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Field Investigation of Warm Mix Asphalt Temperatures	Work Plan ☐ Construction ☐ Evaluation ☐ **Final** ☒	8. Project No. 9. Project No. 10. Project No.

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Jongchul Song

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14. Supplementary Notes

15. Abstract

Purpose and Need

State Departments of Transportation began to implement or are considering to adopt warm mix asphalt (WMA) for various reasons. One common benefit anticipated from the use of WMA is reduced risk associated with cool weather paving and compaction of stiff asphalt mixes. This potential benefit means, among others, an extended paving season for North Dakota, as indicated in the recent questionnaire survey given to the asphalt paving contractors working in the state (Gullickson 2011).

From the literature review, it is observed that the previous research efforts were focused on laboratory evaluation of particular performance characteristics of WMA. Although there were field testing and observations of WMA indicating that specified density was achieved with less compactive efforts, field temperatures of WMA and their relation to the resulting density have not been investigated sufficiently. To make an informed decision on implementing the use of relatively new WMA into highway paving practice, a better understanding is needed of the material's field temperature-density relation.

Objective

The objective of the research reported here was to make field observations of WMA temperatures and HMA temperatures during paving operations and make a comparison of their temperatures in relation to compacted density. To achieve this objective, thermal images of WMA and HMA during paving were acquired using an infrared camera, from three asphalt pavement construction projects in North Dakota, over a nine-month period from September 2011 to May 2012. These paving projects were among the five WMA pilot projects that NDDOT planned for the 2011 paving season, and due to the investigators' equipment problems, temperature recording was performed only on the three projects

Summary

Field temperatures of three different types of WMA additives or processes were compared to HMA temperatures: Advera, Evotherm, and foamed asphalt. Based on the observations from ND 3 and ND 15 paving that pointed to the consistent directions, it can be concluded that WMA was laid down at lower temperatures by 25 to 30 °F than HMA and that WMA temperatures were less variable for a given day of paving. WMA appeared to cool more slowly than HMA, but the amount of WMA temperature drop varied depending on the paving cycle time.

The findings from this investigation provide support for reduced rate of cooling of WMA temperatures. Future research is suggested to examine the potential of WMA for extending paving seasons. Specific efforts in support of the research objective may be focused on assessing through computer simulation WMA's relative advantages of lowering the risks associated with cool weather paving.

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FINAL REPORT

Field Investigation of Warm Mix Asphalt Temperatures

Jongchul Song (Principal Investigator)
Jerry Gao (Co-Principal Investigator)

Department of Construction Management and Engineering
College of Engineering and Architecture
North Dakota State University
Fargo, ND 58108-6050

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November 2012

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT

EXPERIMENTAL PROJECT NO.

1	STATE	Y EAR		NUMBER	SURF
	NDSU	2011	-	02	

CONSTRUCTION PROJ NO: SPR-R033(005) (8)

LOCATION: ND (28)

EVALUATION FUNDING (48)

1	X	HP&R	3	DEMONSTRATION
2		CONSTRUCTION	4	IMPLEMENTATION

NEEP NO. (49):

PROPRIETARY FEATURE? (51): X Yes / No

SHORT TITLE

TITLE (52): Field Investigation of Warm Mix Asphalt Temperatures

THIS FORM

DATE (140): MO. November -- YR. 2012

REPORTING: 1 INITIAL 2 ANNUAL 3 X FINAL

KEY WORDS

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145 Warm Mix Asphalt	167 Thermal Camera
KEY WORD 3	**KEY WORD 4**
189 Evotherm	211 Advera
UNIQUE WORD	**PROPRIETARY FEATURE NAME**
233	255

CHRONOLOGY

Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
277 June 2011	281	285 November 2012	289	293 November 2012

QUANTITY AND COST

QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS): 1 (297)

UNITS (305):

1	LIN. FT	5	TON
2	SY	6	LBS
3	SY-IN	7	EACH
4	CY	8 X	LUMP SUM

UNIT COST (*Dollars, Cents*): $15,137 (306)

AVAILABLE EVALUATION REPORTS

CONSTRUCTION (315)	PERFORMANCE	FINAL
		X

EVALUATION

CONSTRUCTION PROBLEMS (318):

1	X	NONE
2		SLIGHT
3		MODERATE
4		SIGNIFICANT
5		SEVERE

PERFORMANCE (319):

1		EXCELLENT
2		GOOD
3	X	SATISFACTORY
4		MARGINAL
5		UNSATISFACTORY

APPLICATION

(320):

1	ADOPTED AS PRIMARY STD.	4	X	PENDING
2	PERMITTED ALTERNATIVE	5		REJECTED
3	ADOPTED CONDITIONALLY	6		NOT CONSTRUCTED

(Explain in remarks if 3, 4, 5, or 6 is checked)

REMARKS

321

The objective of the research reported here was to make field observations of WMA temperatures and HMA temperatures during paving operations and make a comparison of their temperatures in relation to compacted density. To achieve this objective, thermal images of WMA and HMA during paving were acquired using an infrared camera, from three asphalt pavement construction projects in North Dakota.

