Operator's Manual

PURWheel Laboratory Wheel Tracker

Mississippi Transportation Research Center

"An Industry, Agency & University Partnership"

Mississippi State University
Isaac L. Howard
Jesse D. Doyle
Thomas D. White
Joe Ivy

And

Innovative Broadcast Services
Olen Booth

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Background

Cooley et al. (2000) performed a state of practice review of loaded wheel testers in the United States and found the following devices:

- Georgia Loaded Wheel Tester (GLWT)
- Asphalt Pavement Analyzer (APA)
- Hamburg Wheel Tracking Device (HWTD)
- French Wheel Tester (LCPC)
- One-Third Model Mobile Load Simulator (MMLS3)
- Purdue University Laboratory Wheel Tracking Device (PURWheel)

The original PURWheel was developed in the 1990's at Purdue University. The device incorporated two independently controlled wheels powered by pneumatic cylinders, an environmental chamber, and the ability to measure deformation of the specimens during testing. The device had the capability to incorporate wet or dry testing, pneumatic or steel wheels, and wheel wander. Figure 1 is an example specimen tested in the original device, and Table 1 provides data reported as precision and bias by Stiady et al. (2003).

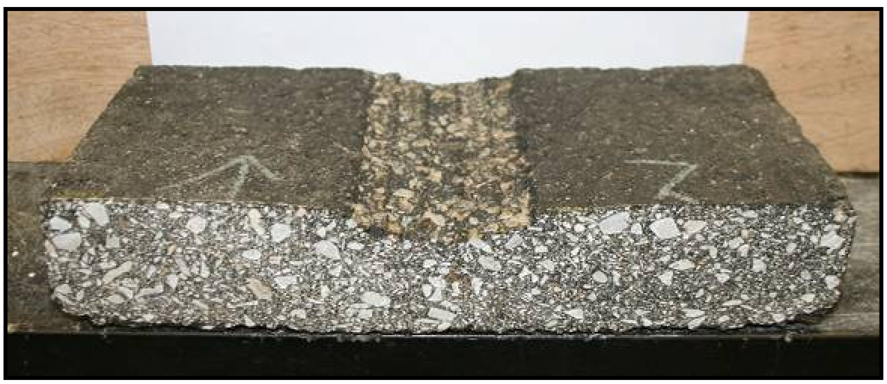


Figure 1. Example Slab from Original PURWheel

Table 1. Precision and Bias Data from Stiady et al. (2003)

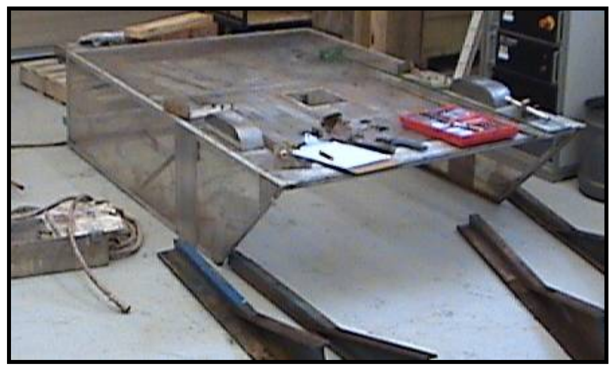
Specimen	D_V (g/cm^3)	G_{mb} (---)	V_a (%)	Rut Depth (mm)
1	2.203	2.292	7.5	1.4
2	2.219	2.308	6.9	1.2
3	2.229	2.319	6.4	2.0
4	2.193	2.281	7.9	1.9
Avg.	2.210	2.300	7.2	1.6
Stdev.	0.016	0.017	0.7	0.4
Cov.	0.7	0.7	9.3	25.0

- *D_v is volumetric density: dry weight divided by total volume.*
- *Laboratory sample, specimen thickness of 38 mm, 9.5 mm NMAS, P_b of 5.5%, G_{mm} of 2.478.*
- *620 kPa contact pressure; rubber tire; dry test; 50 C; 20,000 passes.*

A second generation PURWheel was developed for the Indiana DOT with hydraulic rather than pneumatic components. After development of the second PURWheel, Purdue University did not have need for the original and graciously donated both it and the corresponding linear asphalt compactor (*LAC*) to Mississippi State University on August 17, 2007. The original equipment was far from in working condition; Figure 2 shows photos of the device largely disassembled soon after arrival to the MSU campus. A manual was never developed for the original PURWheel.

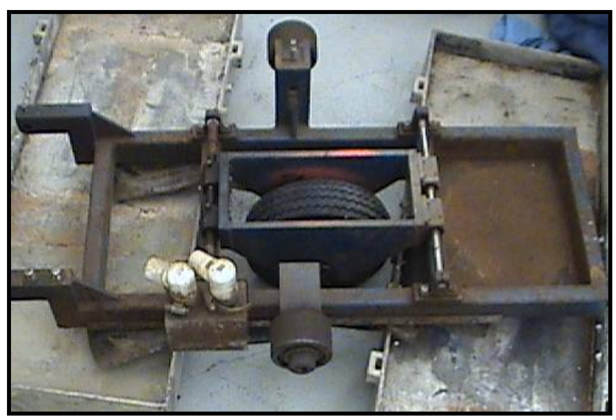
This manual was written for two reasons: 1) describe the renovation and modifications to the original PURWheel from its as-received condition; and 2) develop a working document for operators of the PURWheel that can be used to gain understanding of the device, provide operational parameters, and serve as a maintenance and repair guide. Literature from Purdue University was used as a resource during development of this document.

(a) Front View Without Hood



(b) Hood Without Insulation and Rails

(c) View Into Tank Without Mold



(d) Wheel and Carriage

Figure 2. As Received PURWheel Condition

Terminology and Major Components

An overall view of the current PURWheel with key components labeled can be seen in Figure 3. The terminology of Figure 3 has been used throughout this document. The PURWheel is equipped with six temperature measurement devices as outlined in the following list. Control thermocouples are attached to and read by the PURWheel control box while measurement thermocouples are written into the data files.

Air: Two bead thermocouples measure temperature of the enclosure above the specimens. One of the thermocouples is used for control and the other for measurement.

Tank: One bead thermocouple and one stainless probe are used to measure temperature at the bottom of the tank. When the tank is filled with water (i.e. wet test), the value is noted *Tank(W)* and when the tank is filled with air (i.e. dry test) the value is denoted *Tank(D).* The stainless probe is used for measurement and the bead thermocouple is used for control.

Mold: Two bead thermocouples measure temperature of the bottom of the mold containing the specimens during testing. They are labeled *Mold(L)* and *Mold(R)* for the left and right wheel tracks, respectively.

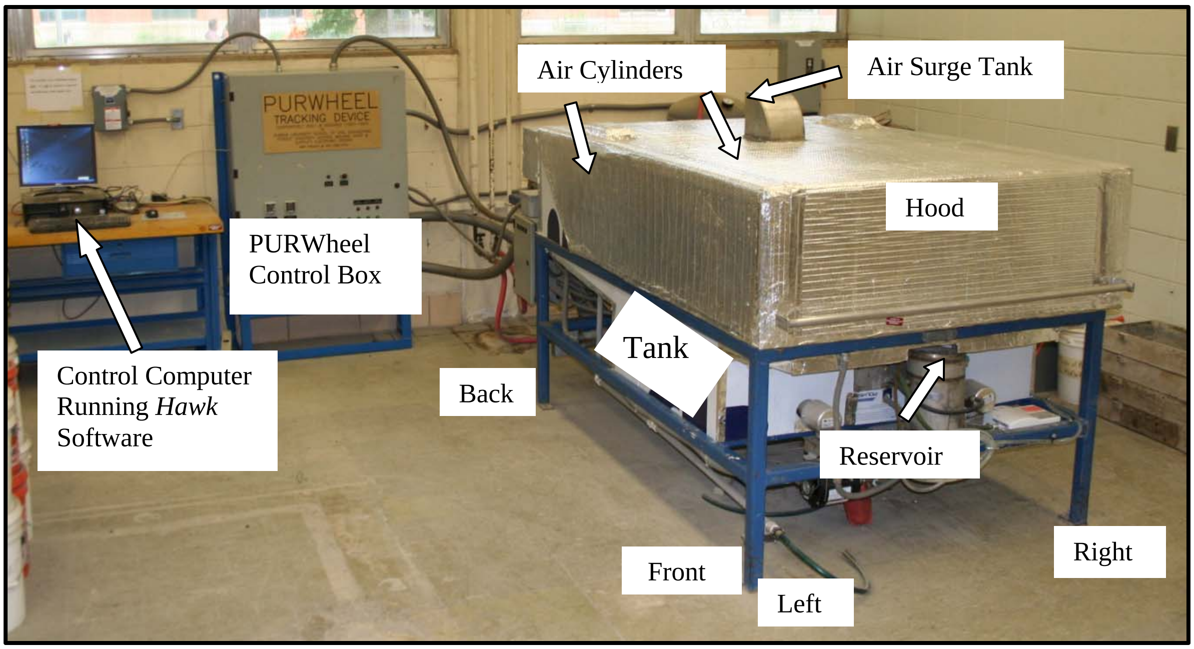


Figure 3. Terminology and Major PURWheel Components

The current PURWheel is equipped with three air circulation fans. Two of the fans circulate air within the hood and tank and the third fan can bring air from outside the device. Two fluid pumps allow a circulating flow through two independent systems: 1) within the Tank for wet testing; and 2) within the Reservoir to allow expedient and consistent specimen temperature heating. Five heaters are present: two heat the air within the Hood, two heat the water in the Tank during wet testing, and the final heater is for the fluid within the Reservoir circulation system.

The current version of the PURWheel is insulated in a manner that is noticeably different than the original to allow temperatures required by a southern state. The Tank is insulated with a rigid foam insulation that is 12.7 mm thick with an R-value of 3.2. An aluminum honeycomb insulation was placed on the Hood and over the honeycomb foil insulation with an R-value of 3.7 was attached which can be seen in Figure 3.

Two specimens can be tested simultaneously within the device using two independently controlled pneumatic (air) cylinders. Rut depth of each specimen is monitored with a 25 mm stroke submersible spring return LVDT with a flat smooth stainless steel tip adapted to meet the needs of the PURWheel. The specimens are loaded with pneumatic rubber tires that are 100 mm diameter, approximately 50 mm wide while unloaded, split rim, 4-ply, saw tooth tread, and have an 860 kPa (125 psi) maximum inflation pressure.

Hardware Modifications

Non-Temperature Related Modifications

Essentially all moving parts and complimentary components were replaced (e.g. rails and bearings). The metal frame and wheel tracking assembly were sanded, coated with rust resistant enamel, and painted. LVDT's, fluid pumps, and heaters were replaced. The track where the LVDT's ride was originally made of brass. Teflon was originally used in lieu of brass but it was changed to stainless steel after the Teflon was scratched by the LVDT's. Numerous electrical and electro-mechanical components were also replaced.

Temperature Related Modifications

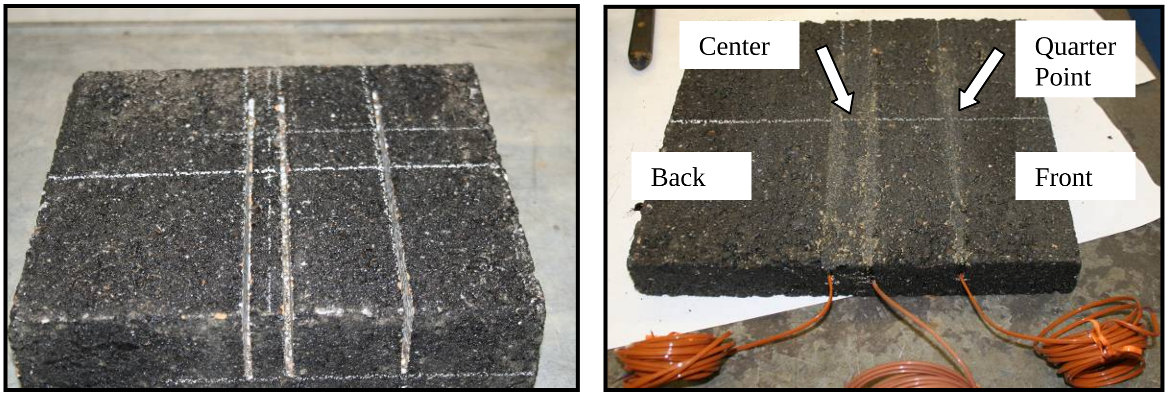
Temperature was one of the most challenging facets of the PURWheel renovation and modification and was thus a primary focus. Numerous efforts were made over a period of several months and only those efforts that provided understanding of the advancement of the device from its original to final condition are included. Pan and White (1999) indicated thermocouples were embedded in slabs during the original development.

Omega *TC-TT-T-20 PFA* insulated bead thermocouples were used in the PURWheel renovation; they replaced all existing temperature measurements but the stainless probe. The same thermocouples were embedded into asphalt slabs to measure temperature behavior of the materials. Figure 4 shows photos of the instrumented slabs, in particular the two thermocouples installed on either side of the centerline and the third thermocouple installed at the quarter point of the slab. Orientation of the slab within the PURWheel is also shown. All thermocouples were installed at mid-depth and mid-width.

Four categories of temperature data were collected while re-furbishing and updating of the PURWheel:

> 1) A *National Instruments NI Compaq Daq 9172* chassis and *NI 9211* modules were used in conjunction with a program written in *LabView*™ to acquire the temperature measurements external to the PURWheel. Samples were taken every ten seconds using thermocouples that had been verified using externally calibrated thermometers at temperatures ranging from ice to near boiling water. Data taken in this manner has been denoted *NI*. All slab temperature data was measured with the *NI* system.
>
> 2) Data was read from the PURWheel control box (i.e. control sensors) shown in Figure 3 and was denoted *PWCB* for PURWheel control box.

3) Proprietary software from a local electronics company was used to re-program the system. Data collected from this software was referred to as *The Hawk* or *Hawk*.
4) Manual measurements made with thermometers on the top of the hood (*Hood*) and in the water reservoir for the mold circulation system (*Res*).



(a) Grooves Cut into Slab *(b) Thermocouples Installed*

Figure 4. Instrumentation of Asphalt Slabs

A total of 20 trials were performed on the PURWheel beginning in January 2009 where data was collected and stored. Dozens of additional laboratory data acquisition efforts were made where data was collected, used during the lab work, and not stored. This data was not recorded as a trial since it was for immediate use and provided no long term value. Ambient conditions for the air and steel of the PURWheel were 20 to 24 C unless otherwise noted. All slab temperature measurements were at mid-depth unless otherwise noted.

Trial 1 measured temperature at three locations within a 40 mm thick slab placed in the left track; two measurements at the center of the slab and one measurement at the slab third point in the back of the PURWheel were made. The goal of Trial 1 was to obtain a reasonable measure of the amount of time necessary for a slab to reach 60 C with a layer of honeycomb insulation on the hood of the device and no other insulation installed. The results are shown in Figure 5; the time was approximately 160 min.

Trial 2 had a 40 mm slab in the left track and a 102 mm slab in the right track. Three temperature measurements were made: two measurements at the center of the 102 mm slab and one measurement at the center of the 38 mm slab. No modifications were made to the PURWheel between trials 1 and 2. The goal of Trial 2 was to determine repeatability of heating a 40 mm slab (17 minutes difference) and compare heating of thin and thick slabs. The test was performed for 450 minutes and the maximum temperatures recorded are shown in Figure 6.

Trial 3 had a 40 mm slab in the left track and a 102 mm slab in the right track (Figure 7). Four temperature measurements were made: two at the center of the 102 mm slab, one at the center of the 40 mm slab, and one at the quarter point of the 40 mm slab. During testing it was observed that the air temperature was only 41 C on the PURWheel control box, which explains the 40 mm slab being on the order of 58 C and the 102 mm slab being on the order of 56 to 57 C, rather than at 60 C as in Figures 5 and 6. Key observations from Trial 3 were that the 40 mm slab heated faster than the 102 mm slab in earlier stages but convergence occurred prior to 60 C. Also note that the shape of the temperature curves differed when the air heaters were not functioning in their typical manner. An additional observation was that the temperature on top of the hood was 35 C, the air inside the hood was 41 C, and the ambient air was 23 C.

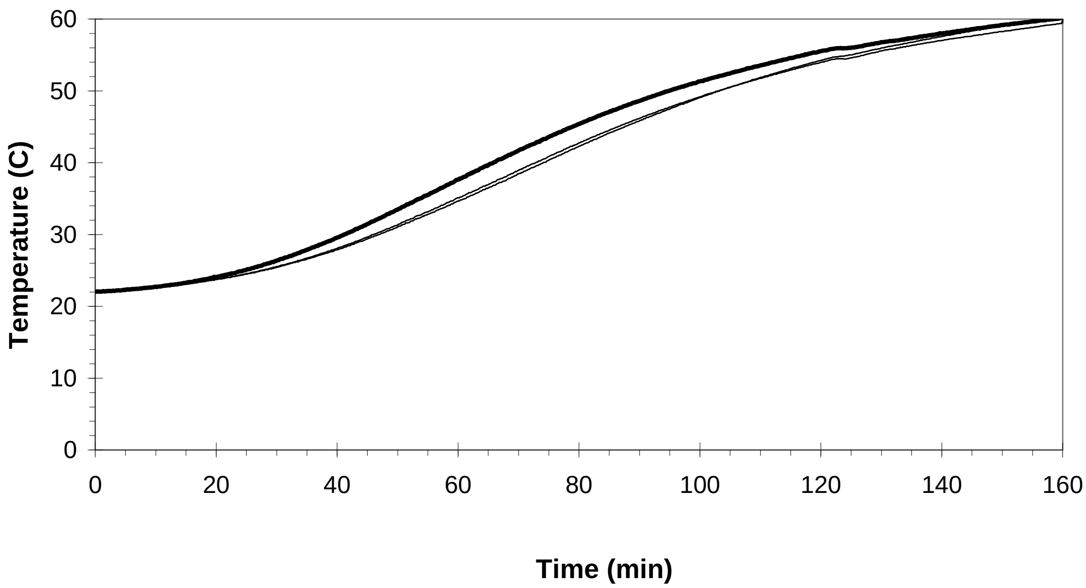


Figure 5. Temperature Trial 1: 40 mm Thick Slab

Trial 4 incorporated measurement of the temperature of the water in the reservoir circulating and heating the molds, which is referred to as *Res*. The water in the reservoir tank is return water and would be the coolest water in the mold circulation system. Manual measurements with the control sensor at the standard setting showed the water between 60 to 62 C over a period of 400 minutes.

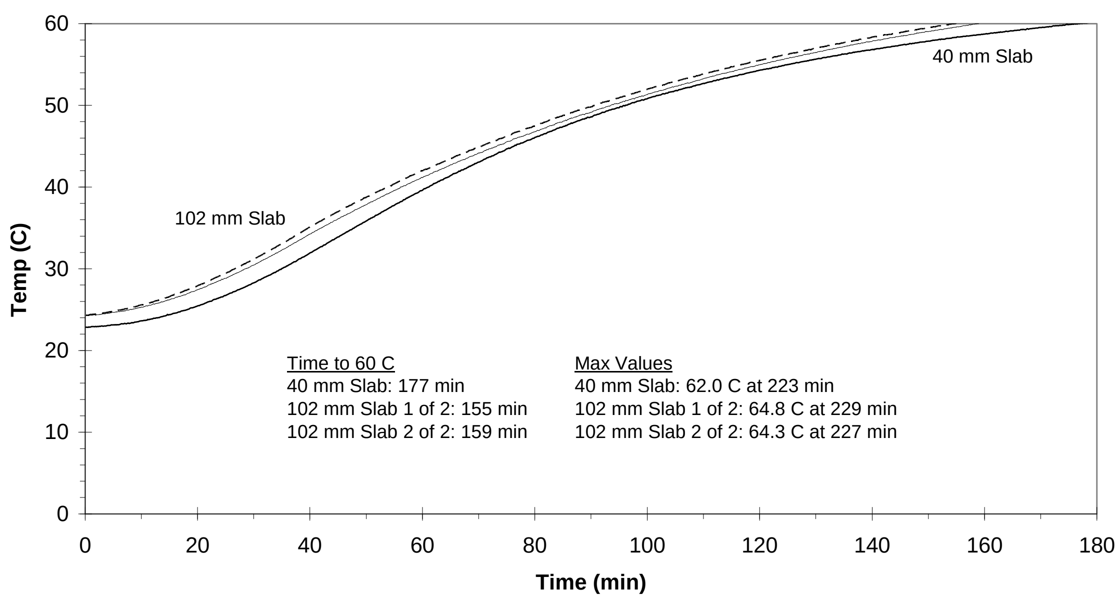


Figure 6. Temperature Trial 2 Results

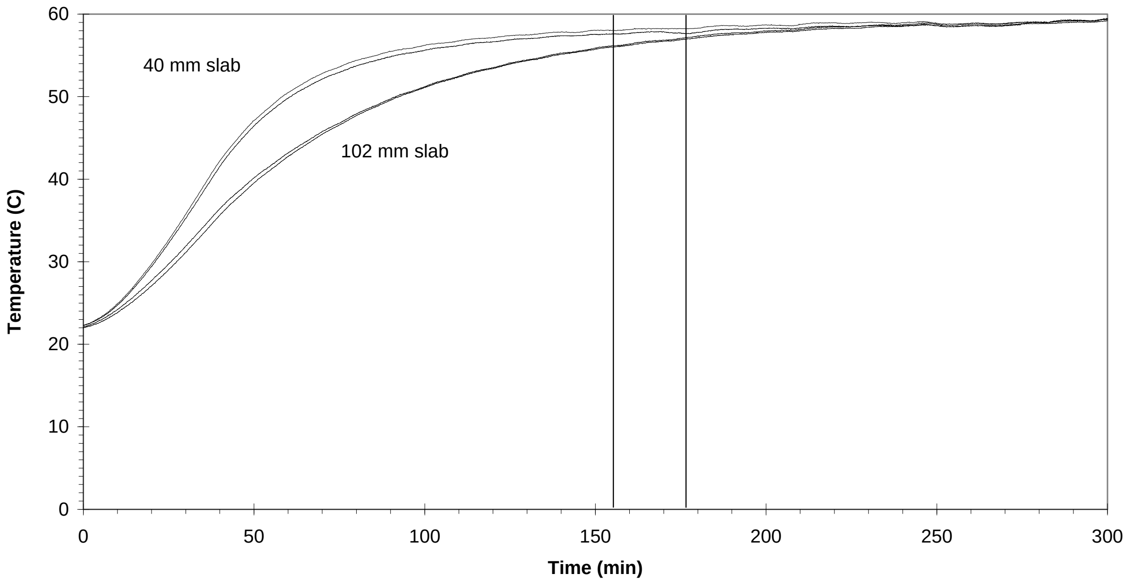


Figure 7. Temperature Trial 3 Results

A second layer of insulation was added to the top of the PURWheel prior to Trial 5. Additional bead thermocouples were wired to the PURWheel *Air* and *Tank* instruments in duplicate and were measured with the *NI* system. Discrete measurements were taken from the *Hawk* software and PURWheel control box. Two key observations from Trial 5 were: 1) the significant difference in temperature between the *Air* and *Tank*; and 2) deviation in temperature recorded by the PURWheel control box (*PWCB*) and the *Hawk* software relative to the *NI* acquired data in some instances. These differences are expounded in later trials.

Between Trial 5 and Trial 6 a single fan was installed between the left and right tracks oriented to intake the warmer air in the hood and re-locate it into the tank to improve temperature uniformity. As seen in Figure 8, a noticeable improvement in temperature uniformity was achieved; a temperature gap on the order of 25 C existed in Trial 5, which was reduced to on the order of 8 C in Trial 6. With the improved circulation of heat, the original heaters were incapable of achieving the needed temperature of 60 C. Figure 9 shows all data collected during Trial 6, which further emphasizes the problem with air temperature measurement with the PURWheel control box.

Trials 7 and 8 investigated thermocouple control device calibrations and cabling. *Air* thermocouples in the PURWheel were wired directly to the *NI* system at the input location (included cabling from original system between the thermocouples and readout location). Additional thermocouples placed at the same location were also measured by the *NI* system with only new cable. At higher temperatures (i.e. above 45 C) measurements containing original cable began to deviate from those without this cable and the magnitude of the deviation increased with temperature. Also, trends between readings using the original cable were not necessarily consistent from one trial to another.

