permeability, k_{20}	**6.08E-02 m/s**	***6.08E+00 cm/s***

Test No.	Manometers (cm)		Head, h (cm)	Q (cm^3)	t (s)	Q/At (cm/s)	h/L	Temp (^{o}C)	k_{20} (cm/s)
	H_1	H_2							
1	78.1	78.0	0.1	30.1	60.35	0.00	0.01	10.1	5.54E-01
2	77.5	77.4	0.1	85.9	60.3	0.01	0.01	9.9	1.59E+00
3	76.9	76.8	0.1	113.8	60.3	0.01	0.01	9.4	2.14E+00
4	76.5	76.4	0.1	129.3	60.3	0.02	0.01	9.0	2.47E+00
5	76.0	75.9	0.1	139.0	60.35	0.02	0.01	9.3	2.63E+00
6	75.1	75.0	0.1	121.7	49.15	0.02	0.01	9.3	2.83E+00
7	74.5	74.4	0.1	98.8	36.4	0.02	0.01	9.0	3.13E+00
8	73.9	73.8	0.1	96.4	33.65	0.02	0.01	9.1	3.29E+00
9	73.1	73.0	0.1	95.0	31.85	0.02	0.01	9.1	3.42E+00
10	72.1	72.0	0.1	98.3	31	0.02	0.01	9.1	3.64E+00
11	71.1	71.0	0.1	97.0	30.85	0.02	0.01	9.1	3.61E+00
12	70.4	70.3	0.1	106.8	18.75	0.04	0.01	8.9	6.59E+00
13	69.1	69.0	0.1	96.5	15.35	0.05	0.01	8.3	7.42E+00
14	68.1	68.0	0.1	104.8	16.4	0.05	0.01	8.7	7.44E+00
15	67.1	67.0	0.1	94.3	14.15	0.05	0.01	8.8	7.73E+00
16	66.2	66.1	0.1	107.6	15.55	0.05	0.01	8.8	8.03E+00
17	65.2	65.1	0.1	97.8	14.2	0.05	0.01	8.9	7.96E+00

18	64.2	64.1	0.1	103.1	14.35	0.05	0.01	8.7	8.36E+00
19	63.1	63.0	0.1	101.7	13.65	0.06	0.01	8.6	8.70E+00
20	62.9	62.8	0.1	111.8	14.1	0.06	0.01	8.4	9.33E+00
21	62.2	62.0	0.2	105.6	14	0.05	0.01	13.1	3.82E+00
22	61.1	61.0	0.1	101.0	14.6	0.05	0.01	13.1	7.00E+00
23	60.1	60.0	0.1	105.4	16.1	0.04	0.01	12.5	6.74E+00
24	59.2	59.0	0.2	101.7	16.1	0.04	0.01	11.3	4.50E+00
25	58.1	58.0	0.1	94.6	16.25	0.04	0.01	9.4	6.61E+00
26	57.2	57.0	0.2	108.3	13.15	0.06	0.01	9.4	4.68E+00
27	55.2	55.1	0.1	106.3	13.15	0.06	0.01	9.5	9.17E+00
28	55.2	55.1	0.1	106.3	13.15	0.06	0.01	9.4	9.18E+00
29	54.6	54.5	0.1	106.3	12.45	0.06	0.01	9.7	9.60E+00
30	53.6	53.5	0.1	107.6	11.85	0.07	0.01	9.9	1.01E+01
31	52.4	52.3	0.1	107.7	10.85	0.07	0.01	10.1	1.10E+01
32	51.1	51.0	0.1	106.5	10.4	0.07	0.01	10.1	1.14E+01