Form FHWA 1461

Disclaimer

The contents of this report reflect the views of the author or authors who are responsible for the facts and accuracy of the data presented herein. The contents do not reflect the official views of the North Dakota Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Acknowledgements

The research reported here was sponsored by North Dakota Department of Transportation, and the authors gratefully acknowledge their financial support and guidance throughout the course of this research. Especially, Tom Bold, Kyle Evert, and Ron Horner of the Materials and Research Division have provided the research team with timely guidance in planning and executing research tasks. The authors also appreciate support of asphalt paving contractors for the research team's field data collection. However, the contents of this report reflect solely the opinions and views of the authors and not necessarily those of the NDDOT, and neither does this report constitute a standard or specification.

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CHAPTER 1. INTRODUCTION

State Departments of Transportation began to implement or are considering to adopt warm mix asphalt (WMA) for various reasons. One common benefit anticipated from the use of WMA is reduced risk associated with cool weather paving and compaction of stiff asphalt mixes. This potential benefit means, among others, an extended paving season for North Dakota, as indicated in the recent questionnaire survey given to the asphalt paving contractors working in the state (Gullickson 2011).

WMA is typically produced in the 220-275°F (104-135°C) range, which is as much as 100°F below HMA production temperatures. Although WMA is produced at lower temperatures, its viscosity can be reduced, thereby reducing the risk associated with cool-weather paving and compacting stiff mixes. Reduced viscosity of WMA can improve general compaction efficiency as well. From the prior research, it can be observed that any instances of improved performance of WMA, as compared to HMA, will depend on the nature of a particular type of WMA technology employed, and production and paving temperatures (Diefenderfer and Hearon 2010). Reducing the production temperature without additional materials handling or the use of best practices for asphalt mix production can lead to incomplete drying of the aggregate, which could have negative impacts on long-term performance (Corrigan et al. 2010). In addition, Starry (2010) stressed that field procedures must be closely monitored to ensure WMA be laid down before binder viscosity increases to the limit of its compactability.

From the literature review, it is observed that the previous research efforts were focused on laboratory evaluation of particular performance characteristics of WMA. Although there were field testing and observations of WMA indicating that specified density was achieved with less compactive efforts, field temperatures of WMA and their relation to the resulting density have not been investigated sufficiently. To make an informed decision on implementing the use of relatively new WMA into highway paving practice, a better understanding is needed of the material's field temperature-density relation.

RESEARCH OBJECTIVES AND TASKS COMPLETED

The objective of the research reported here was to make field observations of WMA temperatures and HMA temperatures during paving operations and make a comparison of their temperatures in relation to compacted density. To achieve this objective, thermal images of WMA and HMA during paving were acquired using an infrared camera, from three asphalt pavement construction projects in North Dakota, over a nine-month period from September 2011 to May 2012 (Table 1). These paving projects were among the five WMA pilot projects that NDDOT planned for the 2011 paving season, and due to the investigators' equipment problems, temperature recording was performed only on the three projects shown in Table 1.

Table 1. Asphalt Pavement Projects for Field Data Collection

Project No.	**Project Limits (RP)[1]**		**HMA (RP)[2]**		**Evotherm (RP)[2]**		**Advera (RP)[2]**		**Foamed (RP)[2]**	
	Begin	**End**	**Begin**	**End**	**Begin**	**End**	**Begin**	**End**	**Begin**	**End**
SS-3-015(010)060	60.444	73.565	-	-	69.97	73.38	-	-	62.92	67.43
SS-3-015(018)073	73.626	81.086	76.64	80.04	-	-	-	-	-	-
SS-4-003(011)159	159.34	177.19	165.00	167.82	-	-	160.00	162.39	-	-

Note [1] indicates mile points covering the entire paving project.
[2] indicates mile points between which thermal images were obtained and that are only a subset of actual paving limits.