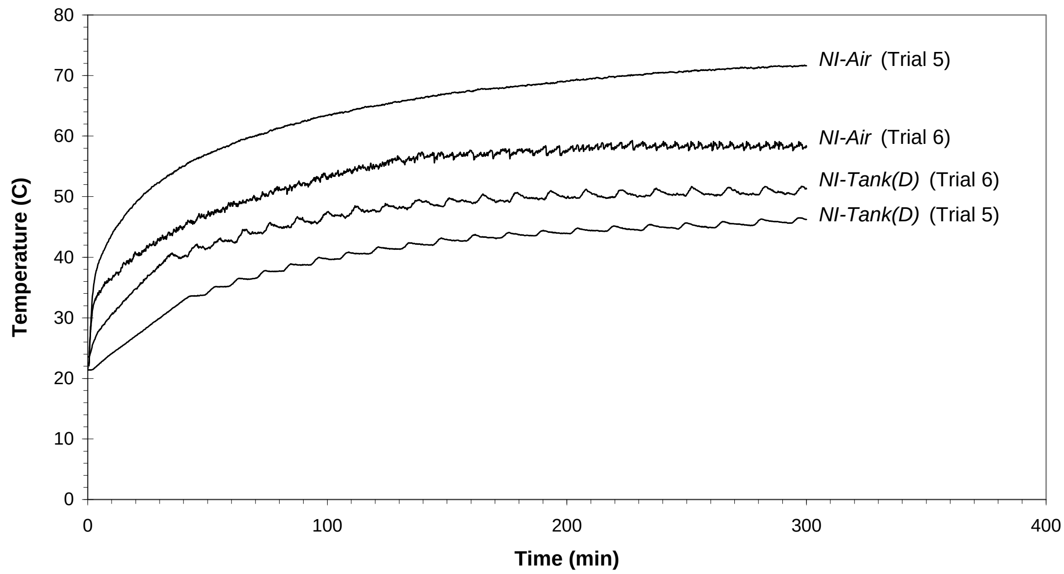


Figure 8. Temperature Trial 5 and 6 Results

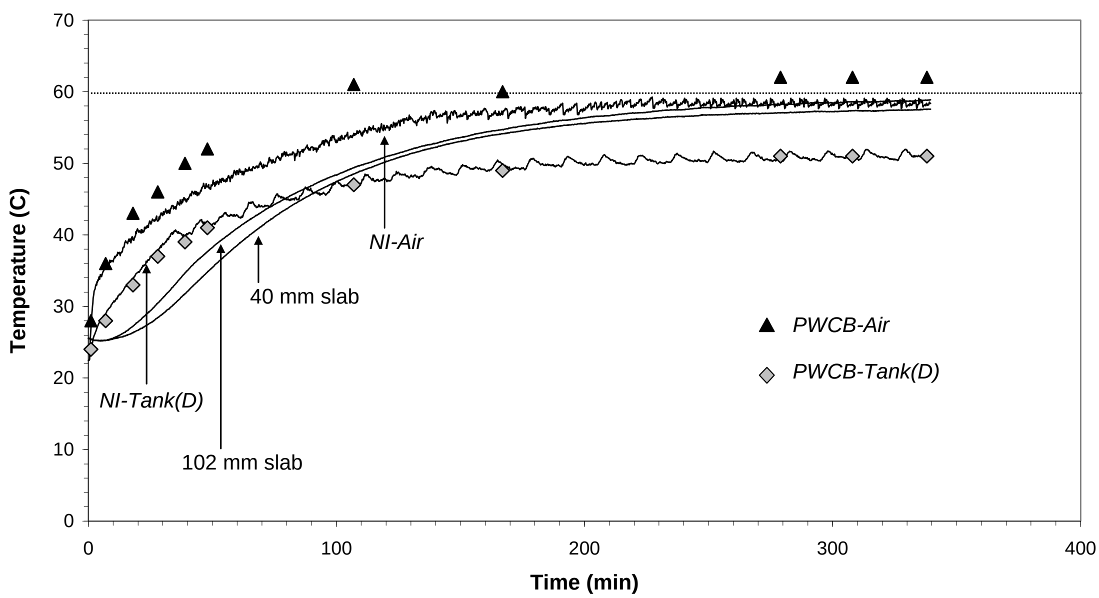


Figure 9. Temperature Trial 6 Results

Prior to Trial 9, improved capacity heaters and two fans oriented to move air from the hood toward the front of the Tank of the PURWheel were installed. The magnitude of temperature improved, while the temperature differential increased from on the order of 8 C to on the order of 13 C. Problems with temperature measurement in the hood of the device are readily seen from the long duration test. Stabilization of temperature occurred approximately 500 minutes into the test, which began with the entire unit at room temperature (Figure 10).

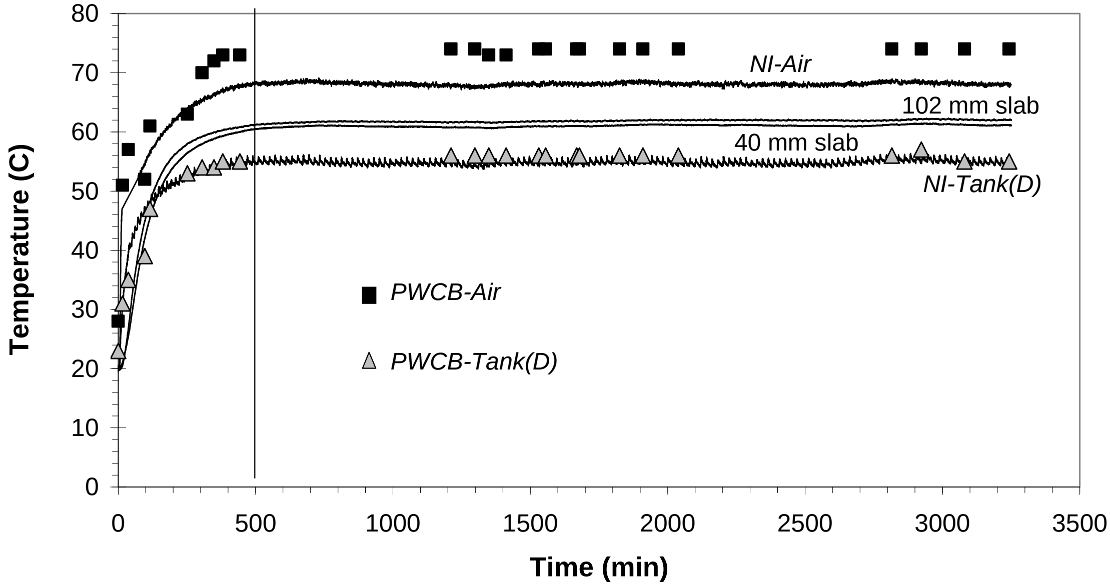


Figure 10. Temperature Trial 9 Results

Prior to trials 10 and 11, insulation was placed on the bottom of the PURWheel. Trial 10 investigated mold temperatures, tank temperatures, and effects of the new insulation. With the *Res* temperature on the order of 60 C, *Mold* temperatures were 61 to 63 C. These sensors occasionally measured values impractical for the test conditions (e.g. 75 C) but since they are only present for general information no attempts were made to correct these behaviors. *Mold(R)* is believed to measure temperatures in some instances that are a few degrees Celsius higher than the actual temperature. *PWCB-Tank(D)* temperatures aligned with *NI-Tank(D)* temperatures while *Hawk-Tank(D)* temperatures were up to 4 C lower than the other values. The insulation placed on the bottom of the device allowed closure of the hood and tank temperatures to within 3 C or less. Prior to the cumbersome act of removing the existing cable, it was spliced at the location where the new thermocouple cable had been wired to the existing cable to provide a direct comparison of the PURWheel thermocouple to the existing thermocouple. The values were essentially the same, which prompted removal of all existing cable related to temperature measurement in the PURWheel hood.

Figures 11 to 13 provide findings of Trial 12. Both Trial 6 and Trial 12 show the 102 mm slab heating faster and to a higher value than the 40 mm slab. Trial 12 had heaters on a lower setting and was primarily to compare the relative slab heating behaviors and evaluate the new cable system. The new cable removed discrepancies in *Air* temperature measurement of the hood. Temperature measurements taken by the *Hawk* in the tank were still lower than the other readings, but to a reasonable and predictable level.

Trial 13 investigated the external heater switches and controls in conjunction with the new heaters. The switches did not adequately control the heaters. Temperature control from the left to the right sides of the PURWheel was a concern in addition to temperature magnitude control. Trials 14 to 17 more carefully investigated manual heater controls and the new insulation system. Relative temperatures of the left and right air inlets were also investigated during these trials. Air inlet temperatures were on the order of 10 C higher than *Air* temperature in the hood. Trial 18 showed approximately a 3 to 4 C difference in the air inlets. The manual heater controls were deemed insufficient and replaced with software temperature controls.

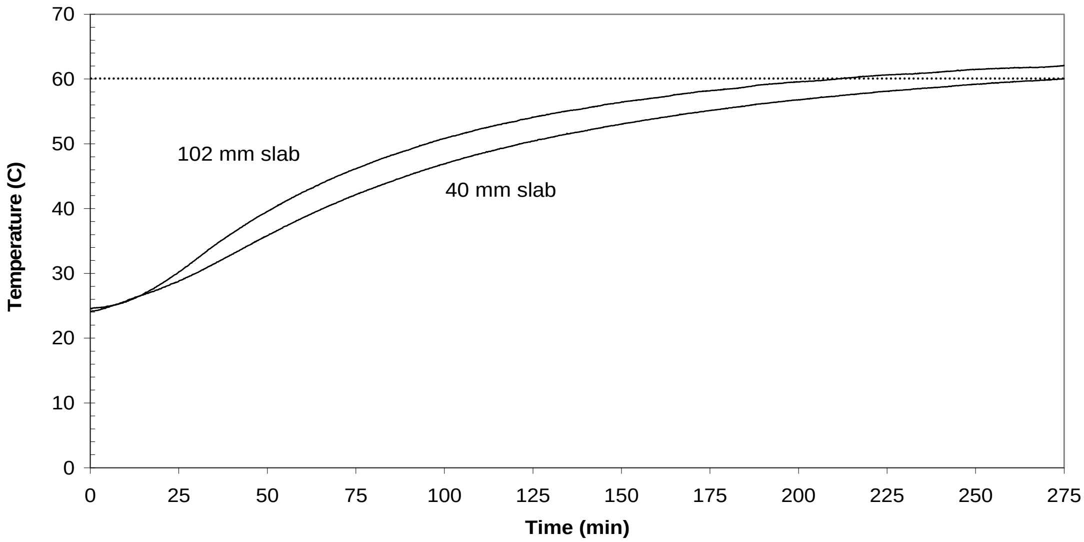


Figure 11. Temperature Trial 12 Slab Test Results

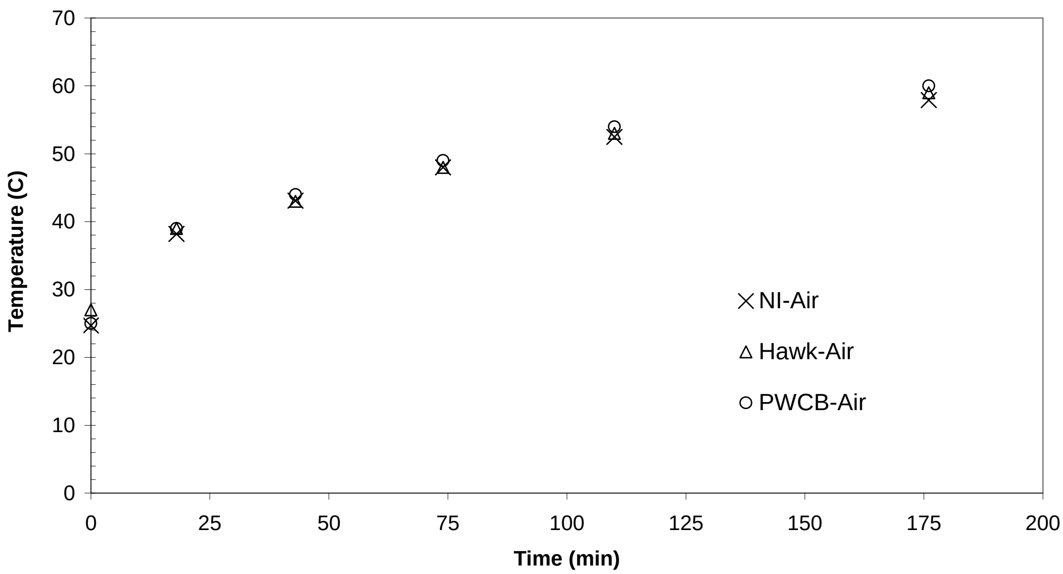


Figure 12. Temperature Trial 12 Air Test Results

Trial 19 tested the electronic software controls cycling with settings of 59 to 61 C. Air temperatures were 57 to 61 C (very reasonable for the application); there was practically no difference in the hood and tank temperatures. Temperature cycled frequently and it took the heater a brief period to begin heating again (easily addressed by having settings of 60 to 62 C, for example). Software problems occurred during Trial 19 where the program would not cease to heat; *Air* temperatures exceeded 80 C.

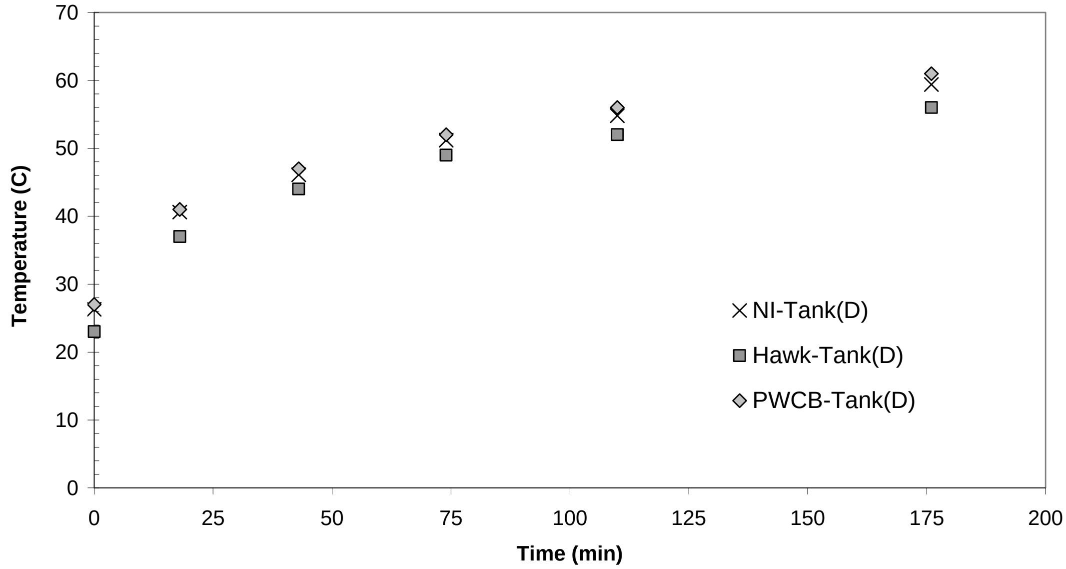


Figure 13. Temperature Trial 12 Tank Test Results

Trial 20 extended the efforts of Trial 19; results are shown in Figure 14. Trial 20 also incorporated program improvements to alleviate some of the differences in measured Tank temperatures. Figure 15 is an excerpt of Trial 20 showing the cycling frequency. The heaters cycled every two minutes when settings were 59 to 61 C when being controlled by the software routine. As seen, the *Air* temperature changes over a 3 to 4 C range fairly quickly. Comparisons of the *Air* and *Tank(D)* temperatures are shown in Figures 16 and 17. A single operator took all readings over a duration of less than one minute. All values differed by less than 2 C, and during a one minute interval the temperatures can easily change by this magnitude as shown in Figure 15. *Air* and *Tank(D)* temperature measurements were deemed acceptable at the conclusion of Trial 20.

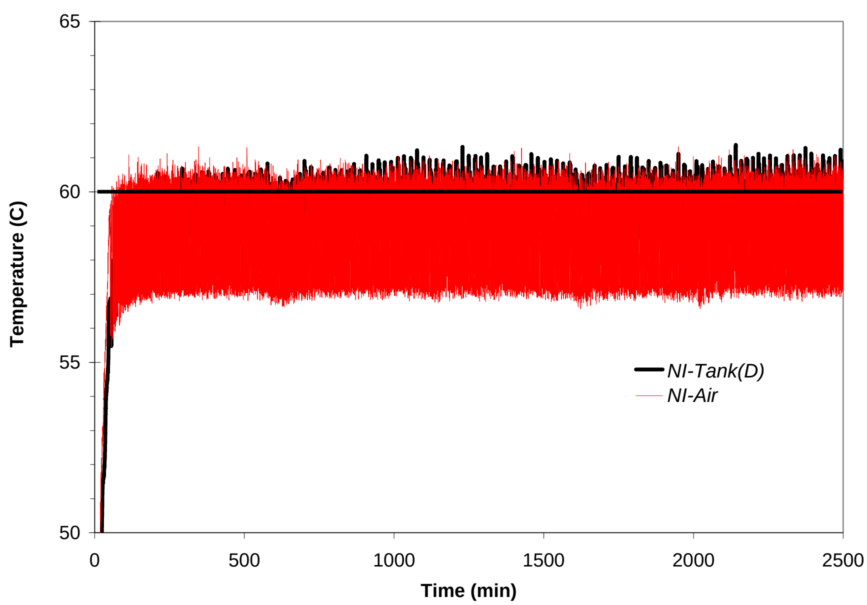


Figure 14. Temperature Trial 20 Test Results: Continuous *NI* System Readings

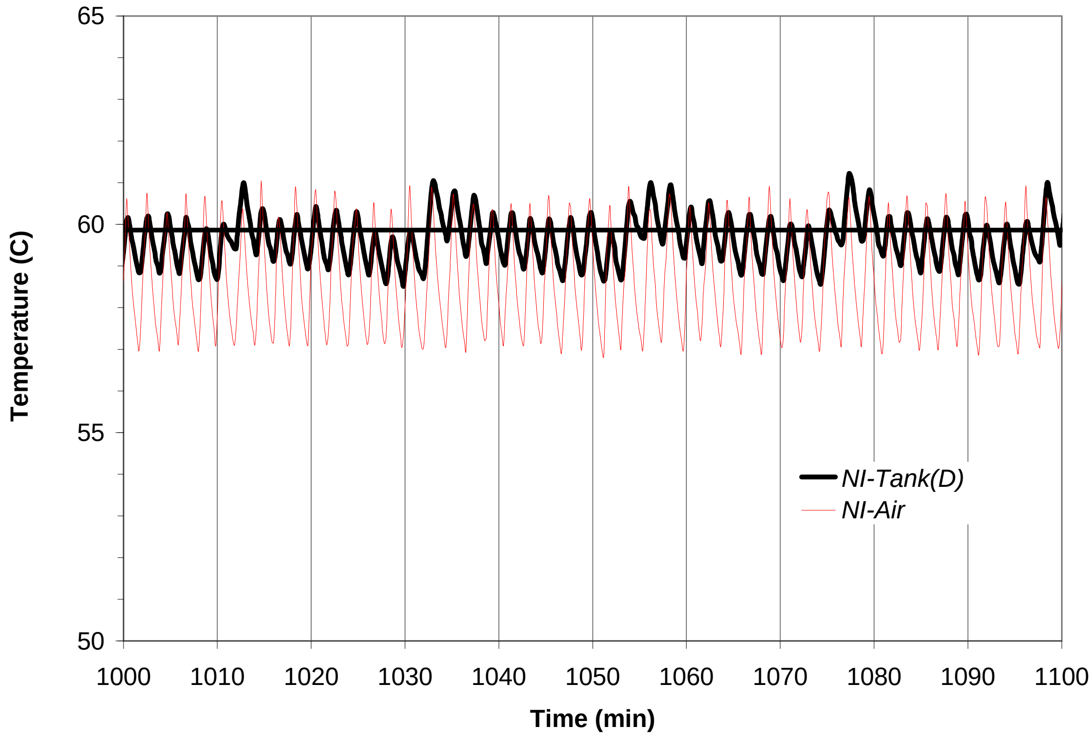


Figure 15. Excerpt of Continuous *NI* System Temperature Trial 20 Test Results

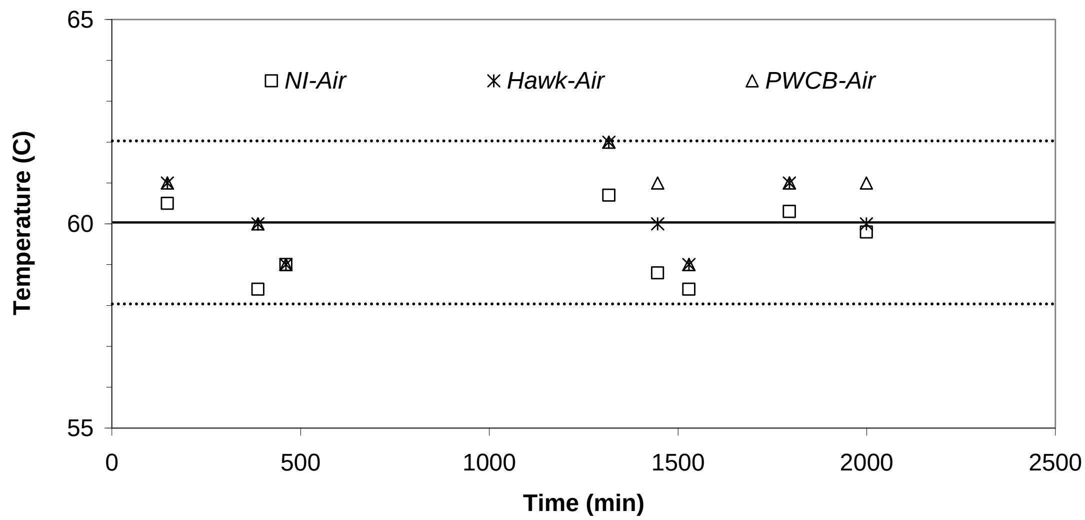


Figure 16. Temperature Trial 20 Test Results: *Air*

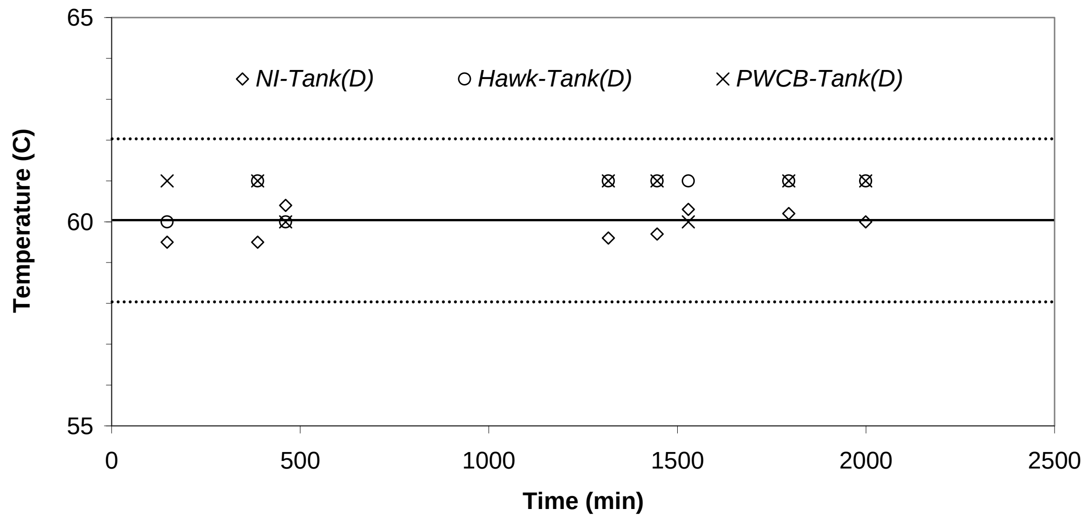


Figure 17. Temperature Trial 20 Test Results: *Tank(D)*

After Trial 20, bead thermocouples were covered with a metal tube to prevent direct contact with air flow from the heater to provide a more stable temperature condition and minimize wear on electrical contractors. Additionally, the entire reservoir water circulation system was removed, hoses and fittings replaced, mold circulation plates and the reservoir tank cleaned, and a mixture of 50% antifreeze and 50% water incorporated to minimize corrosion of the system and reduce evaporation. Corroded manifolds were also replaced and a corrosion sink placed in the bottom of the tank.

Calibration

Once all hardware and software modifications were complete, a complete calibration of the system was performed. The calibration included the four components of the original development, yet was more extensive in many areas. The remainder of this section describes the calibrations.

Temperature Calibration

Temperature calibration was to achieve 64 ± 1 C in the center of the slab while having an air temperature differential between the hood and tank of 3 C or less. The provisional standard for the Asphalt Pavement Analyzer (*APA*) is AASHTO TP 63-09, which indicates the test temperature should be the high binder grade temperature that is standard for the area. The standard binder grade for Mississippi is PG 67-22, though states in the region commonly use PG 64-22 (e.g. Arkansas). Additionally, MDOT conducts *APA* testing at 64 C in the majority of cases. Temperature calibration was performed for 15 hour periods. Four combinations were required for the calibration (left and right track having 40 mm and 72 mm thick slabs).

Calibration *Run 1* was used to make slight adjustments to water pumping pressure and to cycling of the *Air* temperature. During temperature modifications it was observed that the temperature cycling frequency would wear out electrical contactors too quickly and could potentially cause the software to lose control of temperature. To slow the cycling rate, a small metal tube was placed over the bead thermocouple using caulk to prevent direct contact with air flow from the heater, which provided a much more stable temperature control condition that did not change the behavior of the slab. The cycling time increased from on the order of 90 seconds to on the order of 270 seconds at temperature settings of 63 to 65 C.

Calibration *Run 2* had the 40 mm slab in the right track and the 72 mm slab in the left track. The hood was opened on the heated device and the specimens were placed into the molds with the hood open for ten minutes. The hood was then closed. Time began when the specimens were placed in the mold. Ten minutes would be a time earlier than the specimens could be grouted in place and was selected to provide one extreme for grouting specimens. Figure 18 shows the efficiency in which the device maintained temperature gradients across the specimen. Figures 19 and 20 show the time needed for the specimens to reach equilibrium as well as the stability of the renovated PURWheel. Figure 21 shows the temperature uniformity within the test specimens. The only parameter not in full compliance was the test temperature, which was addressed later in the calibration.

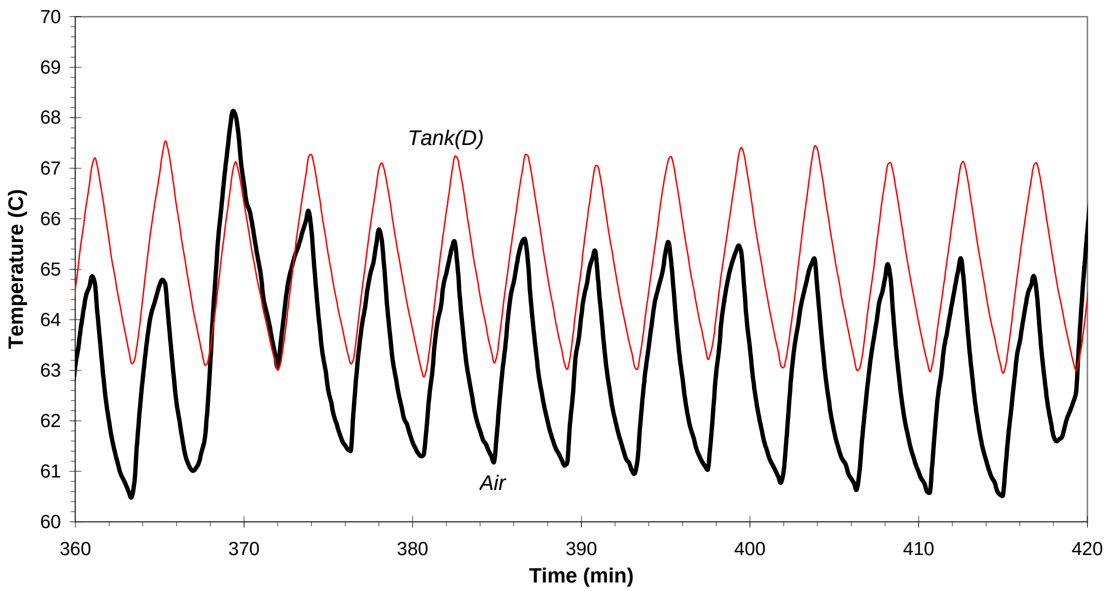


Figure 18. Comparison of Temperature Gradients in Calibrated PURWheel

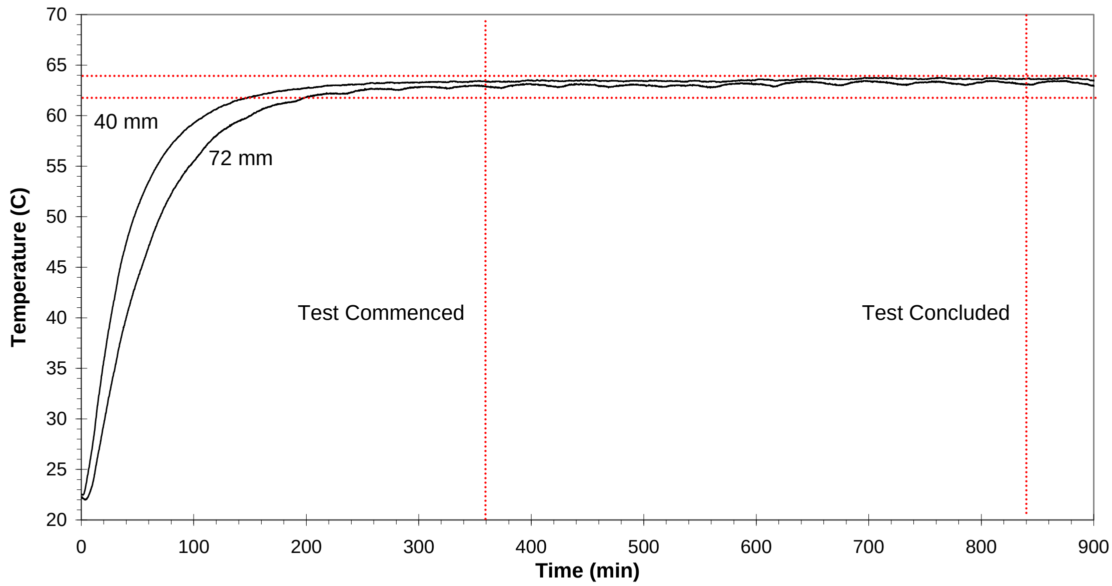


Figure 19. Temperature Conditions Within Slabs: Calibration *Run 2*-Full View

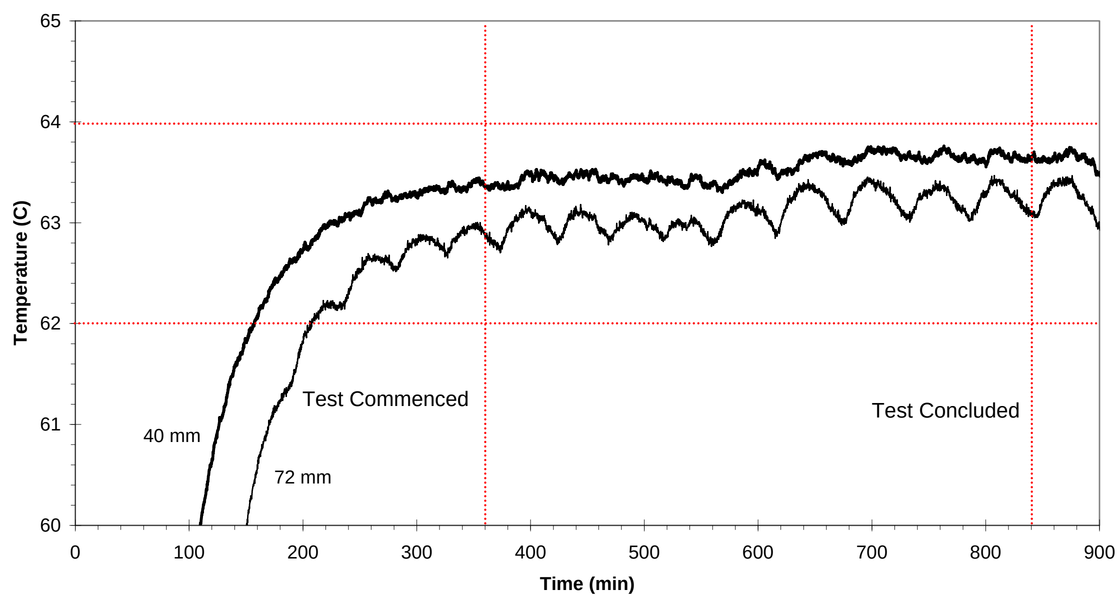


Figure 20. Temperature Conditions Within Slabs: Calibration *Run 2*-Truncated View

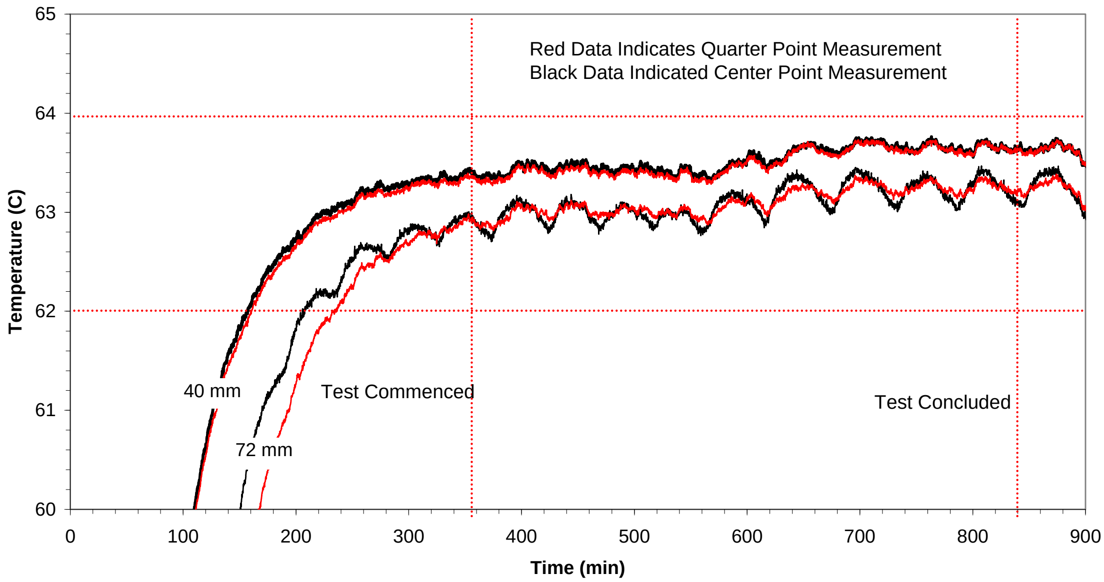


Figure 21. Temperature in Center and Quarter Points of Slabs: Calibration *Run 2*

Calibration *Run 3* had the 72 mm slab in the right track and the 40 mm slab in the left track. All other parameters were the same as *Run 2*. The same behaviors shown in Figures 18 and 21 occurred and have not been shown for brevity. Figures 22 and 23 are under the same conditions as Figures 19 and 20 with exception of the track where the specimens were placed. As seen, the right track heated the specimen on the order of 1 C higher than the left track, which is an acceptable tolerance. An additional behavior investigated in *Run 3* was time to cool specimens once removed from the device and placed under a fan; 4 hr was found to be sufficient.

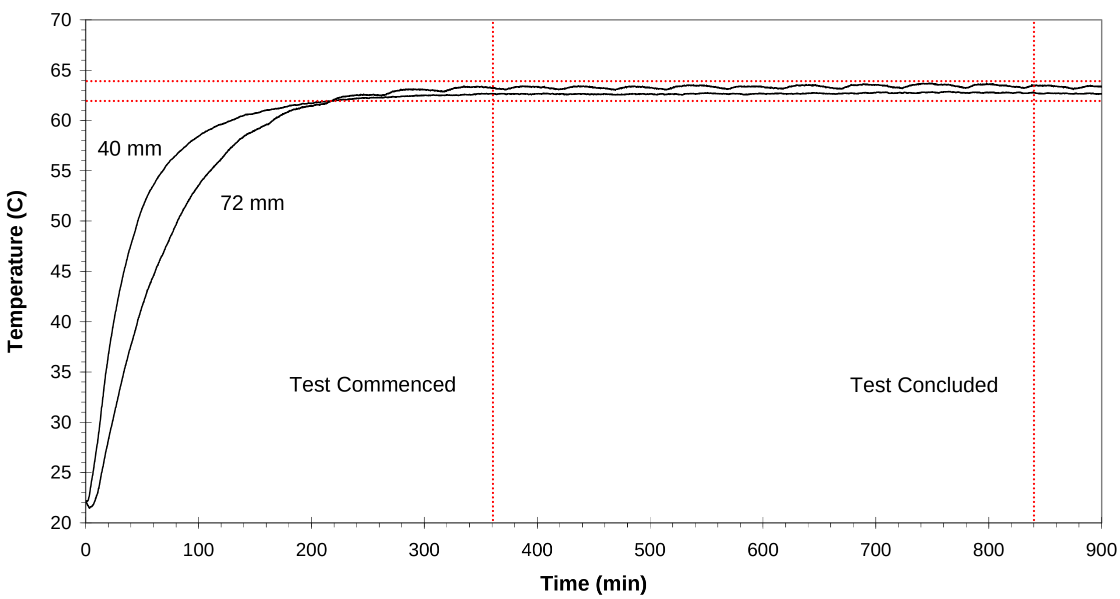


Figure 22. Temperature Conditions Within Slabs: Calibration *Run 3*-Full View

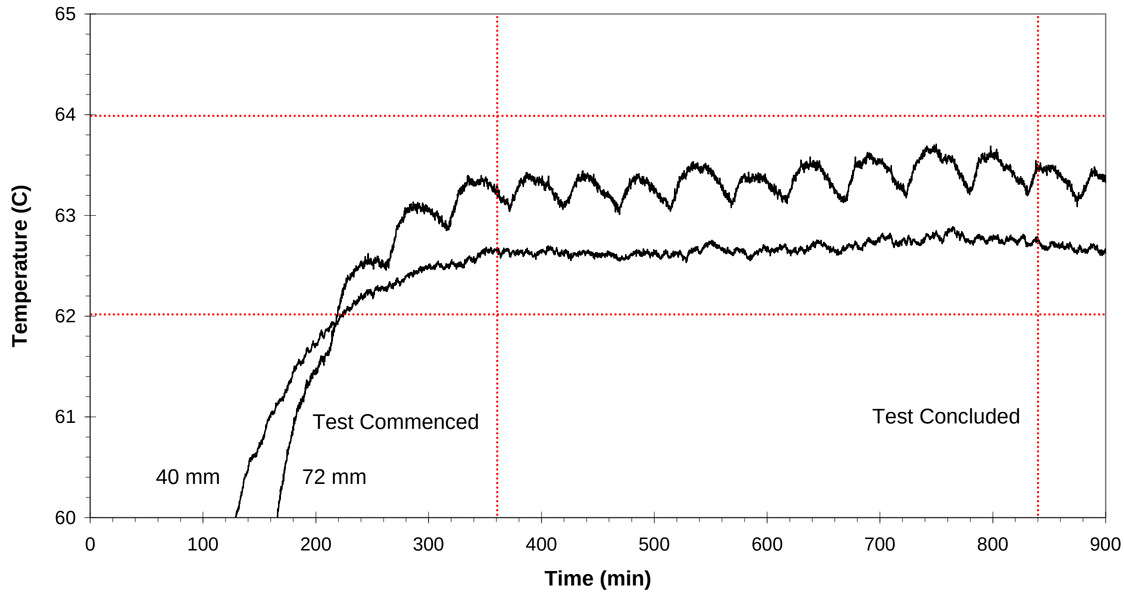


Figure 23. Temperature Conditions Within Slabs: Calibration *Run 3*-Truncated View

Calibration *Run 4* tested the ability of the molds to heat specimens with the hood open. The PURWheel was heated overnight with the hood closed and the instrumented specimens outside the hood. The hood was opened for one hour and then the specimens were placed in the molds while the hood remained open for the next six hours. After six hours of heating with the hood open, the hood was closed and readings were taken for 24 additional hours. During the test bead thermocouples were taped to the specimens surface to provide a direct surface temperature measurement (tape completely covered the thermocouples). Figure 24 provides evidence that the temperature gradient in the slabs from the surface to the center in the renovated equipment is practically non-existent and that the functionality of the system is acceptable. The 72 mm slab was similar and not shown for brevity.

The 40 mm slab heated to 41 C in the first 360 min of calibration *Run 4*, while the 72 mm slab heated to 48 C under the same conditions. Once the hood was closed, both the 40 mm and 72 mm specimens were at an acceptable temperature (test would commence at 720 min as shown in Figure 24), indicating the time the hood is open while specimens are prepared is not significant as long as the water circulation system and the molds are properly heated and remain on the entire time. This data also indicates that a protocol with a 360 min wait after achieving temperature in the device is of no concern for any conditions.

Calibration *Run 5* was conducted with all parameters as they would be during an actual test including the re-furbished water circulation system and thermocouples covering the metal tubes. The setting for heating the *Res* water was increased to meet the 64 $\pm$ 1 C temperature requirement. Specimens were placed in the heated device and test results can be seen in Figures 25 through 27. Figure 25 and Figure 26 show the system and corresponding settings are acceptable and that the renovated system is very stable in terms of temperature. Figure 26 shows the test specimens are in a uniform temperature environment where temperature gradients within the specimen are practically non-existent (a behavior not fully quantifiable based on review of previous PURWheel literature).

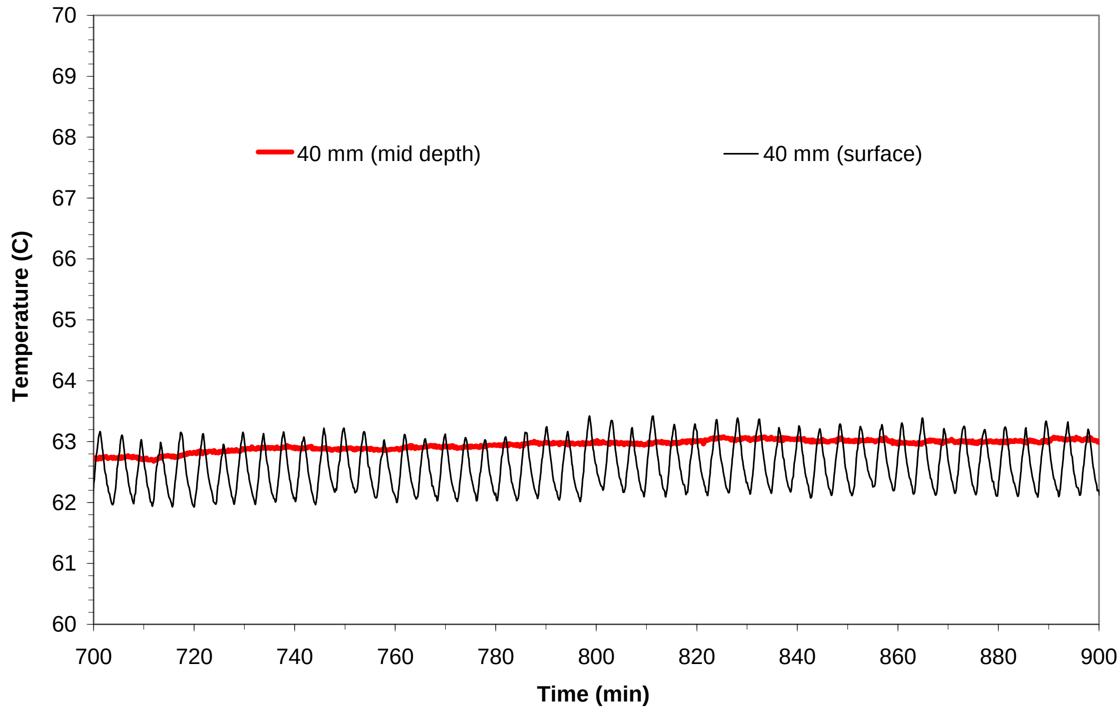


Figure 24. Temperature Properties Within 40 mm Slab: Calibration *Run 4*

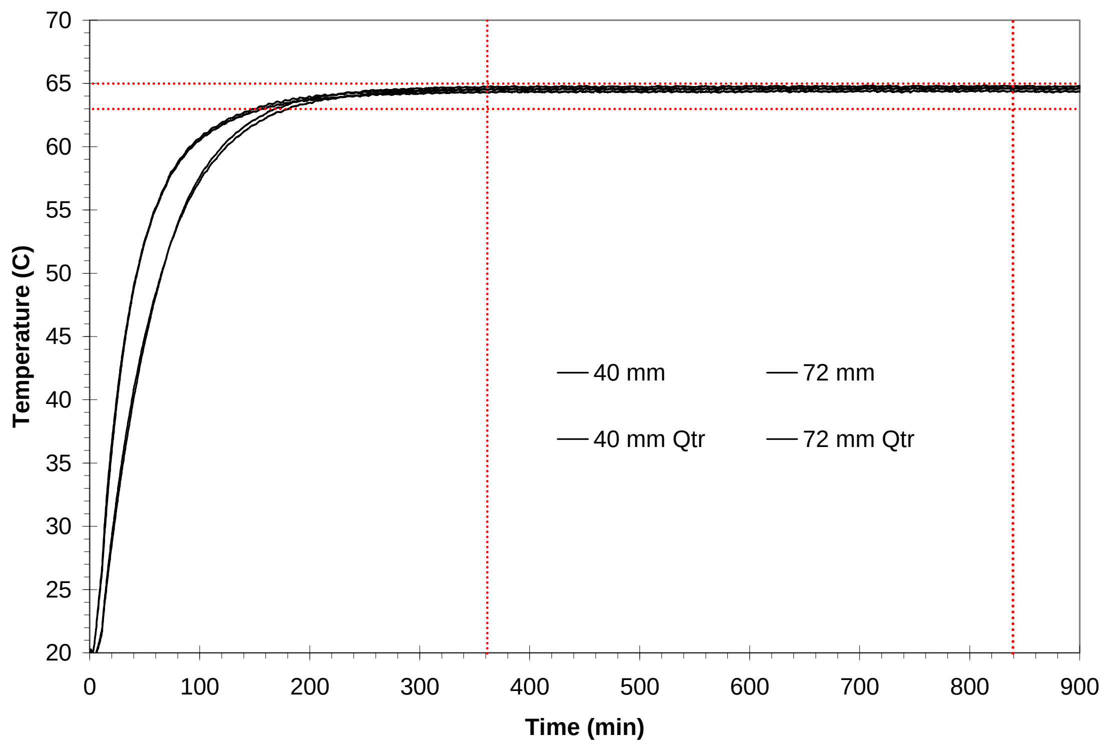


Figure 25. Temperature Conditions Within Slabs: Calibration *Run 5*-Full View

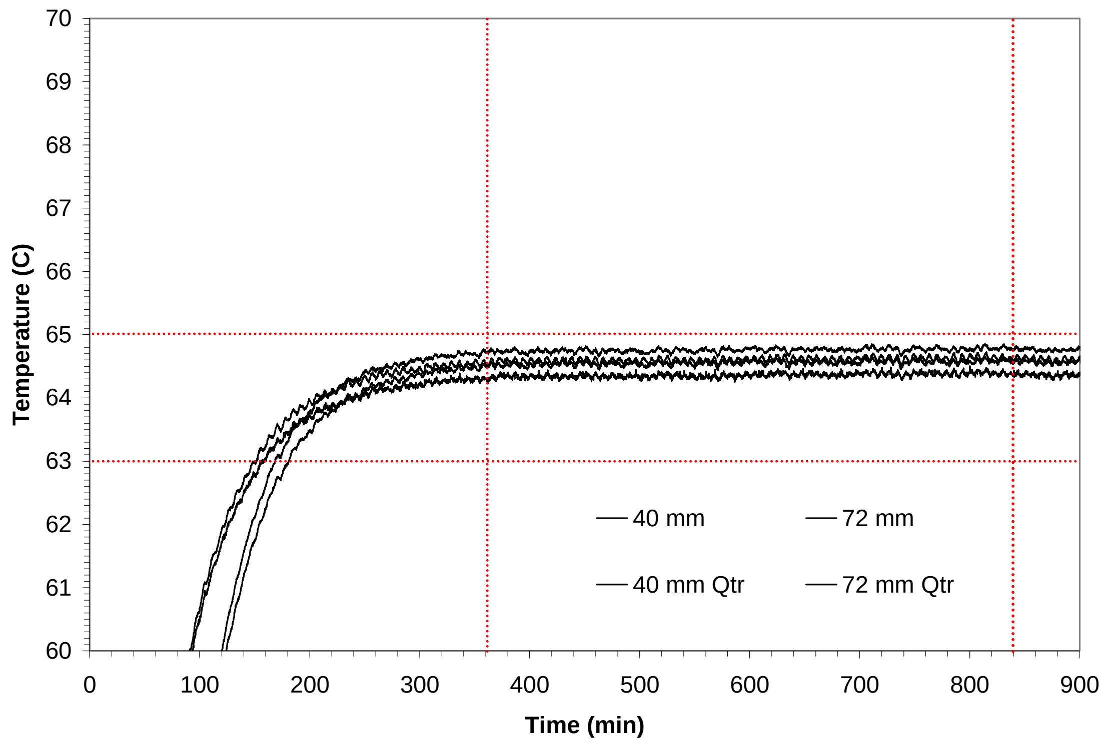


Figure 26. Temperature Conditions Within Slabs: Calibration *Run 5*-Truncated View

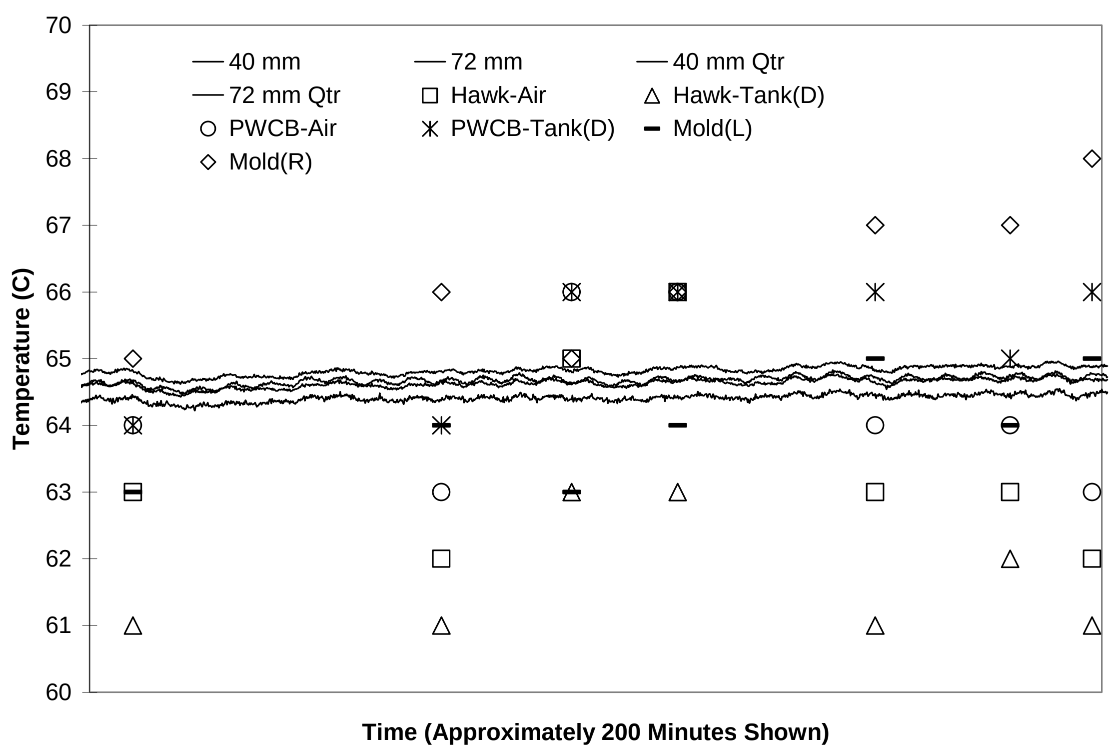


Figure 27. Measurement of All Temperature Conditions-Calibration *Run 5*

Specific take aways from temperature calibration are as follows. First, conditioning of specimens after fully grouted, the hood closed, and the equipment to temperature should be performed for six hours (360 min) to ensure temperature uniformity. Second, the *Air* temperature settings should be 63 to 65 C on the *Hawk* software, which prompts the system to either commence or cease heating when temperature is measured at either 62 or 66 C. Third, the *Res* heater control is to be aligned with the red mark made on the PURWheel to provide proper circulation fluid temperatures.

Secondary take aways from temperature calibration are as follows. First, *Hawk-Tank(D)* measurements are believed to be 2 to 4 C lower than actual temperatures. This behavior is not perceived to be problematic or to affect test results, so attempts to alleviate the difference were not made. Second, *Mold(R)* measurements are believed to be a few degrees Celsius higher than actual measurements. As with *Hawk-Tank(D)* measurements this behavior is not perceived to be problematic or to affect test behaviors. In the event these behaviors do become problematic in the future, they will be addressed at that time.