Temperature recording of WMA and HMA during paving was conducted at one fixed location each time, at the following intervals: (1) out of haul truck, (2) immediately behind the asphalt paver, and (3) immediately before and after each roller. After the finish rolling was complete, temperature recording was repeated at another fixed location. For each paving project, field data collection was performed for two full days for each different asphalt mix type (HMA, Evotherm, Advera, or foamed).

Thermal images that contain asphalt temperatures at different locations and different steps in the paving operation were then processed in the office to isolate the

region of interest (i.e., freshly laid asphalt) from the overall imaged area so that the average temperature of the fresh asphalt only could be determined at each instance. This processing was essentially manual since it was performed on each individual thermal picture although the software provided by the infrared camera vendor was useful. Details of field data collection efforts are described in Chapter 2 Field Data Collection, where the field data collected are also presented.

Average temperatures of WMA and HMA were compared, and they were related to compacted density that had been determined from cores taken in the field. These cores were made available through NDDOT to the investigators. Cores were taken by the contractor working on the paving job, at random locations determined by NDDOT, which did not coincide with the locations of temperature recording. Comparison of WMA and HMA temperatures during paving as well as their relation to compacted density is described in Chapter 3 Data Analysis. Chapter 4 concludes this report by summarizing the findings of data analysis and suggesting future research.

CHAPTER 2. FIELD DATA COLLECTION

The primary data collected as part of this research were temperatures of WMA and HMA during paving. The general scope of work for all three paving projects where temperature recording was performed was blade patching on the existing HMA pavement and an overlay of HMA and/or WMA, compacted to thickness of two inches. Table 2 lists other information of the three paving projects. The first two projects listed in Table 2 were let separately for bids, but they were completed by a single paving contractor and together constitute approximately 21 miles of a continuous segment of state highway ND 15. ND 15 is an undivided two-lane rural highway as well as ND 3. Asphalt concrete used for ND 15 and ND 3 paving was PG 58-28. ND 15 and ND 3 paving were also similar in the use of the windrow elevator attached to the paver and in the types of breakdown and finish rollers used, i.e., double steel drum rollers in vibratory and static modes, respectively.

One notable difference between ND 15 and ND 3 paving was the type of intermediate rollers used. For intermediate rolling, ND 15 paving utilized a pneumatic tire roller while ND 3 paving utilized a double steel drum, vibratory roller. The average intermediate rolling time during ND 15 paving was between four and five minutes, being approximately one to three minutes shorter than the intermediate rolling in ND 3 paving. However, more significant difference in rolling time arose from finish rolling: on average, ND 15 finish rolling took approximately eight minutes, and ND 3 fifteen to eighteen minutes. One possible explanation for this rolling time difference is that ND 15 paving involved long haul of 40 to 45 miles, thus asphalt mix arriving at the paving site potentially cooler and necessitating completion of rolling within a fairly short period of time after laydown. The overall paving time from laydown to finish rolling was slightly over 21 minutes on average for ND 15 paving, and it ranged from 31 to 36 minutes in ND 3 paving.

Table 2. Project Information Collected

Project No.	Road name	Grade & Brand of Asphalt Concrete	Aggregate	Compacted thickness	Haul distance	Rollers	Asphalt Mix (additive or process)	End points of temperature recording
SS-3-015(010)060	ND 15	PG 58-28 CHS	FAA[1] 43	2"	40 to 45 miles	Dynapac CC 722, CAT PS-360C (pneumatic tire), Dynapac CC 722 (static)	WMA (Evotherm)	RP 69.97 to RP 73.38
							WMA (Foamed)	RP 62.92 to RP 67.43
SS-3-015(018)073	ND 15	Same as above	Class 29	2"	Same as above	Same as above	HMA	RP 76.64 to RP 80.04
SS-4-003(011)159	ND 3	PG 58-28 Husky	FAA 43	2"	Unknown	Dynapac CC501, Dynapac CC 622 HF, CAT CB 634C (static)	WMA (Advera)	RP 160 to RP 162.39
							HMA	RP 165 to RP 167.82

Note: [1] fine aggregate angularity

An infrared camera shown in Figure 1 was used to obtain thermal pictures of asphalt mat being paved. Starting at unloading of asphalt mix and ending at finish rolling, thermal pictures were taken at one fixed location each time, at the regular intervals in between start and finish of paving, corresponding to laydown and to the times immediately before and after each roller. The camera was mounted on a tripod, approximately five to ten feet from the edge of the pavement, and it was pointed at the right angle to the centerline of the road. The camera was often set up at locations where some physical marker, such as a survey station stake or milepost was present in the proximity. The camera location was also marked using on a handheld GPS receiver.