A verification of tank temperatures with water present (*Tank(W)*) was performed before wet testing commenced; the data is presented in Figure 28. Two thermocouples were submerged in the tank and monitored to determine the accuracy and uniformity of the tank temperature. One was located at the center of the tank suspended midway between the surface and the bottom near the tank temperature measurement thermocouples. The second was located on the right hand side of the tank and rested near the bottom of the tank. The temperature of the water entering the tank was 52 C; once the tank was full, the hood was closed and heating commenced. Tank water temperature reached 64 C approximately 60 minutes after heating commenced and had completely stabilized at 64 C after 90 minutes had elapsed. Similar to temperature measurements taken dry; the *Hawk-Tank(W)* measurements were approximately 2 C less than the actual temperature. *PWCB-Tank(W)* temperature measurements were approximately 2 C higher than actual.

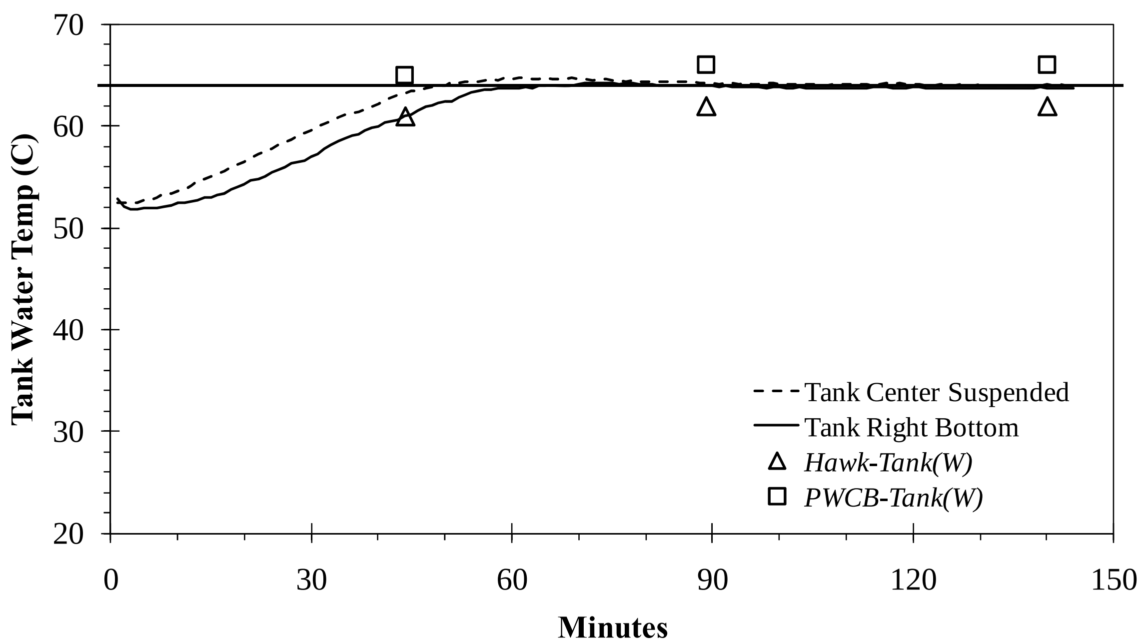


Figure 28. Verification of Tank Temperature for Wet Test

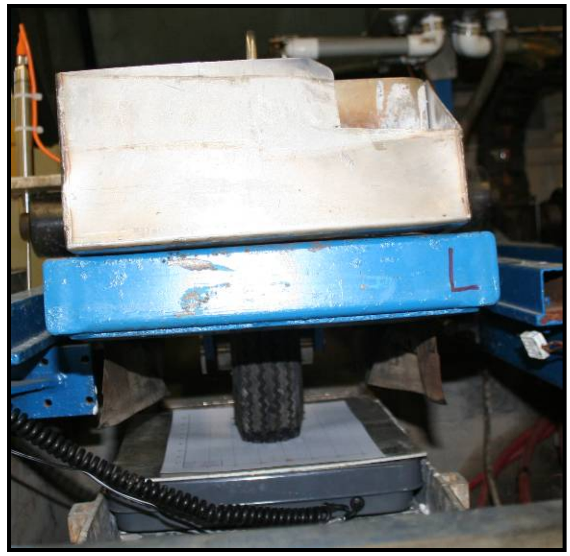
Contact Pressure Calibration

Calibration of the tire pressure and load was conducted to estimate the gross (including treads and area between treads) contact pressure exerted on the surface of the specimen. New tires and inner tubes were installed before contact pressure calibration. All data for calibration was collected with the system at room temperature. Tire pressure was measured with wheels unloaded and not in contact with the specimen; measurements were made with a digital pressure gauge (7 kPa measurement increments). Applied load was measured by placing a portable scale (0.2 kg measurement increments) in the position and to the same approximate height as a specimen; a thin aluminum plate was used to evenly distribute the load across the scale surface (Figure 29*a*). An ink pad was used to thoroughly coat the surface of the tire. A measurement template (printed to true-scale on card stock) was placed on the scale, the carriage was lowered and the load mass was carefully placed on the carriage (Figure 29*b*). Figure 29*c* shows the completed contact area print after the carriage had been raised.

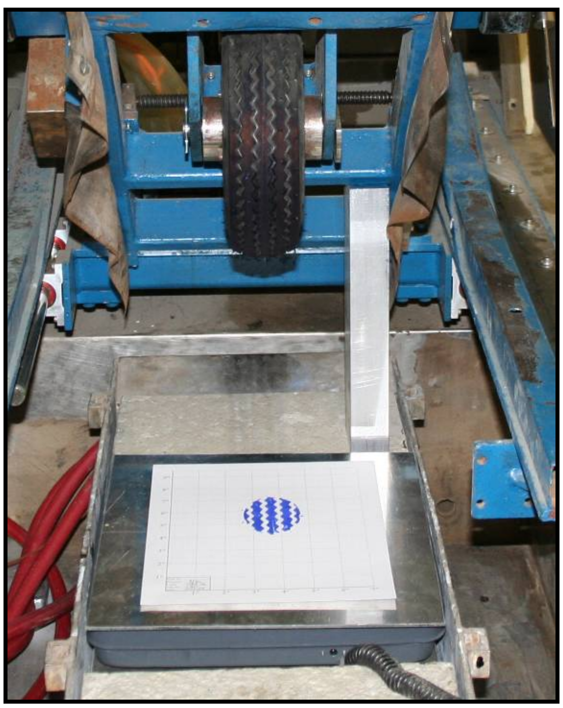
The contact area prints were scanned, imported to AutoCAD, and scaled to true dimensions. An ellipse was found to closely match the perimeter of the gross contact area. Ellipses were drawn for each print and their areas calculated. A final contact area print showing the overlain ellipse representing its area is seen in Figure 29*d*. Contact pressure was calculated as load measured under the tire by the scale divided by the gross contact area. Plots of the contact pressure data are seen in Figure 30 for the left and right tires; the contact pressure for the right tire is less than for the left but the difference is small. The load masses were adjusted to produce approximately the same measured load under the tire; the average measured load for the contact pressure calibrations was 178.6 kg (*st.dev.* = 0.4, n = 11).

PURWheel contact pressure calibration values are shown in Table 2 based on the data in Figure 30. The maximum recommended tire inflation pressure of 862 kPa (125 psi) combined with an applied load of 178.6 kg results in a gross contact pressure on the order of 630 kPa (91 psi). Gross contact area is approximately 2800 mm^2. The difference in contact pressure between left and right was slight therefore a decision was made to use the same parameters for both the left and right tires.

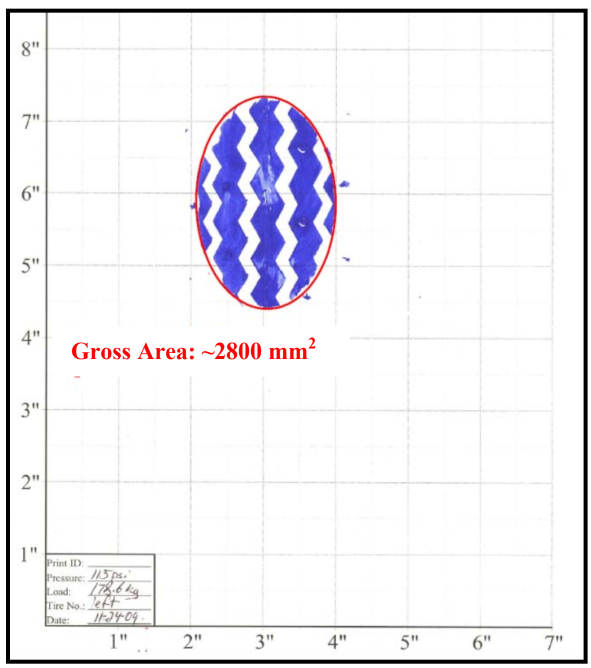
a) Contact Pressure Calibration Layout



b) Contact Area Print Process



c) Layout with Completed Print



d) Final Print with Ellipse Overlay

Figure 29. PURWheel Contact Pressure Measurement Procedure

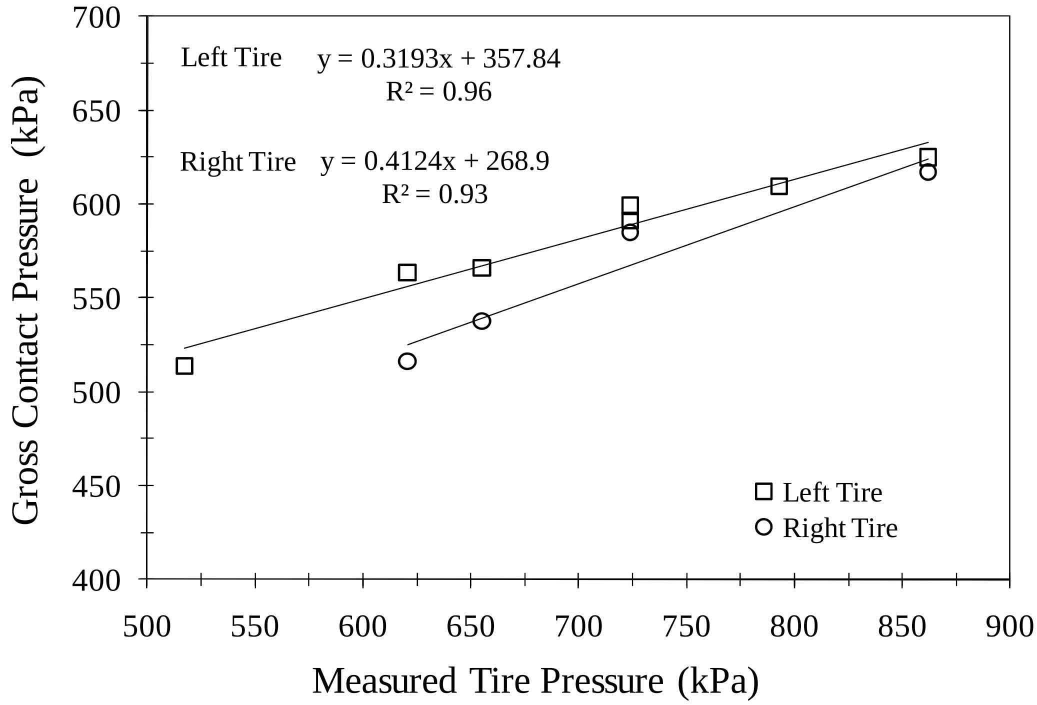
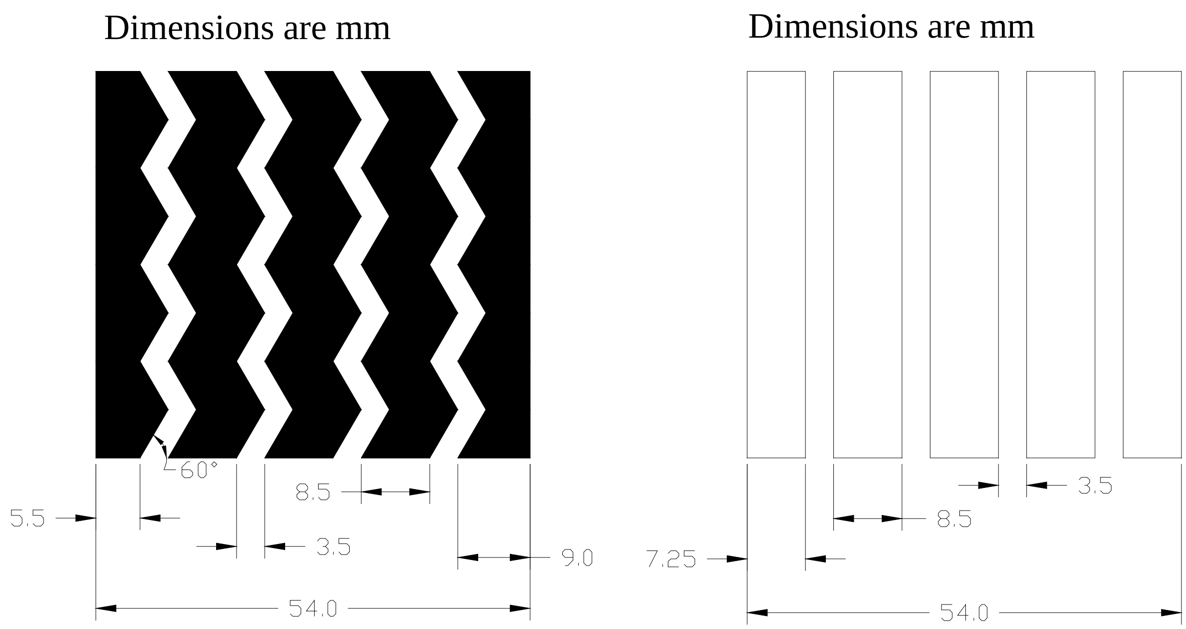


Figure 30. PURWheel Contact Pressure Calibration

Table 2. Summary of PURWheel Gross Contact Pressure Calibration

Measured Tire Pressure	Calculated Gross Contact Pressure	
kPa (psi)	Left Tire	Right Tire
621 (90)	556 (81.6)	525 (76.1)
655 (95)	567 (82.2)	539 (78.2)
690 (100)	578 (83.8)	553 (80.2)
724 (105)	589 (85.4)	567 (82.3)
758 (110)	600 (87.0)	582 (84.4)
793 (115)	611 (88.6)	596 (86.4)
827 (120)	622 (90.2)	610 (88.5)
862 (125)	633 (91.8)	624 (90.5)

A detailed diagram of footprint dimensions for PURWheel tires is shown in Figure 31*a*. Net contact area is the area of only treads and does not include the gaps in between. For any section of tire footprint of arbitrary length, the ratio of net contact area to gross contact area is calculated to be approximately 0.74. An idealized net contact area is shown in Figure 31*b* consisting of rectangles to represent the individual treads. For the recommended tire inflation pressure, the estimated net contact pressure for the PURWheel is 850 kPa (123 psi) (630 ⁄ 0.74 = 850). This is near the tire inflation pressure of 862 kPa (125 psi).



a) PURWheel Tread Detail *b) Rectangular Representation of Tread*

Figure 31. PURWheel Tread Detail

Wheel Speed Calibration

A cycle is defined as complete travel of the cylinder including extension and retraction strokes and a pass is defined as one coverage of the wheel over the specimen (a pass is either a single extension stroke or a single retraction stroke). The *Hawk* software displays a running count of the number of passes completed during the test in multiples of two. A direct measurement of wheel velocity cannot be made with software due to the mechanism in which direction of the cylinder is reversed. Input voltages are given in software that initiate the command for the cylinder to reverse direction. It takes some short period of time for the command to actually stop the cylinder and send it in the opposite direction. The actual distance traveled on each stroke varies which is reflected in the test time but has no effect on the speed with which the wheel travels over the specimen.

Calibration of wheel speed was performed by placing cardboard next to the track where the LVDT's travel during normal testing. Marks were made on the cardboard at the beginning and ending stroke locations of the LVDT periodically over an interval of one-hundred passes (fifty cycles) to define the average and range of stroke lengths. A stopwatch was used while watching the software's pass counter to time the same fifty cycles of each carriage. The average stroke distance divided by the average stroke time was recorded as the average speed of the wheel. Calibration was performed on grouted in place untested specimens with the system at room temperature, both wheels operating and the test parameters of tire pressure and load to simulate actual test conditions. The air regulator located at the back of the PURWheel is set to approximately 415 kPa (60 psi) to ensure that a consistent system pressure can be maintained. To reduce the speed of a wheel, the inline air valve for the corresponding air cylinder located nearest to the PURWheel test chamber is closed (turn knob clockwise). To increase speed of the wheel, the same valve is opened.

The required speed of the wheel is 33 $\pm$ 2 cm/sec (0.74 ± 0.05 mph). The software voltage set points should be adjusted to yield an average stroke length adequate to ensure the wheel travels completely off the specimen before reversing direction. Median stroke length of the left wheel was determined to be 449 mm and median stroke length of the right wheel was determined to be 437 mm. The average speeds of the left and right wheels were calculated to be 32.8 cm/sec for the left wheel and 32.6 cm/sec for the right wheel during initial calibration.

Rut Measurement Calibration

Calibration of rut measurement was performed with the system at room temperature and with the correct tire pressures and masses in the load carriages on freshly installed, un-rutted specimens. Rut measurement calibration was performed as follows. The air supply was turned off and pressure was relieved from the air system. The wheel carriages were manually extended until the wheel was in the center of the specimen (LVDTs were aligned with the black marks on outside of rails). On the **Test Setup** tab within the *Hawk* software both the left and right rut measurements were set to zero (refer to the section of this report concerning software for an overview of the control system).

With the wheels still extended, the LVDT signals were then calibrated within the *Hawk* software. Within the *Hawk* software **Edit** then **Analog** was selected; in the signal calibration dialog, the arrow buttons were used to toggle through the input signal until "left rut" was selected. The left LVDT rod was lifted and a 20.3 mm gauge block placed underneath. The signal was given a few seconds to stabilize before **Calibrate** was clicked within the software and the correct displacement value was input (20.3, the height of the calibrated gauge block). The same procedure was repeated for the right LVDT signal. A 10.1 mm gauge block was used to check the calibration.

Pan (1997) developed a correlation between rut deformation data collected by the PURWheel and total rut depth as measured by manual methods. The correlation is given in Equation 1; its R^2 was reported as 96% based on over forty measurements.

$$R_M = 0.0153(R_T)^2 + 1.3R_T \qquad \text{(Equation 1)}$$

R_T is the rut depth measured by LVDT and recorded by PURWheel software and R_M is the total rut depth measured manually; the units of both variables are mm. This correlation has been found to still be applicable to the current software and data collection techniques. However the comparison between manual and adjusted electronic data has been found to be less accurate for specimens that exhibit rapid changes in deformation and large total rut magnitudes (i.e. wet tests that exhibit significant stripping). The PURWheel data as recorded is exported from the software and the adjustment is applied during the post-processing stage.

Test Parameters

This section summarizes the available literature concerning test parameters as the PURWheel was originally designed and operated as well as describes the test parameters currently utilized in the renovated machine. The original machine and test procedure allowed for parameters of specimen thickness and test temperature to be adjusted. While the equipment was being refurbished, the decision was made to focus on one test temperature and two nominal specimen thicknesses. The capability for other specimen thicknesses and test temperatures may be developed at a future date with minimal calibration effort and test fixtures.

Previous Test Parameters

Pan and White (1999) indicated typical specimens were 29 cm wide, 31 cm long, and had 6 to 8% air voids. The authors also indicated that 38, 51, and 76 mm were typical slab thicknesses for surface, binder, and base layers, respectively. PURWheel specimens are larger than Hamburg specimens; on the order of twice as large. Stiady et al. (2003) recommended slab thicknesses of 38, 51, 76, 102, and 127 mm for nominal maximum aggregate sizes of 9.5, 12.5, 19, 25, and 37.5 mm, respectively. Wang (2000) indicated a maximum PURWheel slab thickness of 102 mm.

Typical test temperatures ranged from 55 to 60 C with an upper range of 65 C in previous testing (Pan and White 1999). For Indiana conditions, test temperatures were 60 C for surface mixes, 57.5 C for binder mixes, and 54 C for base mixes. Stiady et al. (2003) stated test temperatures from 25 to 65 C with a $\pm$ 1 C precision. Based on the data collected on the re-furbished device, the original temperature precision stated is questionable. Habermann (1994) recommended the test temperature be based on the binder grade, or field test temperatures.

Heating of specimens prior to testing was not clearly definable based on review of Purdue University literature. Pan and White (1999) reported conditioning of specimens for 20 minutes in a wet test and 60 minutes in a dry test after reaching the target test temperature with no indication of how long a specimen required to reach the target test temperature. Habermann (1994) indicated a 20 minute specimen conditioning time was taken from previous German works but was noted not to be necessarily correct. Stiady et al. (2003) indicated the specimen was placed in the mold and then the heating system was turned on.

Stiady (2000) indicated that as the tire pressures increase, contact area decreases due to stiffening of the tire in typical conditions. It was also stated that the PURWheel tire stiffens to a point and then begins to balloon with added pressure which increases the contact area. Tire pressure calibration resulted in 2,394 mm^2 gross contact area as a result of a 175 kg mass in the carriage that produced a vertical force of 152 kg measured with a bench scale. Using the gross contact area resulted in a gross contact pressure of 620 kPa. When only the treads were considered in the calculation, the actual contact area was 1,800 mm^2, which resulted in an actual contact pressure of 825 kPa. Pan and White (1999), Wang (2000), and Stiady et al. (2003) reported that a 175 kg mass in a wheel carriage coupled with a tire inflation pressure on the order of 793 kPa resulted in a contact pressure on the order of 620 kPa. Habermann (1994) noted that contact pressure changed during loading and that the reported values were those prior to testing.

Wang (2000) indicated wheel velocity could be set between 20 to 40 cm/sec. Pan and White (1999) and Stiady et al. (2003) indicated a wheel velocity of 33 $\pm$ 2 cm/sec. These sources also reported a test termination criteria of either 20,000 passes or a 20 mm rut depth. Stiady et al. (2003) indicated a wet test was to be conducted with a water depth of 25 mm above the specimen. According to Pan and White (1999) data collection in the original

PURWheel consisted of acquiring 9 points near the middle of the specimen with a 10 mm spacing between each and that data was collected once every 250 passes.

<u>Current Test Parameters</u>

Specimens as tested in the PURWheel are roughly 29 cm wide and 31 cm long. Two thicknesses of pavement specimens were selected and test fixtures fabricated: 1) *thin* 38 ± 6 mm (1.5 ± 0.25 in), and 2) *thick* 76 ± 6 mm (3.0 ± 0.25 in). One target test temperature was selected; 64 ± 1 C. Once the test chamber reaches a specified threshold temperature, a delay timer is activated within the *Hawk* software to allow for specimen conditioning and for specimen thermal equilibrium to occur. The delay timer is set for 360 min at the conclusion of which specimen tracking begins. The same delay period is used for both the wet and dry tests; however the period of pre-heating required to reach the threshold temperature is slightly longer for the dry test than for the wet test.

Wheel speed parameters are the same as previous work, 33 ± 2 cm/sec. The gross contact pressure at the beginning of the test is approximately 630 kPa (91 psi) with a gross contact area of approximately 2800 mm^2. This is obtained with a tire inflation pressure of 862 ± 7 kPa (125 ± 1 psi) and a load measured under the tire at surface of the specimen of 178.6 ± 1.0 kg. The resulting net contact pressure is approximately 850 kPa (123 psi).

A pass is defined as the wheel traversing over the specimen one time due to the air cylinder extending or retracting. A stroke is the equivalent of a pass. A cycle is one extend pass and one retract pass for a total of two passes. Rut depth measurements are collected by the *Hawk* software during each retract pass over the specimen. The rut depth is measured from the original surface. Measurements are collected at carriage positions roughly corresponding to the central 200 mm (8 inch) of the specimen to minimize edge effects on rut depth measurements. Typically on the order of 20 rut measurements are collected per pass evenly spaced over 200 mm. The measurements are averaged by the *Hawk* software and reported as the rut depth for every even numbered pass. A continuously updated average of rut depth for the prior 5 retract passes is kept by the *Hawk* software and used to determine termination criteria. A test is terminated prior to 20,000 passes if the average rut depth of the prior 5 passes exceeds the termination criteria. Manual measurements of both transverse and longitudinal (wheel path) specimen deformation are also recorded.

Software

The original software used for controlling the PURWheel was written in a *C* programming environment. The software used in the renovation of the PURWheel was *The Hawk* (or *Hawk*) developed by *Innovative Broadcast Services* (*IBS*) in Starkville, MS. Provided *IBS* was not local to MSU, *LabView*™ would have been used in the renovation. The entire software environment was re-worked so no description of the process has been provided. This section contains an overview of the software; specific details needed to run a test are provided in the appropriate section. To run the *Hawk* software, click the M-State icon on the desktop labeled *Shortcut to PURWheel*.

Figure 32 shows the initial front screen of the *Hawk* software; the inputs shown are defaults for the current device and test protocols. The series of red lights in the second row from the top shows the status of various systems and circuits. The series of green buttons in the third row are used to send commands manually. A series of tabs on the fourth row are used to toggle between screens, each of which will be explained in turn. The ***Overall View*** tab shown in Figure 32 presents the current status and values of the important PURWheel systems. These include the current temperatures of *Hawk-Air*, *Hawk-Tank*, *Hawk-Mold(L)*, and *Hawk-Mold(R).* The current positions of each carriage as well as instantaneous and average rut depths are also shown. Settings for the air heat are also controlled from the ***Overall View*** tab; air heat control can be turned on or off manually with the green toggle located above the air heat upper and lower limit boxes. The ***Tab 1*** view is shown in Figure 33 and the ***Passes and Rut*** tab is shown in Figure 34; both give additional system status information. Note that the *Hawk* software will not receive data from the PURWheel unless a database has been selected and either ***Fill and Heat*** or ***Start*** has been clicked to initialize the software data collection.

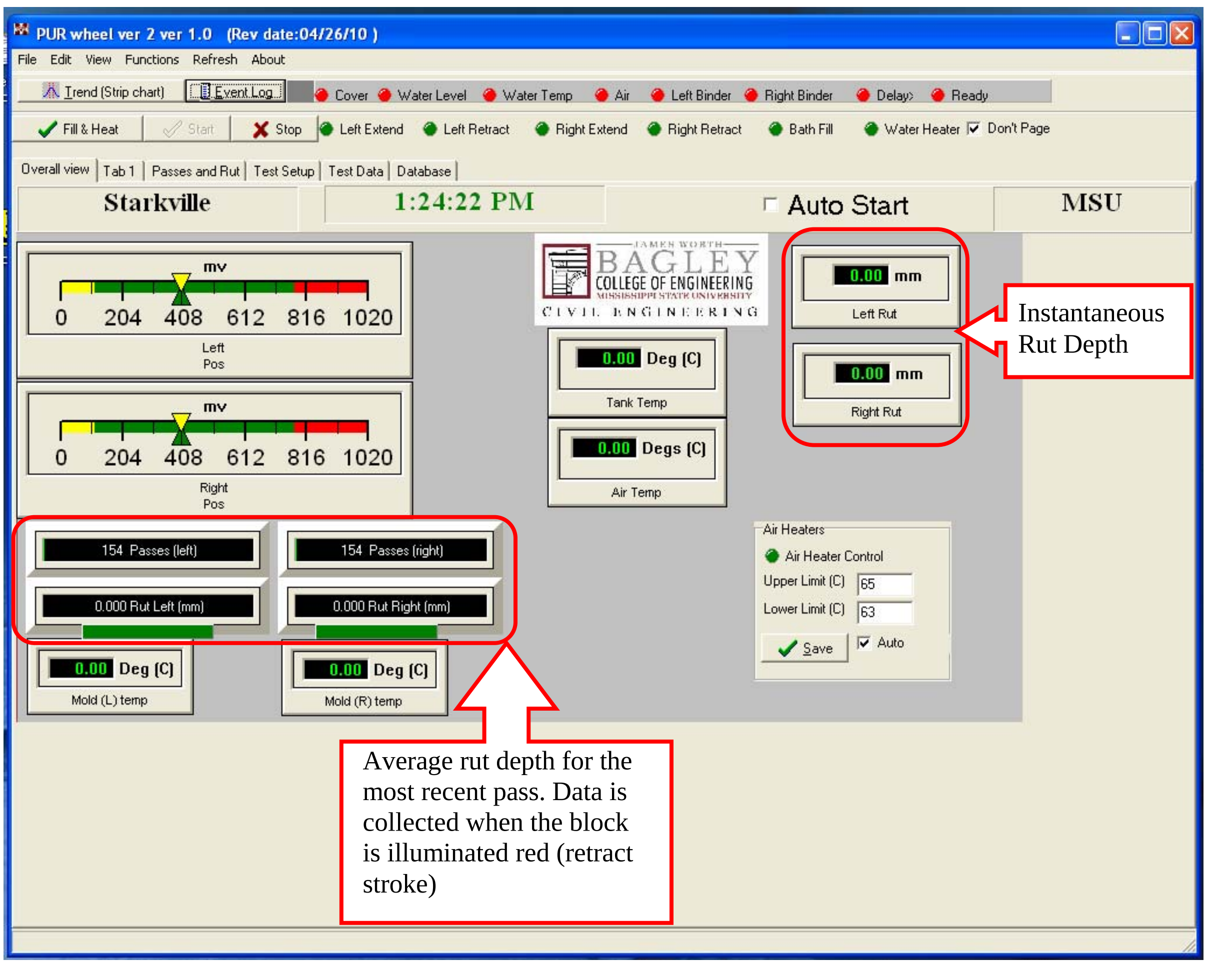


Figure 32. *Overall View* Tab in *Hawk* Software

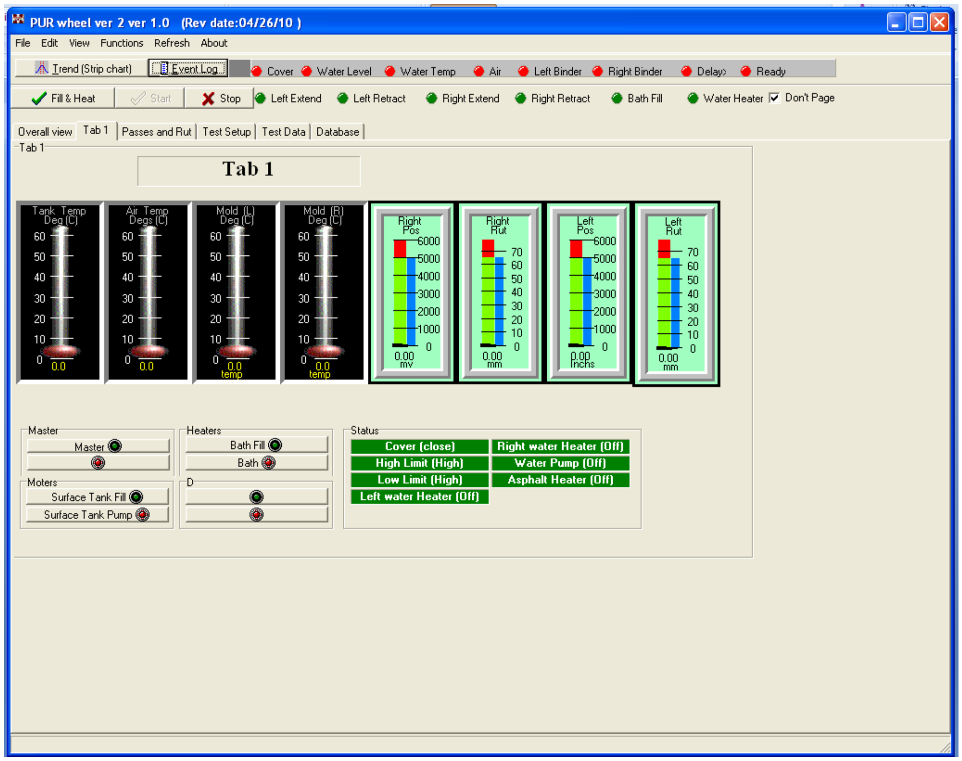


Figure 33. ***Tab 1*** **Tab in** ***Hawk*** **Software**

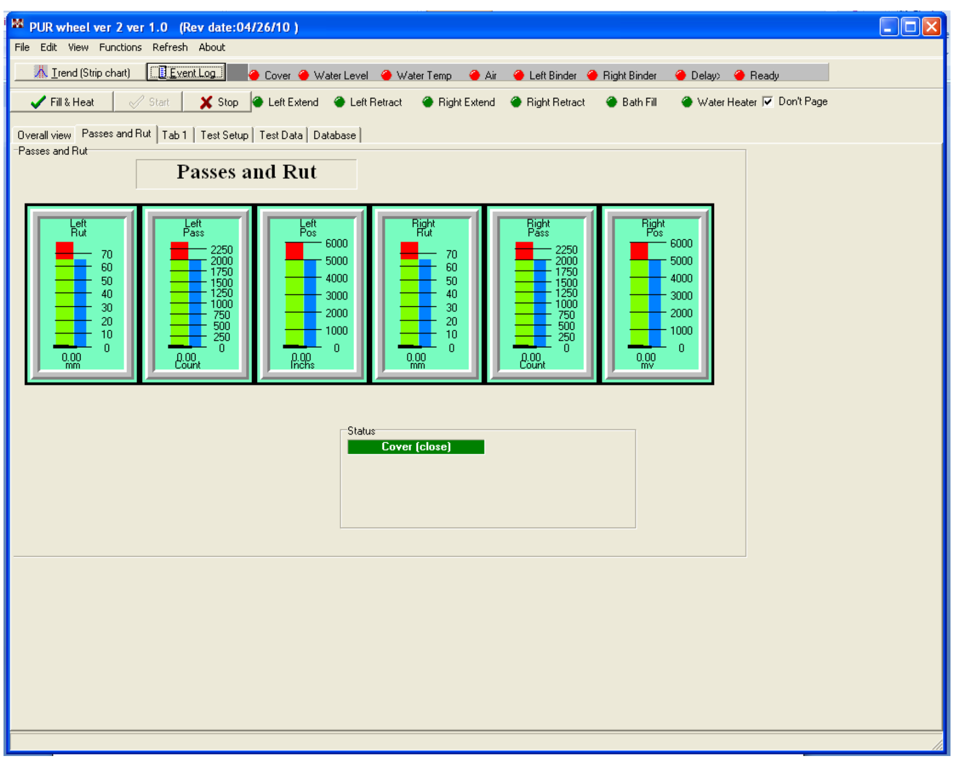


Figure 34. ***Passes and Rut*** **Tab in** ***Hawk*** **Software**

The ***Test Setup*** tab is shown in Figure 35 (current protocol configuration settings are shown); this is where changes are made to settings such as stroke length, rut measurement sampling locations, and calibration of zero rut. The stroke length settings and sampling location settings should not need to be adjusted under ordinary circumstances; the values shown in Figure 35 are the correct values for the current PURWheel equipment setup (June 2010). Zero rut calibration will need to be performed periodically or whenever the concrete blocks are reset (process is described in step 5 of the Test Setup section).

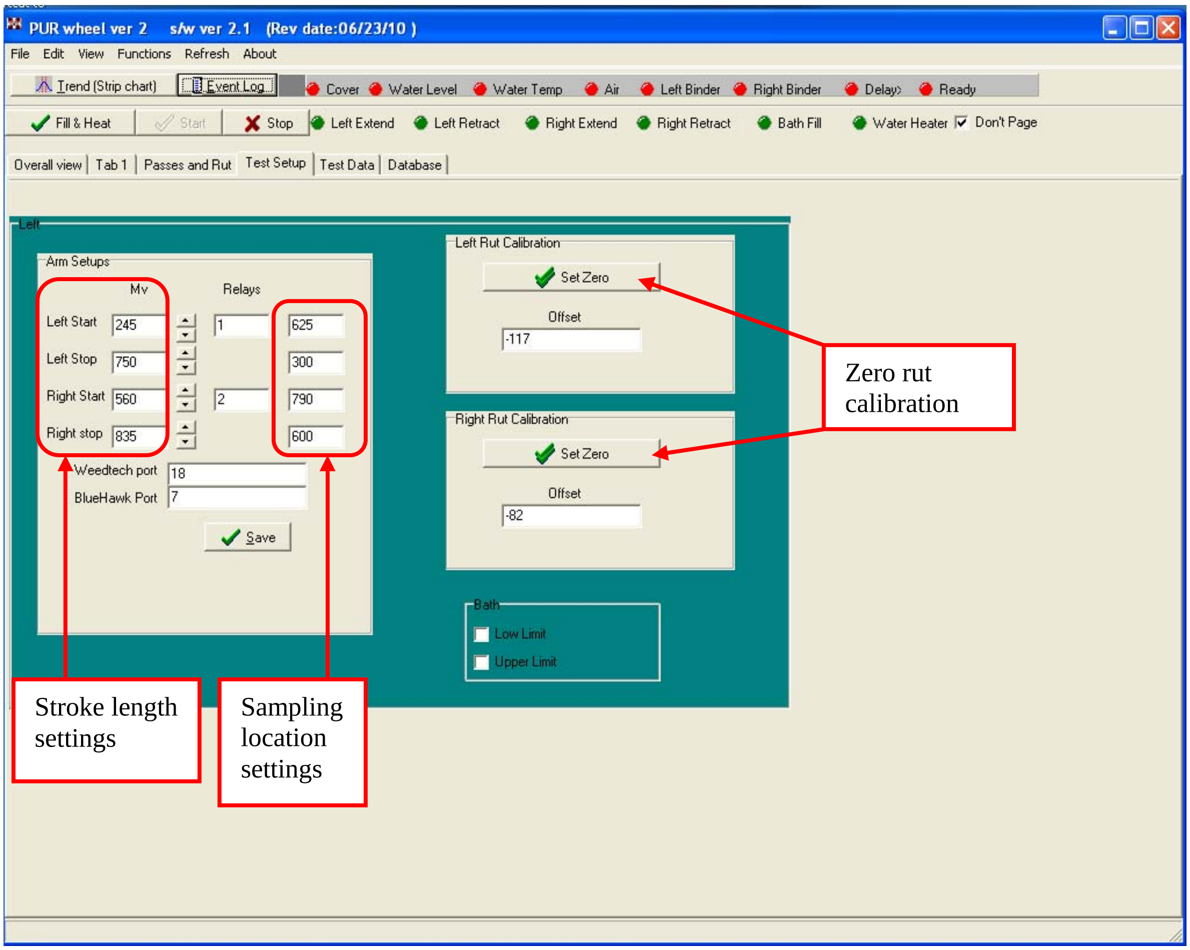


Figure 35. *Test Setup* Tab in *Hawk* Software

The ***Test Data*** tab is shown in Figure 36; this is where databases and specific settings for each PURWheel test are created or modified. A list of databases is seen on the right side of the ***Test Data*** tab screen; specific test settings for Test030 are seen to the left of the test database list. The settings shown are correct for a wet test; settings for a dry test are identical except for the selection of *Dry* as the test type from the drop down dialog. The Deformation criterion is set to 15 mm, once adjusted with Equation 1 this corresponds to a manually measured rut depth of 23 mm. If the electronically measured rut depth of a specimen reaches 15 mm before 20,000 passes, that side of the PURWheel test is completed, the carriage fully retracts and the other side continues to track until completion. Note that the parameters of Tire Pressure and Mass in Box are for information only and serve no purpose for execution of the test (values shown in Figure 36 are arbitrary default values and are not correct for the actual test parameters). The target temperatures for Mold, Air, and Tank are the threshold temperatures at which the specimen conditioning delay period is triggered once all three threshold criteria have been met.

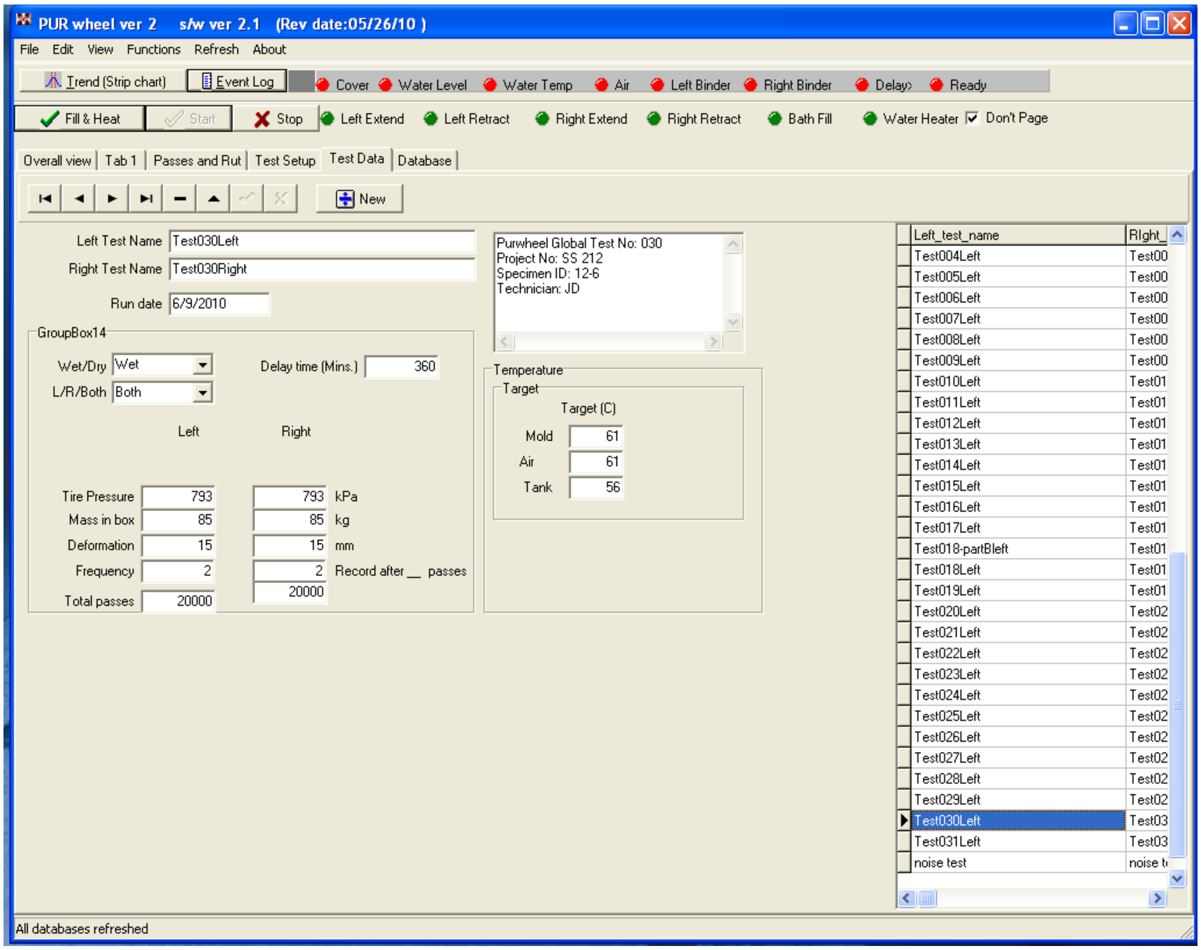


Figure 36. *Test Data* Tab in *Hawk* Software

The ***Database*** tab of the Hawk software shows the raw data contained in the currently selected database file and is not shown for brevity. Three sub-tab views show the data from the overall test, the right test, and the left test respectively. If desired the data contained in a database can be purged by clicking the appropriate button within the ***Database*** tab.

Operation

Safety

Prior to working inside the hood, the lever valve that controls air flow to the cylinders should be nearly but not completely closed. This allows the system to maintain adequate backpressure so that the carriages remain in the retracted position. If backpressure is not maintained, the carriages will slowly roll down from the full retract position as air pressure within the system equalizes. The default position of the wheel carriages is the retract position. There is a hood safety interlock located at the left back of the hood, the cylinders cannot be actuated unless the hood interlock button is depressed. If the cylinders were to attempt to extend for some reason, the air flow rate would be small and consequently the carriage speed would be slow.

Specimen Preparation, Placement and Removal

Laboratory or field specimens can be tested in the PURWheel. Field specimens only require sawing to appropriate test dimensions. Laboratory specimens are fabricated in the linear asphalt compactor (*LAC*), which is described in a complimentary manual *CMRC M 10-1* (Doyle and Howard 2010). Slab specimens from the *LAC* are sawn in half for testing in the PURWheel. The left half of the slab as compacted (nearest the hydraulic cylinder of the compactor) according to the terminology of the compactor is tested on the left side of the PURWheel and vice versa. The specimens are mounted in the PURWheel in the same manner in which they were compacted (i.e. the direction of travel of the compactor is parallel to the direction of wheel tracking and the top of the compacted slab is the top surface of the PURWheel specimen). The 29 cm width of the specimen is in the transverse direction, placing the 31 cm dimension in the longitudinal direction. The sawn edge (middle of original slab) is placed toward the back of the PURWheel.

Two categories of specimens are tested in the current version of the equipment: *thin* specimens (i.e. 32 to 44 mm thickness) and *thick* specimens (i.e. 70 to 82 mm thickness). Minor fixture adjustments would allow specimens 44 to 70 mm to be tested. The bottom of the mold containing the bead thermocouple is protected by a thin cover plate (< 2 mm thick). The mold depths with the cover plate in place are approximately 86 mm. To perform a test on a *thin* specimen, two additional full length aluminum spacer plates (one plate 25 mm thick and the other plate 12.5 mm thick) were utilized over the cover plate, making the depth of the mold 48.5 mm. Concrete reference blocks are installed at the front and back of the mold to provide level reference surfaces for test specimen placement. These reference blocks are typically installed once and used for testing of multiple specimens of that nominal thickness. Stability of the reference blocks is checked before specimens for the next test are placed and the reference block(s) are reset if any movement is present. The installation procedure for concrete reference blocks is described as follows.

Before the concrete reference blocks are installed, a piece of paper is placed at the back of the mold to prevent plaster from escaping the back of the mold (Figure 37*a*); the excess paper is removed once the back reference block is set. The back reference blocks are installed approximately 5 mm above the edge of the mold. Aluminum gauge blocks are used to align the reference blocks (Figure 37*d*). Aluminum spacer plates are used underneath the reference blocks to reduce the thickness of plaster needed. A ratio of 2.5 parts Plaster of Paris to 1 part water by volume is used beneath the reference blocks. The material should be mixed to a smooth consistency without lumps. The plaster is spread (Figure 37*b*) and the block is placed (Figure 37*c*); the plaster mixture takes approximately 2 minutes to set. The block is leveled with the top surface approximately 5 mm above the mold (Figure 37*d*). The front block is placed in the same manner as the back block using the long level to ensure both front and back reference blocks are at the same elevation (Figure 37*e*). The final product for *thick* specimen reference blocks is shown in Figure 37*f*.

a) Preparing Back of Mold

b) Spreading Plaster Mixture

c) Placing Back Block

d) Leveling Back Block

e) Leveling Front Block

f) Front and Back Reference Blocks Installed

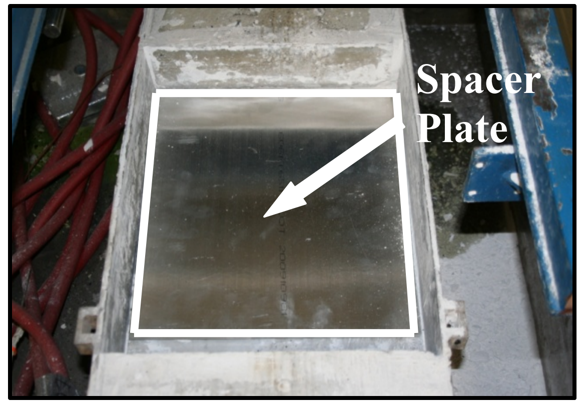
Figure 37. Installation of Reference Blocks

Once concrete reference blocks are in place, PURWheel specimens are installed according to the procedure described in the following paragraphs. For wet tests, only Plaster of Paris is used to install specimens. For dry tests, a grout mixture consisting of 5 parts clean dry sand and 3 parts Plaster of Paris can be used. This grout mixture is adequate to firmly hold specimens in place for dry testing and is easier to remove than 100% Plaster of Paris once a test is complete; however the grout mixture is less resistant to water and therefore is not to be used for wet tests. The Plaster of Paris and sand for the grout mixture is pre-mixed dry in bulk at the previously mentioned 5:3 ratio and then used the same way as the regular Plaster of Paris mixture.

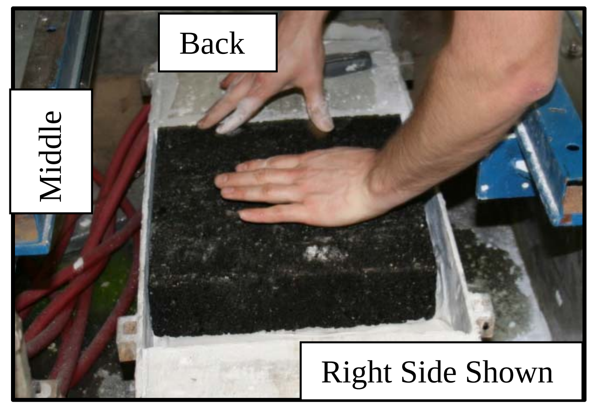
To perform a test on a *thick* specimen on the upper end of thickness for *thick* testing (i.e. 82 mm), specimens were placed directly on the cover plate with 4 mm of grout separating the two. To allow thinner specimens to be tested that did not interfere with the pre-grouted concrete blocks, partial length spacer plates 297 mm by 356 mm with thicknesses of 3.2 mm, 6.4 mm, 9.5 mm, and 12.7 mm were fabricated (Figure 38*b*). To test a 79 mm thick specimen (for example), a 3.2 mm partial length spacer plate was placed under the specimen. To determine if a partial length spacer plate is needed the specimen is placed in position and the approximate gap thickness is visually observed (Figure 38*a*). A small (2 to 6 mm) gap is required to allow an adequate thickness of bonding mixture beneath the specimen. A quantity of either Plaster of Paris bonding mixture (wet test) or grout bonding mixture (dry test) is prepared at a ratio of 2.5 parts mix to 1 part water on a volume basis. Use of a 300 mL beaker for volume measurement of constituents has been found to produce a convenient quantity of prepared bonding mixture. The water and mix is thoroughly blended until a smooth consistency is obtained (a wire kitchen whisk is recommended).

The bonding mixture is spread uniformly over the bottom surface where the specimen will be placed (Figure 38*c*). The specimen is oriented such that the vertical cut face is facing the back reference block (Figure 38*d*). The specimen is placed as closely as possible to the back reference block while the cut face remains parallel to the back reference block (Figure 38*d*). The specimen is also placed nearer the middle of the PURWheel such that the majority of the side to side gap is located on the outside (either left or right depending on which specimen is being installed) of the PURWheel to facilitate removal once the test is complete (Figure 38*d* and Figure 38*e*). The level of the specimen is checked (Figure 38*e*) as well as the vertical alignment (Figure 38*f*). The goal is for the central portion of the top surface of the specimen (where the wheel will travel) to be as level as possible and aligned with the reference blocks on either end (alignment with the back reference block is more significant than alignment with the front reference block). A rubber mallet can be used to seat the specimens if necessary. It is preferred that extra bonding mixture is placed beneath the specimens so that they are slightly higher than final location and the specimen be gently pressed down until the final vertical alignment is reached. This ensures that a good bond is created beneath the specimen.