Figure 1. The infrared camera used (front and rear)

The average duration of asphalt temperature recording at a given location ranged from 25 minutes to 40 minutes, commensurate with the overall paving time at that location it took from unloading to finish rolling. Temperature recording was performed for two full days on each asphalt mix type for each paving job. Besides HMA, three different WMA additives or processes were used, namely Advera, Evotherm, and foamed asphalt, which are among the most tried by the twenty northern states (Saboori et al. 2012). Table 3 summarizes temperature recording efforts, and where dates of temperature recording are not consecutive, paving was interrupted by rains.

One sample thermal picture is shown in Figure 2. Maximum, average and minimum temperatures of pixels bounded in a user-drawn rectangular area (the region of interest) can be seen from the picture. As a rule, the region of interest excluded the tapered edge because the edge would not receive rolling, thus rendering compacted density not applicable, and its temperature would have no bearing. All thermal pictures

taken over the course of this research project are included in Appendix of this report, where they are organized in road name, mix type, lane bound, and location of temperature recording and are ordered by the paving sequence.

Table 3. Summary of Asphalt Temperature Recording Efforts

Road name	Asphalt mix	Lane-miles of temperature recording	Number of temperature recording locations	Dates of temperature recording
ND 15	HMA	7 miles	14	05/21- 05/22/2012
ND 15	WMA - Evotherm	6.6 miles	17	05/24 - 05/25/2012
ND 15	WMA - foamed	9 miles	16	05/31, 06/02/2012
ND 3	HMA	5.6 miles	12	09/19, 09/21/2011
ND 3	WMA - Advera	4.8 miles	10	09/01- 09/02/2011

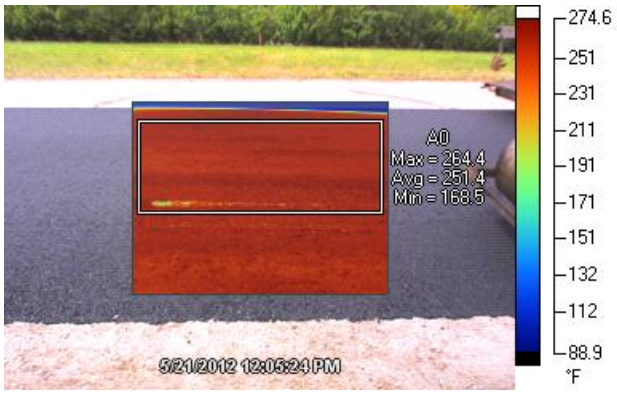

Figure 2. Sample picture of asphalt temperatures

From the compaction control reports of ND 15 and ND 3 paving, prepared by independent testing laboratories, compacted densities were obtained and are summarized in Table 4. From Table 4 it can be seen that core densities achieved from WMA and HMA are fairly similar – average percent air voids differ by 1% or less, and standard deviations of percent air voids vary no more than 0.3%.from one mix type to another. Also it is noted that in-place densities obtained on the days of temperature recording (shaded in Table 4) are similar to those from the days with no temperature recording.

This could be taken that asphalt temperatures during days when temperatures were recorded were not any better or worse, provided that asphalt temperatures have any bearing on attainable densities.

Table 4. Summary of Core Densities

Road name	Mix type or WMA process	Date	No. of core locations	Mat density (lb/ft^3)	% Air voids	% Maximum theoretical density
ND 15	HMA	5/21/2012	12	140.9	6.6%	93.4%
		5/22/2012	14	140.1	7.2%	92.8%
		5/23/2012	13	139.4	7.7%	92.3%
		Average		140.1	7.2%	92.8%
		St.dev.		1.4	1.0%	1.0%
	Evotherm	5/24/2012	11	139.5	7.6%	92.4%
		5/25/2012	11	139.3	7.5%	92.5%
		5/31/2012	4	139.3	7.5%	92.5%
		Average		139.4	7.5%	92.5%
		St.dev.		1.0	0.7%	0.7%
	Foamed	5/31/2012	12	138.9	7.8%	92.2%
		6/2/2012	14	139.6	7.4%	92.6%
		6/4/2012	7	139.1	7.8%	92.2%
		Average		139.2	7.6%	92.4%
		St.dev.		1.4	0.9%	0.9%
ND \3	HMA	9/19/2011	11	141.7	7.7%	92.3%
		9/21/2011	7	141.5	8.1%	91.9%
		9/22/2011	11	141.7	8.0%	92.0%
		9/23/2011	13	141.6	8.0%	92.0%
		9/24/2011	9	141.3	8.2%	91.8%
		9/26/2011	4	141.8	8.4%	91.6%
		9/27/2011	7	141.3	8.5%	91.5%
		Average		141.5	8.1%	91.9%
		St.dev.		0.3	0.8%	0.8%
	Advera	9/1/2011	8	142.4	7.2%	92.8%
		9/2/2011	8	142.0	7.7%	92.3%
		9/6/2011	8	143.6	6.6%	93.4%
		Average		142.7	7.2%	92.8%
		St.dev.		0.2	0.9%	0.9%