Once the specimen is in place an aluminum spacer block is placed in the void between the specimen and the front reference block, leveled, and aligned vertically in the same manner as the specimen (Figure 39*a*). The spacer block is placed using the same bonding mixture as was used for the specimen. The spacer block is placed as closely as possible to the specimen. The spacer block is shorter than the mold is wide; the block is aligned with the majority of the empty space near the outside of the PURWheel to facilitate removal after the test is complete (Figure 39*b*).



a) Dry Check of Specimen Height Alignment *b) Partial Length Spacer Plate*



c) Spreading Plaster of Paris Mixture *d) Installation of Specimen*

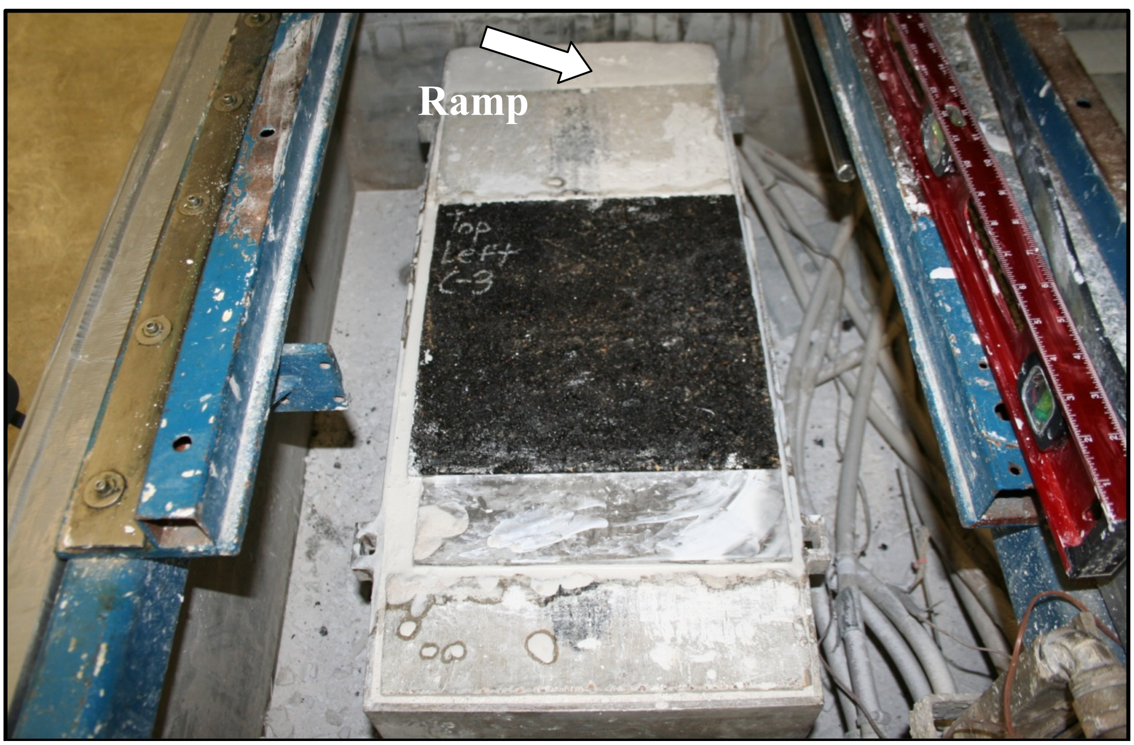
e) Leveling of Specimen *f) Checking Specimen Vertical Alignment*

Figure 38. Placement of Specimens

Large and medium gaps around the specimen and spacer block are filled with the appropriate bonding mixture for the test type. A 2:1 ratio for the bonding mixture is easier to work with. A small beaker for pouring the bonding mixture facilitates the process. A runny mixture of 1 part Plaster of Paris (do not use grout mix) to 1 part water is used to pour into small gaps around the specimen, spacer block, and the reference blocks after specimens are installed. A ramp of Plaster of Paris (2.5 to 1 ratio) is made at the back of the mold to provide a smooth transition of the tire onto the back reference block; it is seen in Figure 39*c*. Testing of *thin* specimens followed the same logic as *thick* specimens with exception of the two full length spacer plates. Different sets of reference blocks and spacer blocks are used for *thin* specimens. The final installed specimen ready for testing is shown in Figure 39*c*.

a) Placement of Spacer Block

b) Alignment of Spacer Block



c) Final Installed Specimen Ready for Testing

Figure 39. Placement of Spacer Block and Final Installed Specimen

The removal procedure for specimens once testing is complete is shown in Figure 40. Before removal the specimens are painted with their test number to facilitate later identification (Figure 40*c*). The plug of bonding mixture located at one end of the spacer block is removed first (Figure 40*a*) followed by the material between the spacer block and the front reference block (Figure 40*b*). A narrow wood chisel or flat-head screwdriver works well for removal of bonding mixture. The bond between the spacer block and the specimen can be loosened by driving a thin putty knife or spatula between them. Once free, the spacer block is removed as shown in Figure 40*c*. Next the bonding mixture in the wider gap along the specimen is removed (this should be nearer the outside of the PURWheel, left for a left specimen and right for a right specimen). Once the bond on the other two edges of the specimen is loosened the specimen is ready for removal (Figure 40*d*). Removal should not be attempted before the specimen has cooled sufficiently to retain its integrity during removal. The specimen is removed by tapping a pry bar beneath the center front edge of the specimen as shown in Figure 40*e* and prying up. The specimen should remove easily; if not make sure that the bond is fully broken on the two remaining sides of the specimen.

Manual Measurement of Specimen Deformation

Manual measurements of the surface of specimens are taken before and after testing to determine surface deformation. A metal frame is clamped to the mold and used as a vertical datum and horizontal measurement location template. The measurement template (Figure 41) is labeled front and back with respect to the PURWheel and has metal pegs on the bottom that fit into the lifting eyes of the molds. The edges of the mold must be clean of excess plaster or grout so that the template rests firmly on the mold edges and there must be no interference from the specimen. Once the pegs are aligned in the lifting eyes of the mold, the template is pushed firmly toward the back until the pegs contact the back of the lifting eyes. Note that the template will only fit when the front and back are orientated correctly. Before use, the template is firmly clamped to the mold with C-clamps in two locations to ensure stability: 1) Right Front; and 2) Left Back.

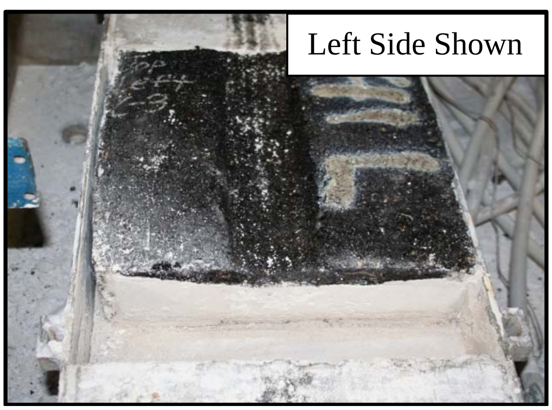
All manual measurements locations are established with respect to the wheel-path centerline; the respective centerlines of the left and right specimens are different. The left side wheel-path centerline is offset 0.5 inch to the left of the right side wheel-path centerline. The manual measurement template is marked with left and right centerline locations as seen in Figure 41. Centerline measurements are taken beginning 1.5 inches from the back of the specimen and advancing by 1 inch intervals toward the front to 11.5 inches (0.5 inches from the front of the specimen). Three cross-section profiles are provided on the template (Figure 41), they are located specific distances from the back of the specimen: 1) 35 mm (1.375 inch); 2) 111 mm (4.375 inch); and 3) 187 mm (7.375 inch). For the cross-section profiles, measurements are taken at 0.5 inch intervals extending four inches to the left and right of the wheel-path centerline; they are denoted by the red marks on the template (Figure 41).

a) *Grout Plug at End of Spacer Block*

b) *Grout in Front of Spacer Block*

a) *Spacer Block Ready for Removal*

c) *Removal of Spacer Block*



d) *Specimen Ready for Removal*

e) *Removal of Specimen*

Figure 40. Specimen Removal Procedure

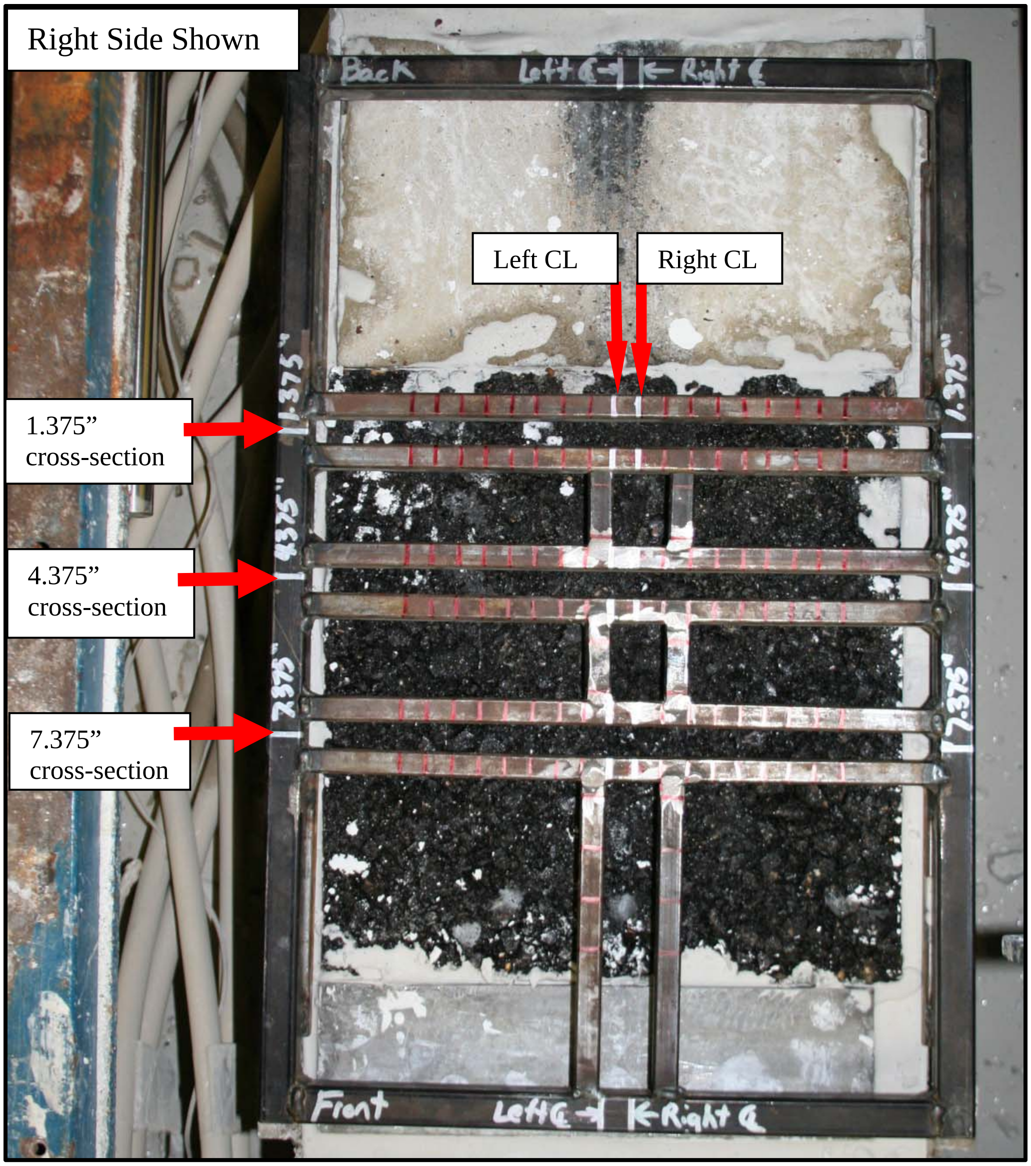


Figure 41. Orientation of Manual Measurement Template

A dial gauge is used to measure the specimen surface at the specified locations before and after the test; the difference in measurements is the surface vertical deformation as a result of the test. The measurement procedure is shown in Figure 42. The base of the dial gauge rests on two adjacent rails. Figure 42*c* is the manual measurement data recording template (provided in Appendix C). Space is provided for entry of specimen surface measurements before and after the test at half inch intervals for each cross-section profile and at one inch intervals for the centerline profile. Data is not typically recorded for the grayed out measurement locations but space is provided in the manual measurement data template and the data may be recorded if desired.

The physical location on the measurement template corresponding to the measurement location shown in Figure 42*c* as **“A”** (right specimen, 1.375” cross-section profile, 4” to left of wheel-path centerline) is shown in Figure 42*a*. The dial gauge is centered on the red tick marks that correspond to the location (Figure 42*a*). Note that the physical location of the dial gauge on the measurement template in Figure 42*a* would correspond to 3.5” left of wheel-path centerline if the measurement template were placed on the left specimen. Measurement location **“B”** (right specimen, 4.375” cross-section profile, 2” right of wheel-path centerline) corresponds to the physical location shown in Figure 42*b*. This physical location would be 2.5” right of centerline if the left specimen were being measured.

Examples of how to read the dial gauge are given in Figure 43; each increment of the outer dial is 0.001” inch and each increment of the inner dial is 0.100”. The inner dial of the specific dial gauge used for manual measurements does not exactly indicate zero when the indicator is at rest as shown in Figure 43*a*). The inner dial indicates zero when the actual measurement is 0.025” as shown in Figure 43*b*. This means that special care must be taken when reading the dial gauge for measurements slightly over an even number of tenths of an inch as shown in Figures 43*c* and 43*d*.

a) Location **A** *(Right Specimen shown)*

b) Location **B** *(Right Specimen shown)*

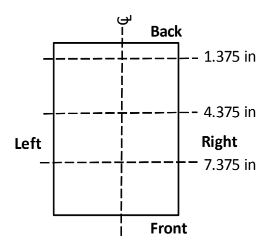
Left		Left								Center								Right
		-4	-3.5	-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4
1.375	Before																	
	After																	
4.375	Before																	
	After																	
7.375	Before																	
	After																	

CenterLine		Front										Back
		11.5	10.5	9.5	8.5	7.375	6.5	5.5	4.375	3.5	2.5	1.375
	Before											
	After											

Right		Left								Center								Right
		-4	-3.5	-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4
1.375	Before	A																
	After																	
4.375	Before													B				
	After																	
7.375	Before																	
	After																	

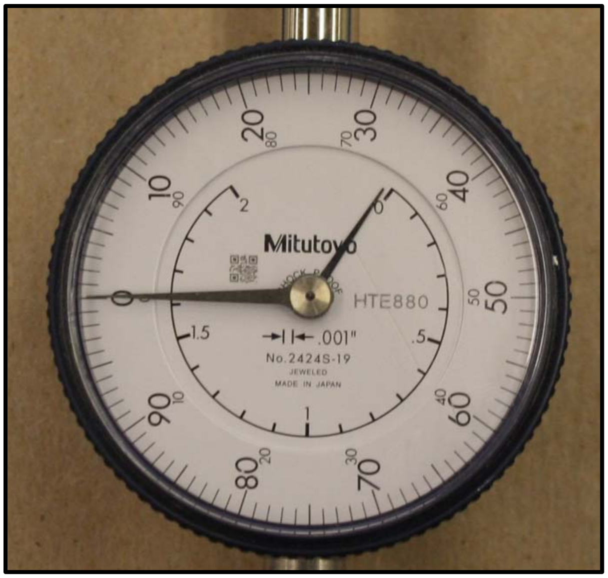
CenterLine		Front										Back
		11.5	10.5	9.5	8.5	7.375	6.5	5.5	4.375	3.5	2.5	1.375
	Before											
	After											

Notes: ____



c) Manual Measurement Data Template

Figure 42. Example Alignments of the Dial Gauge to Manual Measurement Grid



a) Reading of 0.000”

b) Reading of 0.025”

c) Reading of 0.706”

d) Reading of 1.103”

Figure 43. Reading Dial Gauge for Manual Measurements

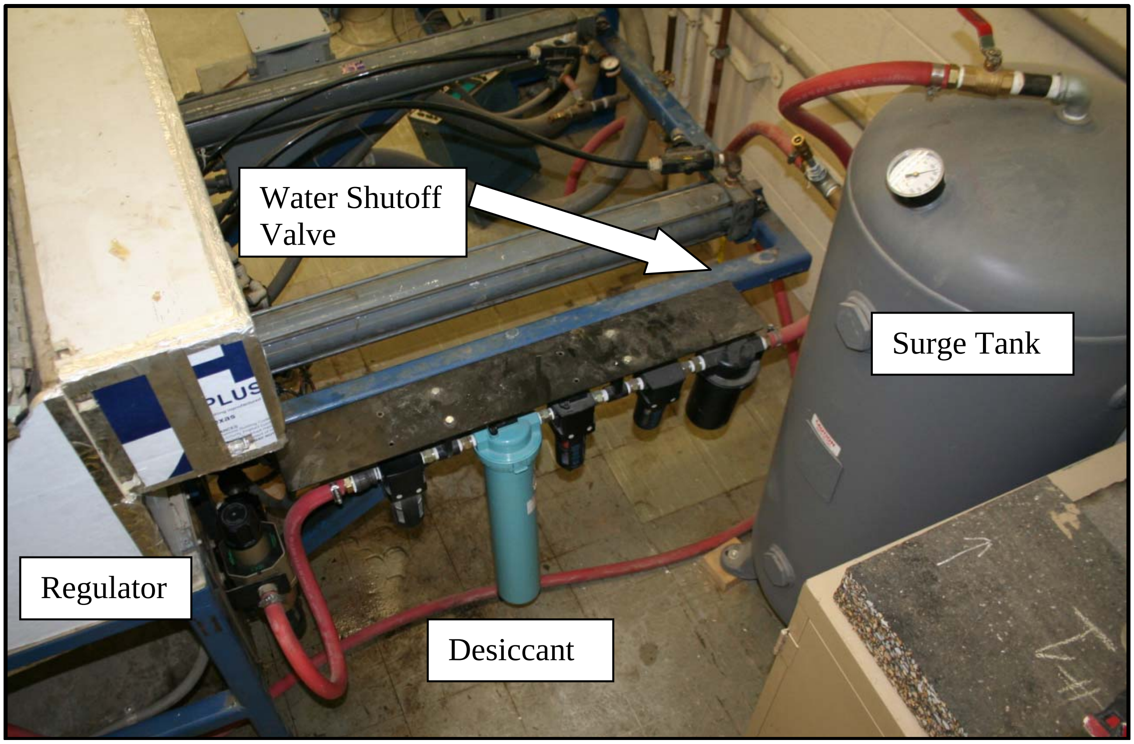
Conducting a Test

Physical and software parameters required to set up and run a test once specimens are in place and pre-test manual measurements have been recorded are described in the remainder of this section in a step by step format. Some general notes concerning setup of PURWheel testing include the following. When exiting the *Hawk* software be patient, it must complete several software routines to properly shut down (5 to 10 seconds). Before restarting the software, open the Windows Task Manager and verify that no copies of the *PURWheel.exe* process are running (check in the processes tab). The computer is restarted before running every test. After placement of the specimens into the machine, a 20,000 pass test takes on the order of eight to nine hours of testing time in addition to the preheat time and the 6 hour specimen conditioning delay period.

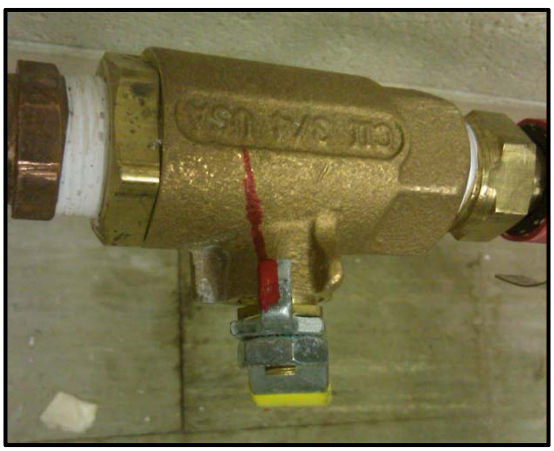
NOTE: Steps 8 and 22 are only needed for the wet test and default settings have been provided previously when the software was demonstrated.

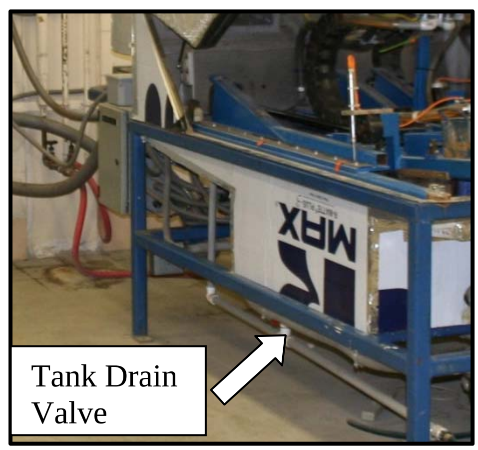
1. Restart the PURWheel computer and log on to *Mississippi State.*
2. Pressurize both tires to 125 ± 1 psi. Use a digital tire pressure gauge and a valve stem extension to provide access with the tires in place on the carriages.
3. Clean the LVDT rails on each side of the PURWheel. Check that the LVDT tips are secure. Lightly re-grease the LVDT rails with Teflon based lubricant.
4. Close the lever valve located near the top of the surge tank in the air system (Figure 44*a*). Open the bleed screw at the bottom of the regulator mounted to the right back of the PURWheel to relieve air pressure in the system (Figure 44*a*).
5. Set the zero rut as follows:
    a. Once pressure has been relieved, manually pull the wheel carriages out until the tires rest on the back concrete reference blocks.
    b. Flip on the power switch located on the right hand side of the PURWheel control box. This supplies power to the PURWheel control systems.
    c. Open the *Hawk* software that is labeled *Shortcut to PURWheel* on the desktop. Select the database named *DummyTest* in the ***Test Data*** tab of the *Hawk* software (Figure 36.) Click ***Fill and Heat*** to start the test.
    d. Click to the ***Test Setup*** tab screen of the *Hawk* software (Figure 35) and click the buttons to set the zero points for both the left and right; the value will not necessarily be zero. It may be necessary to click each button several times to verify that a reasonable value is selected. A reasonable value is one that repeatable to within a range of about 10 or so.
    e. Click to the ***Overall View*** tab of the *Hawk* software (Figure 32) and verify that instantaneous rut depths for each side are approximately zero (e.g. ± 0.1 mm).
    f. Press *Stop* to terminate the test (wait approximately 15 seconds for the test to fully stop). Fully exit the *Hawk* software.
6. Change the desiccant for the air supply before every test (green tube located in-line between the surge tank and the regulator (Figure 44*a*). Cover the top of the small tube inside of the green tube while filling to prevent desiccant from entering the small tube.

7. Close the bleed screw at bottom of the regulator and open the lever valve on top of the surge tank to re-pressurize the air system.
8. **(This step for wet test only)** Verify that the tank drain valve located below the PURWheel tank is closed. Fully open the water supply valve located behind the PURWheel (Figure 44*b*).
9. Turn on the two lever switches located on the wall behind and on either side of the PURWheel. They supply power to the PURWheel heating systems.
10. Verify that all switches located on the front panel of the PURWheel control box are turned on.
11. Verify that the gauge for the reservoir heat system reads greater than 25 psi (pump is normally set to put out 30 psi). Check level of coolant in the reservoir system. It should be filled to approximately 1/2 inch from top of the reservoir tank. If necessary refill with a 50/50 mixture of automotive antifreeze and water.
12. Open the *Hawk* software and click on the ***Test Data*** tab (Figure 36).
13. Go to the last database record by clicking the ►▌ button.
14. Click **New** and enter database names for the left and right tests when prompted.
15. From the drop down menu select wet or dry test.
16. From the drop down menu select if left only, right only, or both tests will be performed.
17. Enter the delay time (should be 360 min unless otherwise stated).
18. Enter the appropriate test parameters:
    a. Sampling frequency should be 2.
    b. Target temperatures should be 61 C for the Mold and Air. The Tank target temperature should be 56 C.
    c. The Total Passes should be 20,000.
    d. The Deformation criteria should be 15 mm (This corresponds to a physical specimen deformation of 23 mm according to Equation 1).
19. Save the test settings by clicking the √ button.
20. Click the ***Overall View*** tab (Figure 32). Select the **Auto Start** option and the click yes when prompted. Wait approximately 15 seconds. Click ***Fill and Heat*** to begin the test.
21. Verify that the air heaters are functioning correctly by placing a hand in front of them. They are located on the left and right sides of the PURWheel at the back of the test chamber near the hinge for the hood.
22. **(This step for wet test only)** Once tank is full close the water supply valve until the red marks are aligned (Figure 44*c*). Note that if the if the water pump does not turn on once the tank is full or if the tank begins to overfill (run into the overflow tube) one or both of the two floats inside the center front of the tank are likely stuck. They can be easily unstuck by hand.
23. Close the hood. Use the hood stand to pull the fan exhaust towards the front of the PURWheel for clearance.



a) Location of Mechanical Systems at Back of PURWheel





b) Water Shutoff Valve Setting

c) Tank Drain Valve Location

Figure 44. Location and Settings of PURWheel Components for Testing

<u>Data Storage and Post-processing</u>

A global numbering system is used to organize PURWheel data beginning with the first test which was labeled PURWheel Test 001. The global numbering system is applied to both electronic data collected by the *Hawk* software as well as to manual measurements, photographs, and tested specimens. PURWheel test data is backed up and maintained on an external hard drive located at the PURWheel control computer. Digital photographs are taken of the specimens after they are mounted into the PURWheel, after testing (from multiple angles) before painting the test number on the specimen, and after testing after painting the test number on the specimen.

Two types of electronic files are stored by the PURWheel: complete database files and reduced files that contain only a portion of the data. To delete the link to a database in the *Hawk* software, select the directory to delete, and press the key labeled (-). To delete the database folder itself, close the *Hawk* software and delete the folder from C:\data\name of database. **Note that C:\PUR_DATA is never to be modified in any way!**

Once a test is complete, the electronic data collected by the *Hawk* software in the complete database files is extracted with an external export program. The external export program is located on the desktop of the PURWheel control computer and is called *Purwheel_export*. To extract and export data, first open the program. Select the appropriate test database from a list of available databases then click **Open**. Click **export right** to export the data from the right specimen. Click **export left** to export the data from the left specimen. Click **export run time data** to export the test history data. The total export process should take on the order of ten minutes to complete. Five Excel *.csv* files are created by the export process. They can be accessed by clicking **Open data folder** within the export program. The *left_short.csv* and *right_short.csv* files contain the summarized rut data and are needed for data reduction.

Data reduction is accomplished by incorporating the aforementioned *.csv* files and the manually measured specimen deformation data into a template Excel spreadsheet. Specific instructions on how to reduce the data are included in the first worksheet tab of the data reduction spreadsheet. Manual specimen deformation measurements are input into the appropriate worksheet tab; the spreadsheet includes plots of specimen centerline profiles and cross-sections. Data from the *left_short* and *right_short* files is pasted into the data reduction spreadsheet; plots of raw and smoothed data are included in the spreadsheet. An example of reduced data from a PURWheel test is provided in Appendix C.

Future Developments

Future PURWheel developments could include the capability to run a Hamburg test; steel wheels are available and only a moderate calibration effort would be required to adjust the temperature settings to 50 C, perform force calibration, and similar. Investigation of additional contact mechanisms is envisioned that could include high pressure tires (greater than 125 psi) or solid rubber wheels. A variety of different materials are anticipated for potential testing such as stabilized base materials. This may require different temperature conditions, loading conditions, or data collection techniques.

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Stiady, J.L., Hand, A.J.T., Noureldin, A.S., Galal, K., Hua, J., White, T.D. (2003). *Validation of SHRP Asphalt Mixture Specifications Using Accelerated Testing.* Final Report, No. 176, Indiana Department of Transportation.

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APPENDIX A –MAINTENANCE AND TROUBLESHOOTING

Maintenance

- Use only a pre-blended mixture of 50/50 antifreeze and water or use distilled water in combination with antifreeze in the reservoir heating circulation system to prevent corrosion of the aluminum parts.

- Periodically clean the carriage guides.

- Periodically clean the spilled plaster and grout from inside the tank.

Prior to Running Every Time.
- Inflate tires.
- Clean the LVDT rail with a clean rag.
    - Recoat the rail with Teflon grease.
- Change desiccant for air drying rack.
- Check that reservoir heating system fluid level is within 1/2 inch of top of reservoir.

Every Month.
- Check the oiler at the back of PURWheel.
    - The level has to be in red range.
    - The oil has to drop in the reading glass.
    - Too much oil will affect muffler but it takes some time for this to occur.
- Lubricate the moving parts of the wheel.

Troubleshooting

If in doubt, shut everything down and start over from the beginning.

Tank will not fill for wet test.
- Check that water valve is open.
- Check that water level float(s) are not stuck.
- Check that the solenoid valve is open.

Tank overflows for wet test.
- Check that water level float(s) are not stuck.

Carriages will not move.
- Check that hood interlock switch is fully depressed when hood is closed.
- Check that air surge tank has pressure and that the valve is open.

APPENDIX B –DIAGRAMS AND SCHEMATICS

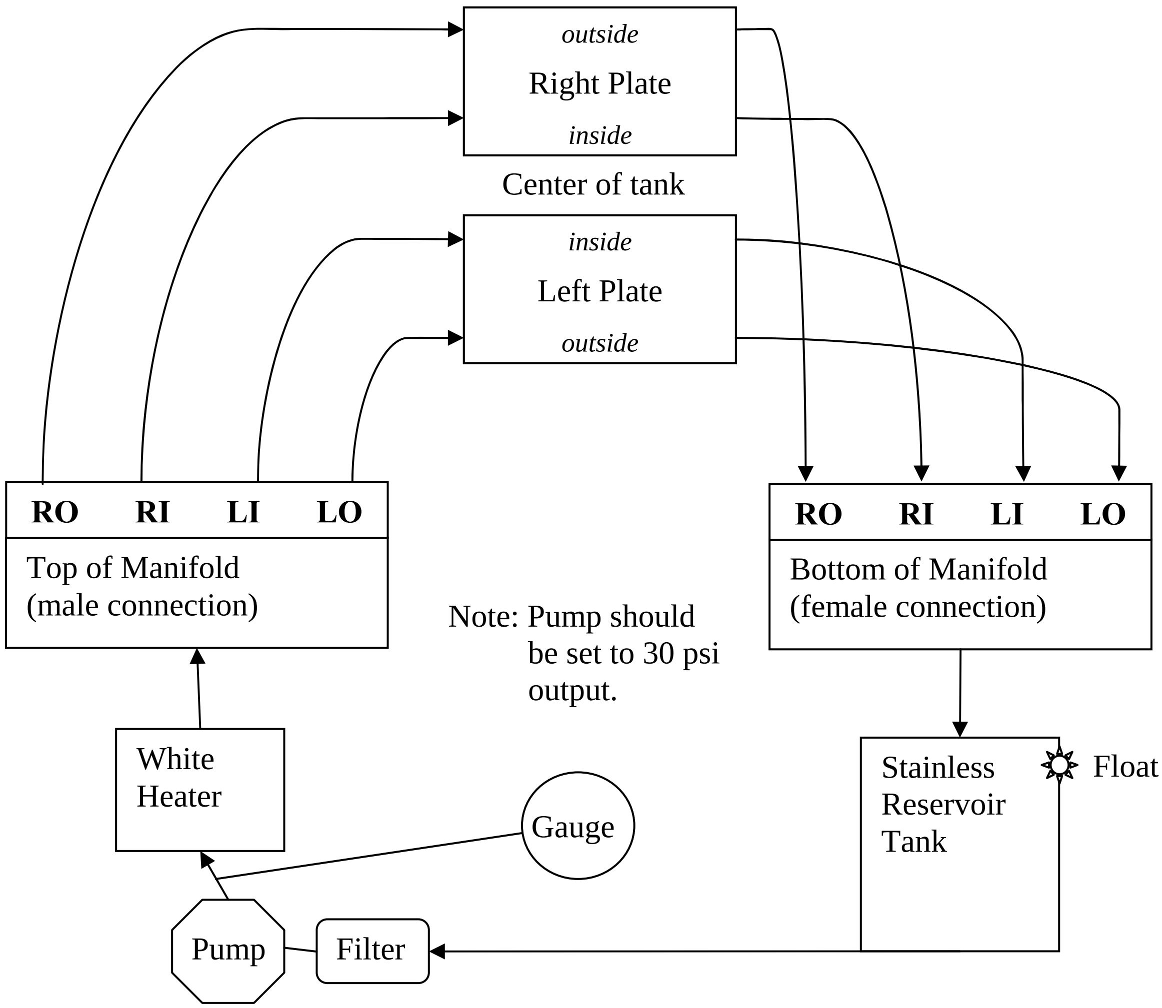


Figure B.1. Schematic of Reservoir Heating System

Overall Block Diagram

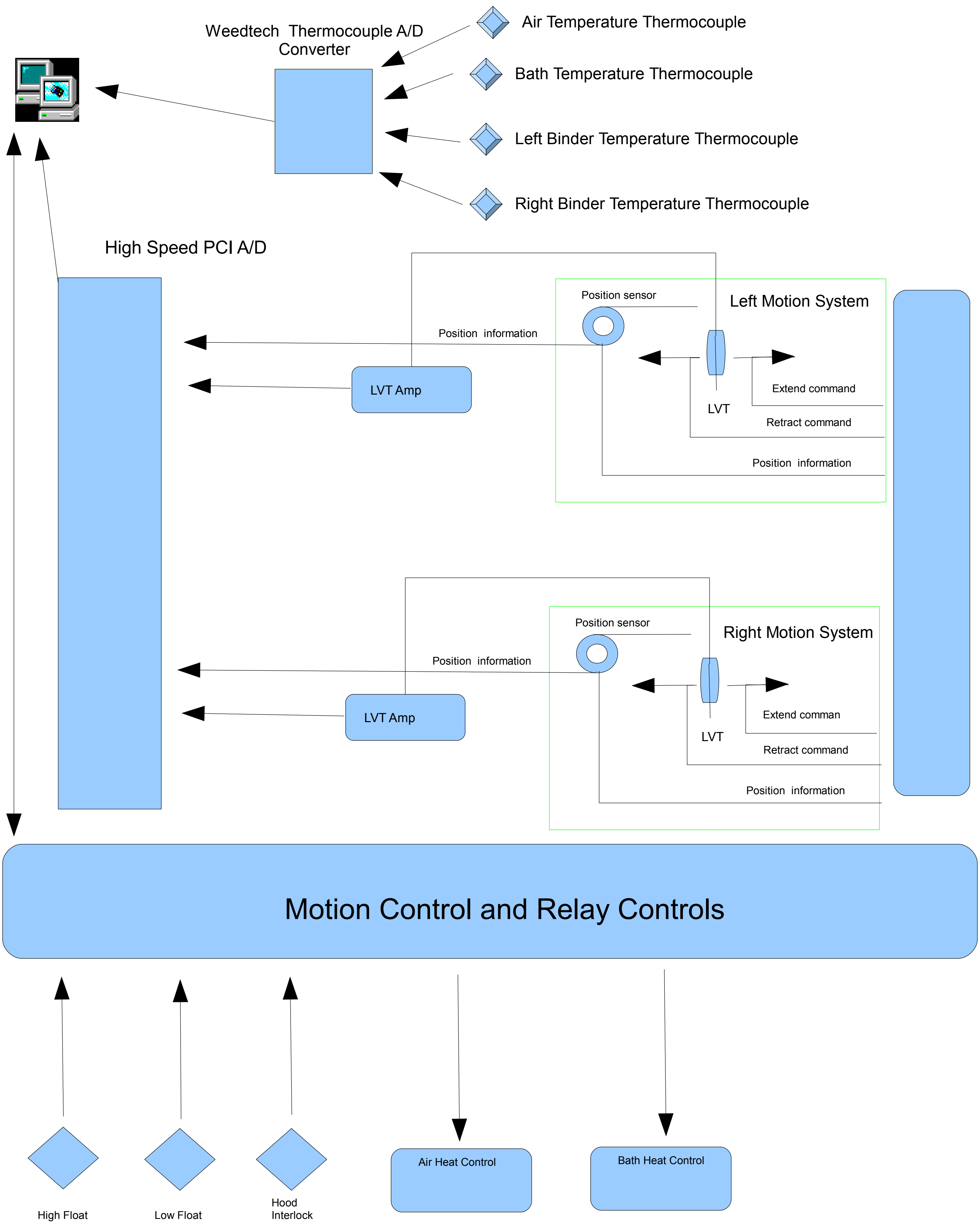
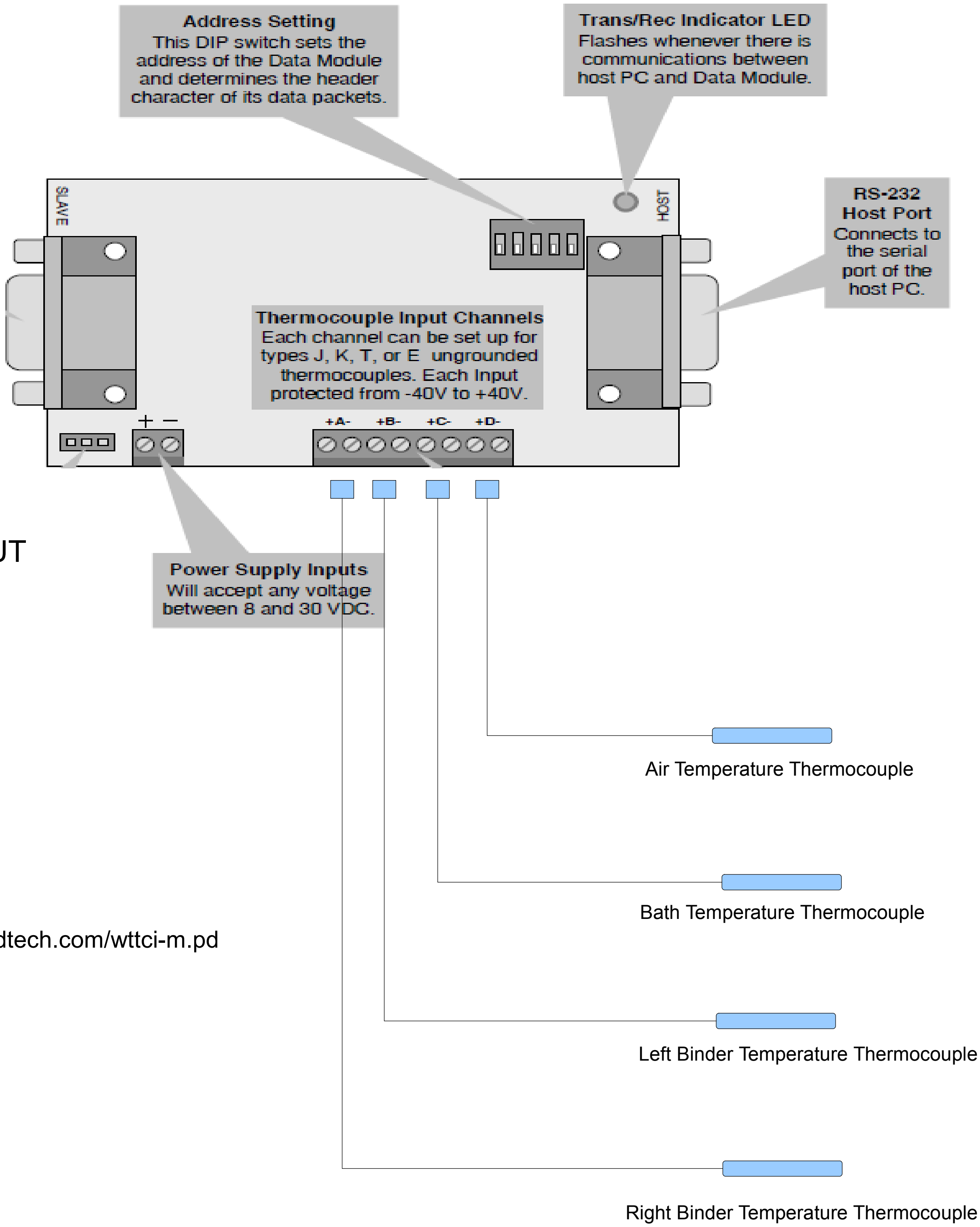


Figure B.2. Overall Block Diagram



DB9 PINOUT

2 Transmit
3 Receive
5 Ground

1,4,6
Power

Module Details

http://www.weedtech.com/wttci-m.pd

Figure B.3. Weedtech Thermocouple A/D Detail

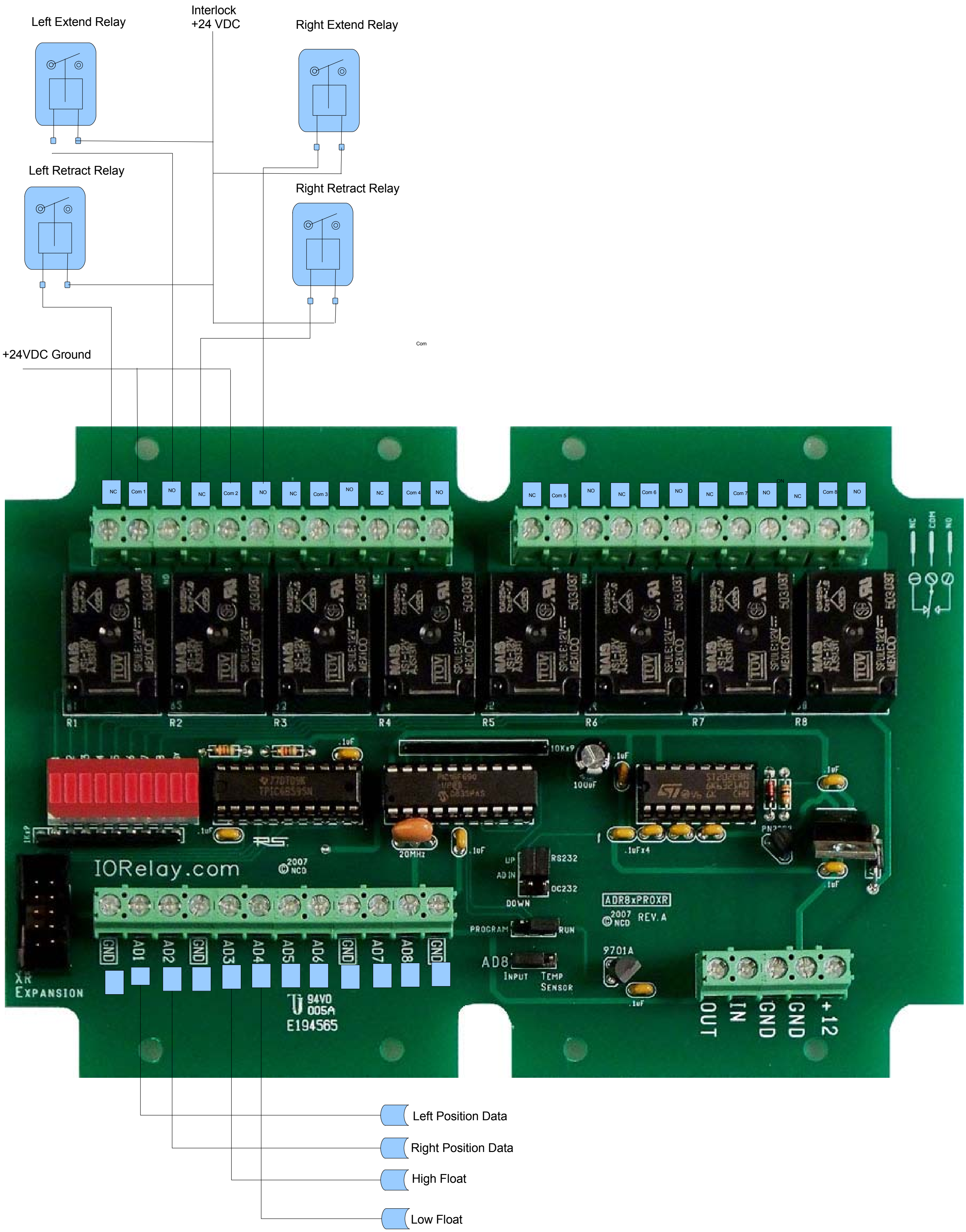


Figure B.4. High Speed PCI A/D Detail

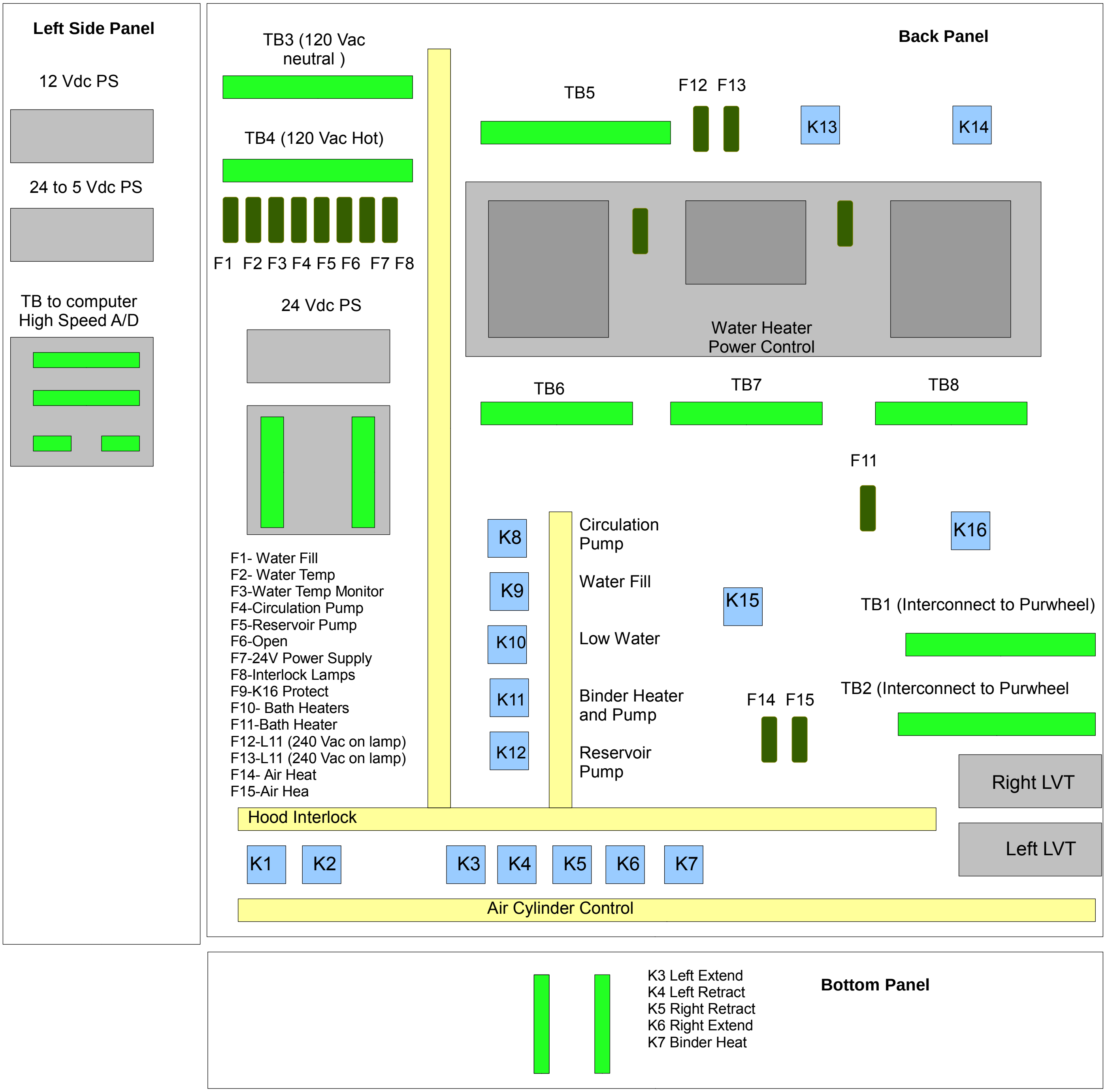


Figure B.5. PURWheel Control Box Component Location Diagram

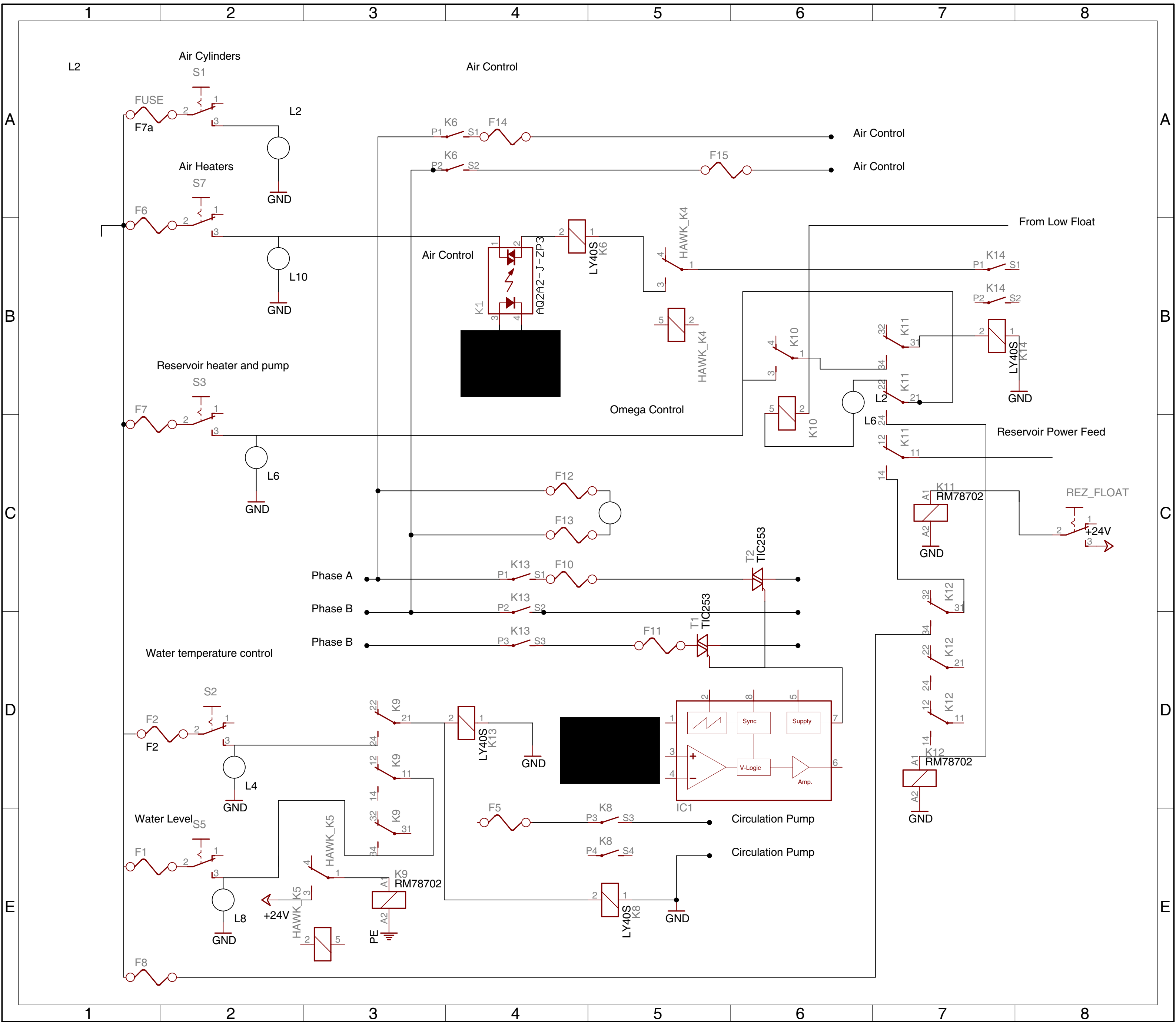


Figure B.6. PURWheel Control System Schematic

APPENDIX C- TEMPLATES AND EXAMPLE TEST DATA

PURWheel Pavement Wheel Tracker

Rutting Test Data Summary

PURWheel Test No:	**037**	**Target Temperature:**	**64**	C
Specimen Test ID:	**9-4**	**Wheel Load:**	**178.6**	kg
Test Date:	**6/18/2010**	**Tire Pressure:**	**862**	kPa
		Test Type:	**Dry**	
		Wheel Type:	**Pneumatic**	