Note: dates of temperature recording are shaded.

CHAPTER 3. DATA ANALYSIS

COMPARISON OF ASPHALT TEMPERATURES

The change of WMA and HMA temperatures over time during ND 3 and ND 15 paving is shown in Figures 3 through 5. Temperatures in Figures 3 through 5 are average temperatures of freshly laid asphalts within the region of interest. As explained before, the region of interest is the asphalt mat area over the 12 feet lane width excluding the tapered edge. Each plotted line in Figures 3 through 5 corresponds to one fixed location at which temperature recording was performed, and marked points on the line represent the intervals at which thermal pictures were taken, e.g., behind the paver, immediately before breakdown rolling, etc. Note that average asphalt temperatures are plotted against time elapsed after laydown by the paver, rather than time elapsed after unloading – all thermal pictures of asphalts taken at the time of unloading can be found in Appendix. The reason for basing the elapsed time not off unloading is that average temperatures of unloaded asphalts tended to be lower than when the asphalts came out of the paver, which should not often be the case. Perhaps it is that a windrow of loose asphalts, formed during unloading, would not have a smooth surface. The surface texture of an object can significantly influence temperature calculation done by an infrared camera, which will "see" an object with the dull surface cooler than actually it is. The inaccuracy can be addressed by adjusting the emissivity value of an object to reflect its surface conditions, but this is not trivial for granular materials like loose asphalts not yet laid down.

Comparing WMA and HMA temperatures during ND 3 paving, shown in Figure 3, the following general observations are made:

- At laydown (behind the paver), WMA temperatures were lower: 223.2 °F for WMA; and 249.5 °F for HMA.
- At the end of breakdown rolling, WMA temperatures were higher than HMA: 194.5 °F for WMA; and 189.3 °F for HMA. This may be that WMA breakdown rolling lasted over 2 minutes shorter than HMA.
- WMA temperatures at each given step, e.g., laydown, were less variable than HMA temperatures at that step.

- WMA temperatures dropped by lesser degrees overall (from laydown till finish rolling): 78.8 °F drop for WMA; 99.3 °F drop for HMA. However, WMA took longer to be paved: 36.5 minutes for WMA; and 31.5 minutes for HMA. This means that WMA cooled more slowly than HMA.
- Temperature drops were more consistent with WMA (standard deviation 7.22 °F) than for HMA (st. dev. 22.2 °F). Also the overall time from laydown till finish was more consistent with WMA (st. dev. 7.5 min.) than for HMA (13.0 min.).