Test Parameter Summary

Air Temp		*Tank Temp*	
Avg.	64	Avg.	61
Min	62	Min	58
Max	66	Max	65

Left Data Summary

Left Binder Temp

Avg.	65
Min	63
Max	67

	Rut (mm)	
Pass #	**Adjusted**	**Manual**
250	0.5	
500	1.0	
1000	1.4	
2000	2.0	
4000	2.9	
8000	3.8	
12000	4.6	
16000	5.3	
20000	5.8	
19998	5.8	7.0

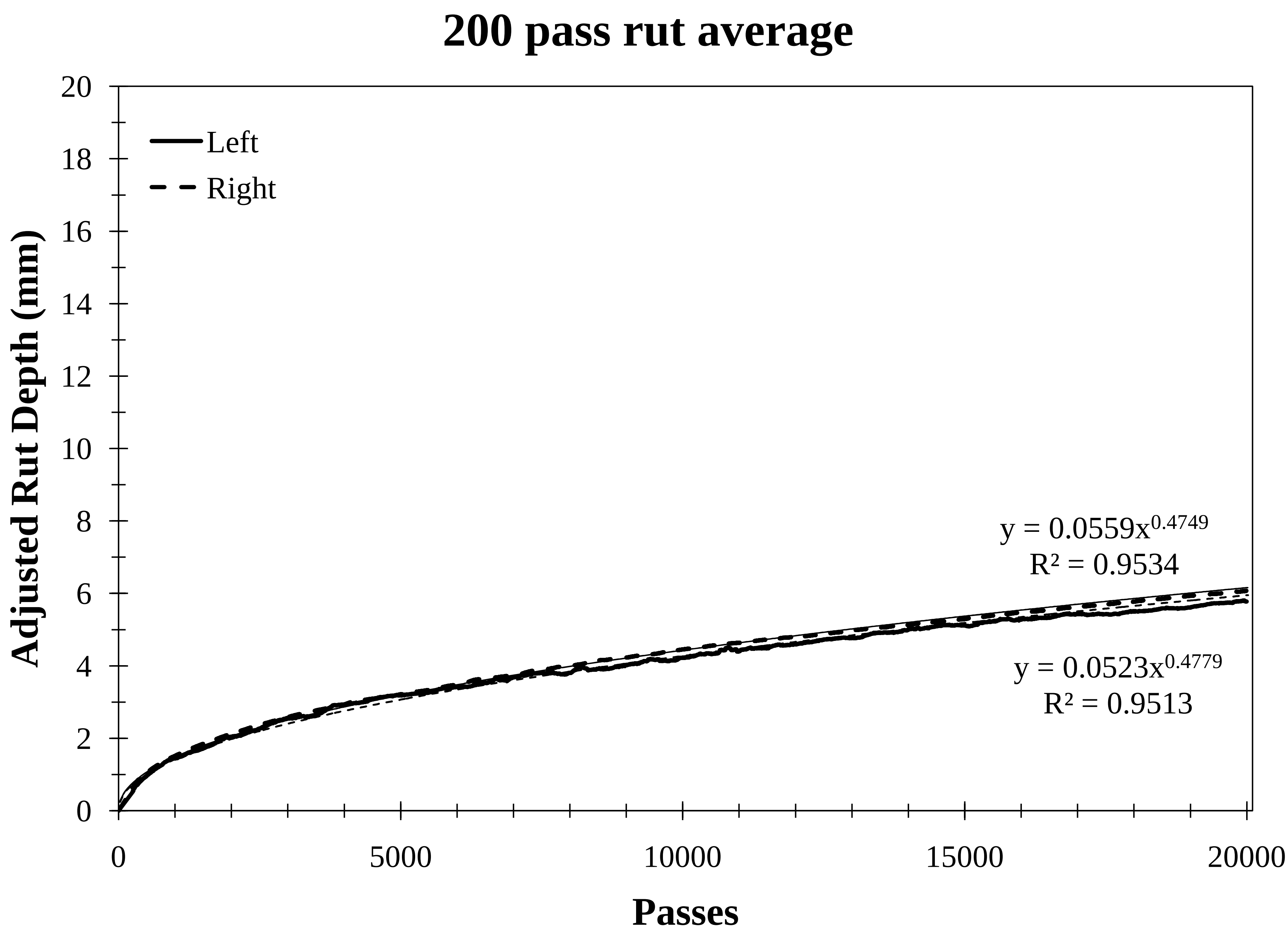
Right Data Summary

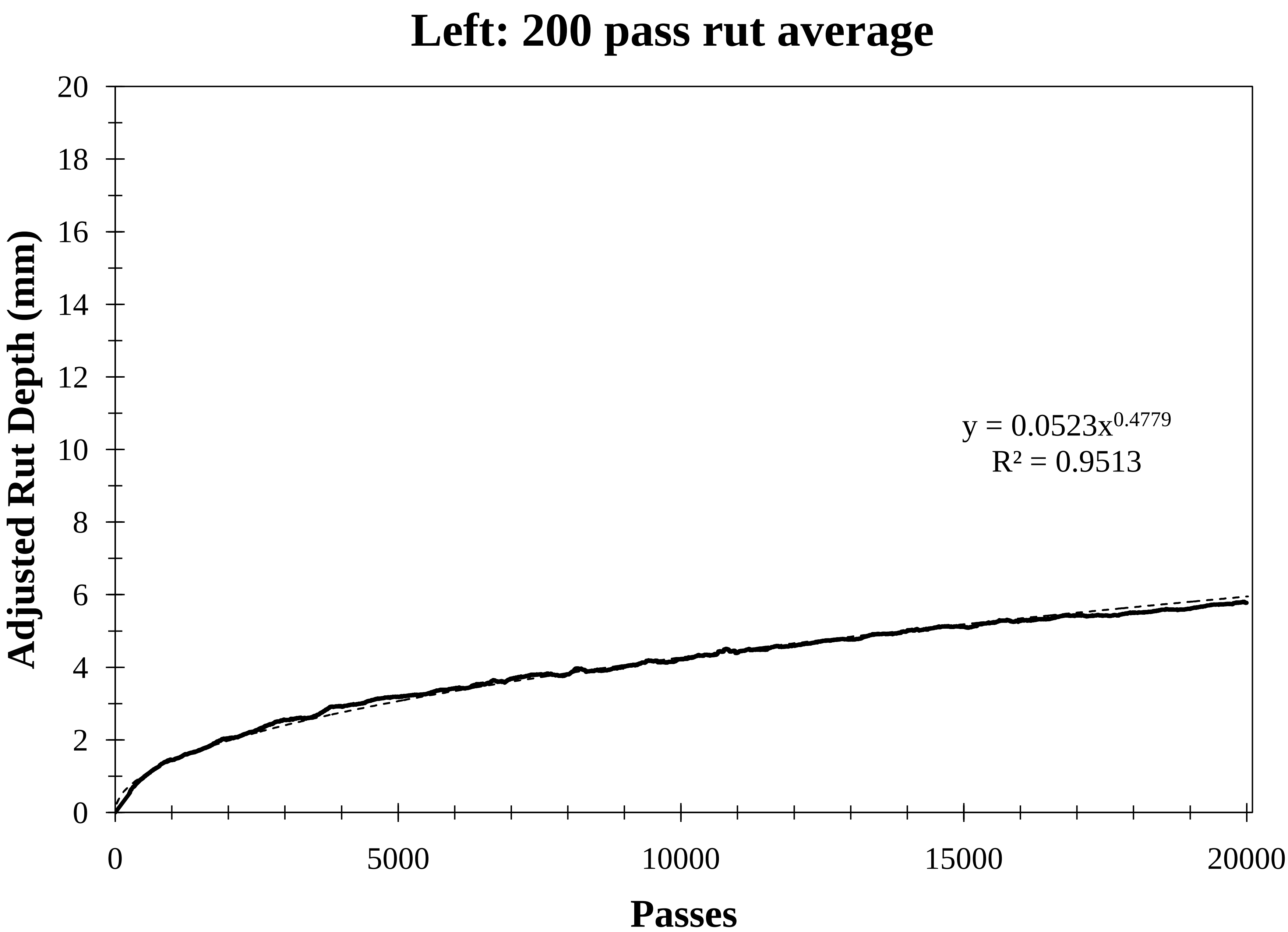
Right Binder Temp

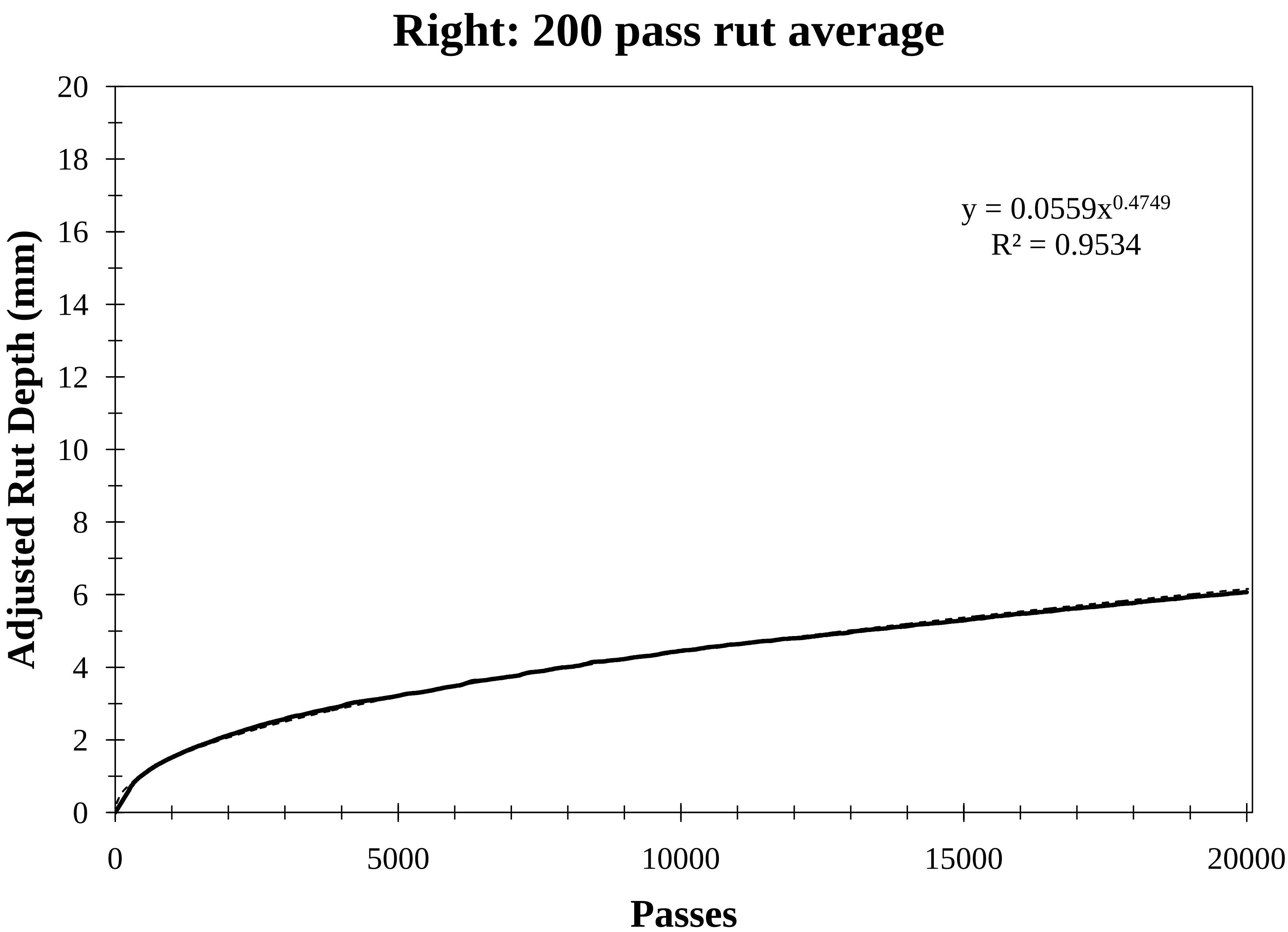
Avg.	67
Min	65
Max	70

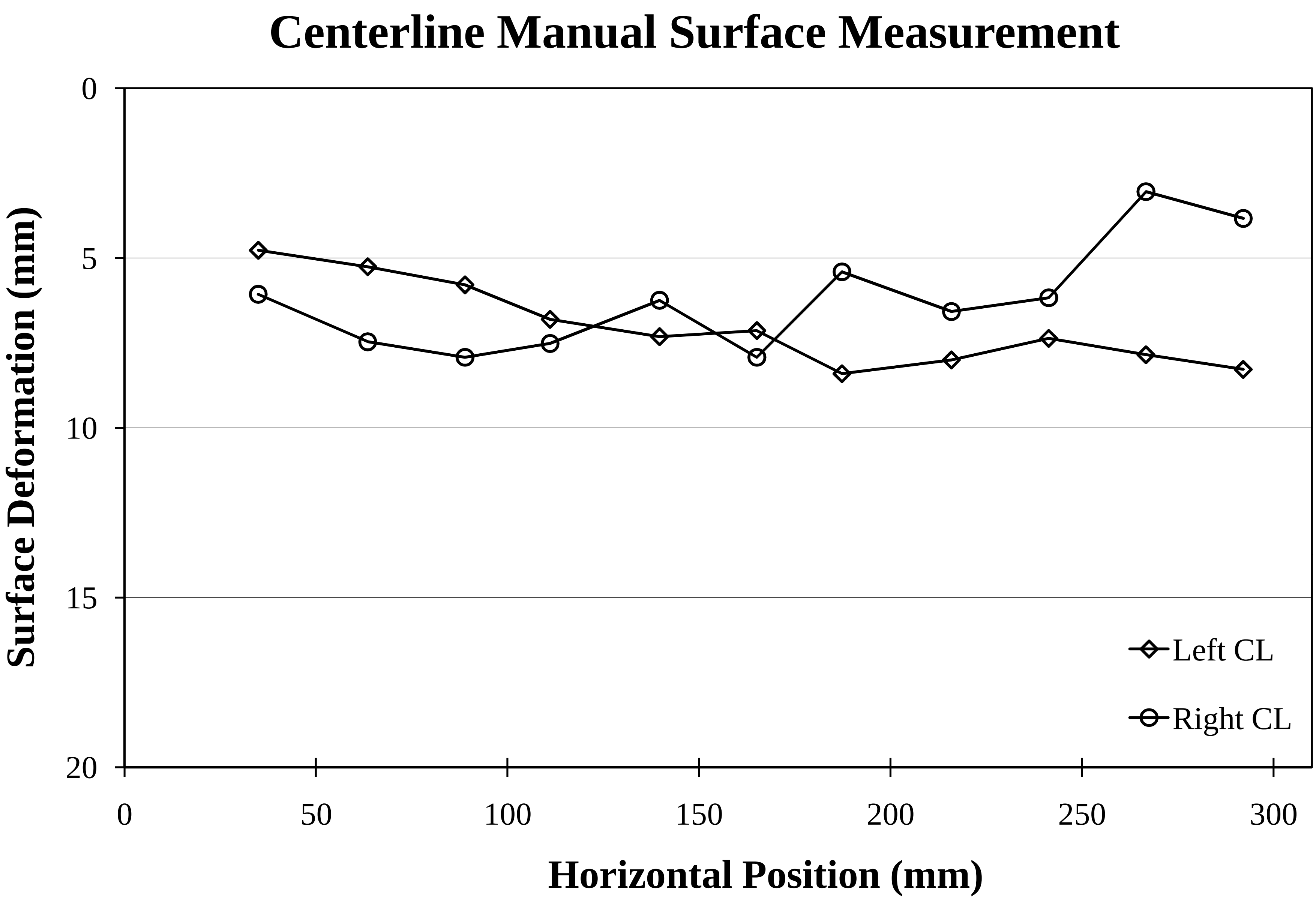
	Rut (mm)	
Pass #	**Adjusted**	**Manual**
250	0.6	
500	1.1	
1000	1.5	
2000	2.1	
4000	2.9	
8000	4.0	
12000	4.8	
16000	5.5	
20000	6.1	
20000	6.1	6.2

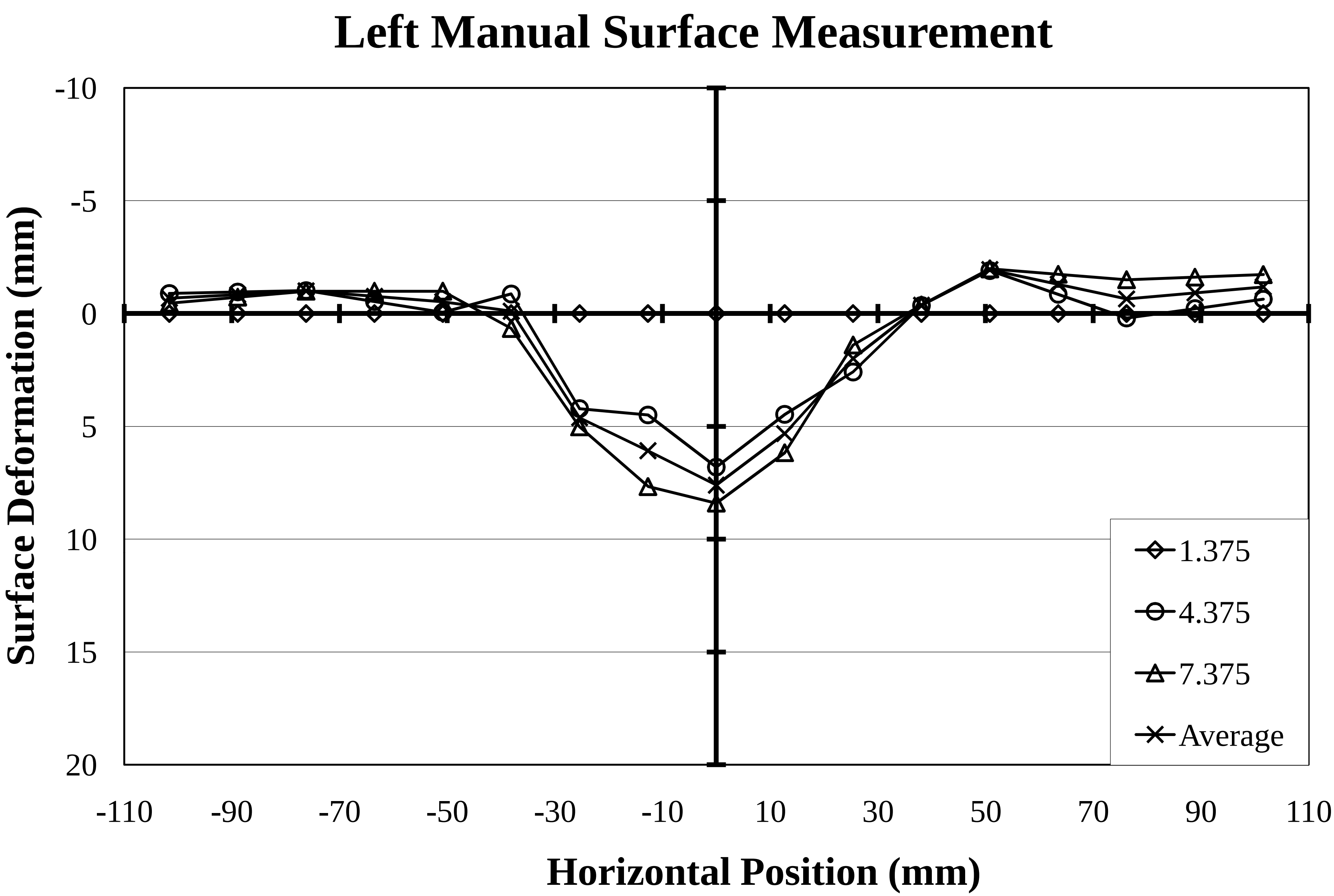
Notes: Compacted left was tested left
Rough wheel path surface texture during manual measurments.


200 pass rut average
Adjusted Rut Depth (mm)
Passes
Left
Right
y = 0.0559x^0.4749
R² = 0.9534
y = 0.0523x^0.4779
R² = 0.9513
0
2
4
6
8
10
12
14
16
18
20
0
5000
10000
15000
20000

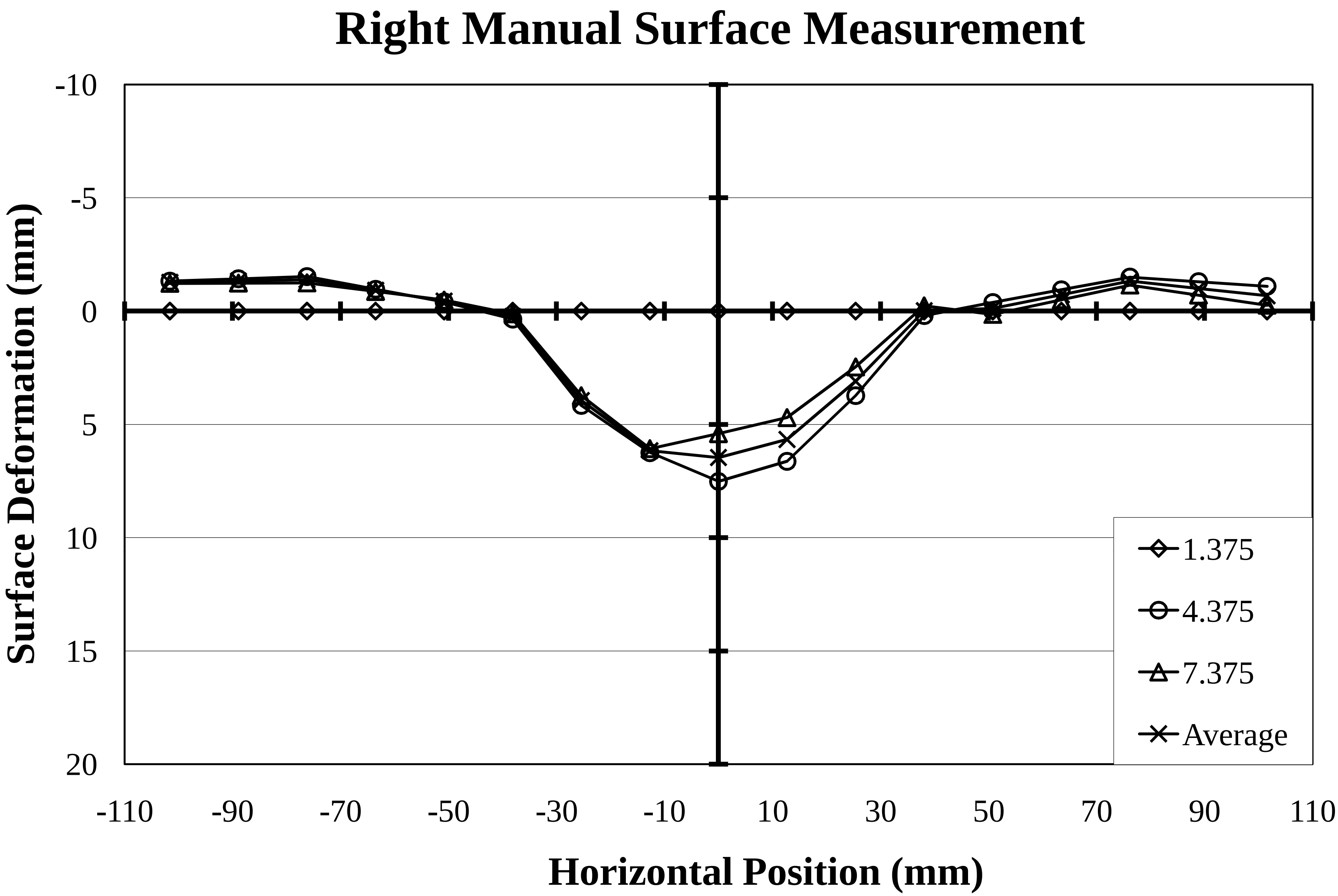

Left: 200 pass rut average
Adjusted Rut Depth (mm)
0
2
4
6
8
10
12
14
16
18
20
0
5000
10000
15000
20000
Passes
y = 0.0523x^0.4779
R² = 0.9513


Right: 200 pass rut average
y = 0.0559x^0.4749
R² = 0.9534
Adjusted Rut Depth (mm)
Passes
0
2
4
6
8
10
12
14
16
18
20
0
5000
10000
15000
20000


Centerline Manual Surface Measurement
Surface Deformation (mm)
0
5
10
15
20
0
50
100
150
200
250
300
Horizontal Position (mm)
Left CL
Right CL



Left Manual Surface Measurement
Surface Deformation (mm)
-10
-5
0
5
10
15
20
-110
-90
-70
-50
-30
-10
10
30
50
70
90
110
Horizontal Position (mm)
1.375
4.375
7.375
Average


Right Manual Surface Measurement
-10
-5
0
5
10
15
20
Surface Deformation (mm)
-110
-90
-70
-50
-30
-10
10
30
50
70
90
110
Horizontal Position (mm)
1.375
4.375
7.375
Average

Test No:__________ Specimen No:__________ Date:__________

Left		Left								Center								Right
		-4	-3.5	-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4
1.375	Before																	
	After																	
4.375	Before																	
	After																	
7.375	Before																	
	After																	

CenterLine		Front										Back
		11.5	10.5	9.5	8.5	7.375	6.5	5.5	4.375	3.5	2.5	1.375
	Before											
	After											

Right		Left								Center								Right
		-4	-3.5	-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4
1.375	Before																	
	After																	
4.375	Before																	
	After																	
7.375	Before																	
	After																	

CenterLine		Front										Back
		11.5	10.5	9.5	8.5	7.375	6.5	5.5	4.375	3.5	2.5	1.375
	Before											
	After											

Notes: ____________________