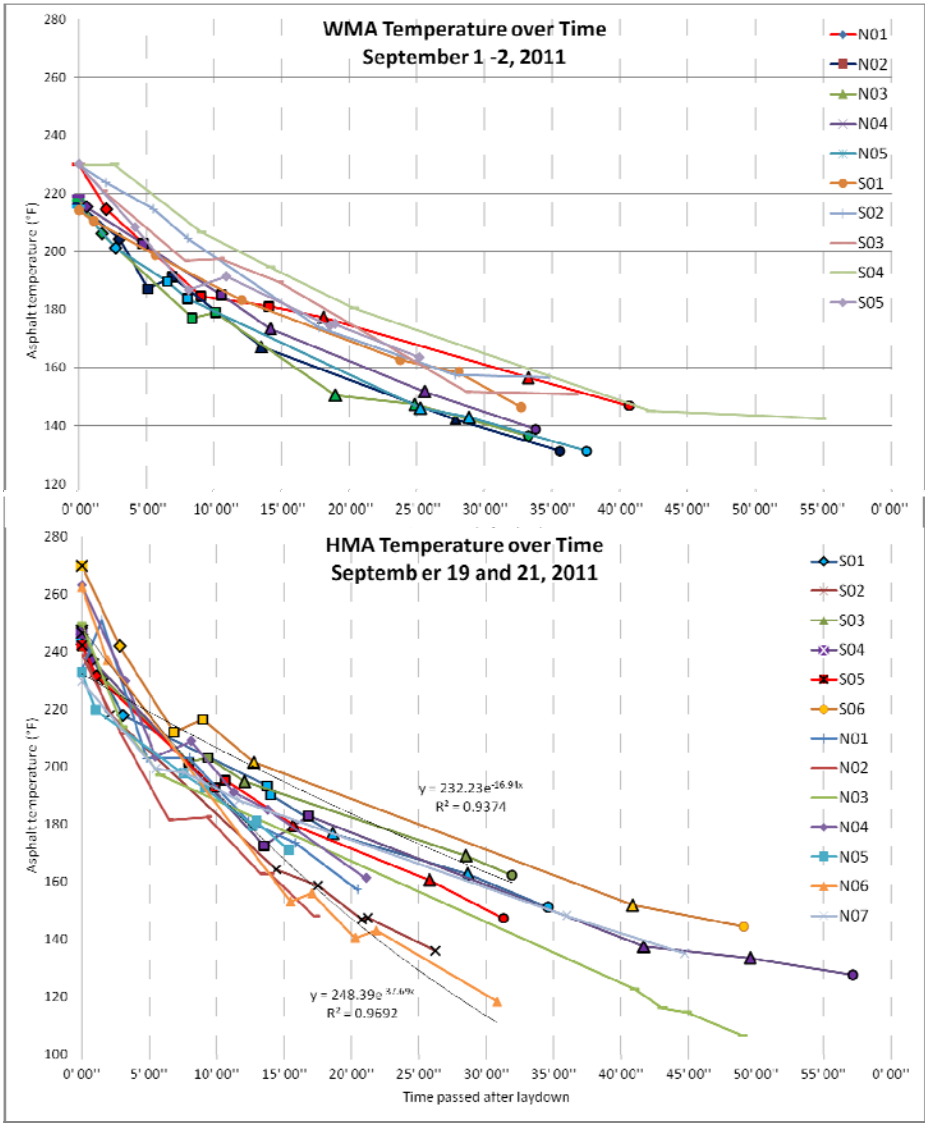

Figure 3. ND 3 WMA and HMA temperature change over time

Comparing WMA and HMA temperatures during ND 15 paving, shown in Figures 4 and 5, the following general observations are made:

- At laydown, WMA temperatures were lower: 223.1 °F for Evotherm; 228.0 °F for foamed asphalt; and 253.5 °F for HMA.
- WMA-Evotherm or foamed asphalt temperatures at each given step, e.g., laydown, were less variable than HMA temperatures at that step.
- WMA temperatures dropped by lesser degrees overall (from laydown till finish rolling): 65.3 °F for Evotherm; 64.5 °F for foamed asphalt; and 76.2 °F for HMA. WMA took just as long to be paved as HMA: 21.0 minutes for WMA, and 21.5 minutes for HMA. Since WMA temperatures dropped by smaller amounts over the time period just as long, it may be said that WMA cooled more slowly.
- WMA temperature drops were slightly more variable compared to HMA: standard deviation 8.64 °F for Evotherm, 9.64 °F for foamed asphalt, and 8.40 °F for HMA. Also the overall time WMA took from laydown till finish was slightly more variable, standard deviation 4.0 minutes for WMA and 3.5 minutes for HMA.

Combining the observations made of ND 3 and ND 15 paving, WMA was laid down at temperatures, typically lower by 25 to 30 °F than HMA (see Figure 6). Also it can be seen from Figure 7 that WMA temperature was more consistent throughout the paving process, exhibiting smaller standard deviations. Furthermore, WMA cooled by smaller amounts than HMA did over the comparable time periods (Figure 8). This suggests that WMA cools more slowly than HMA, but the actual amount of WMA cooling will depend on several factors, including the paving cycle time from laydown to completion of finish rolling (Figure 9). For example, WMA-Advera on ND 3 and WMA-Evotherm on ND 15 were laid down approximately at the same temperature of 223 °F, which was 25 to 30 °F lower than that of HMA on the respective job. However, WMA-Advera cooled by 78 °F over the paving cycle time of 36 minutes, while WMA-Evotherm cooled by 65 °F over the cycle time of 21 minutes.

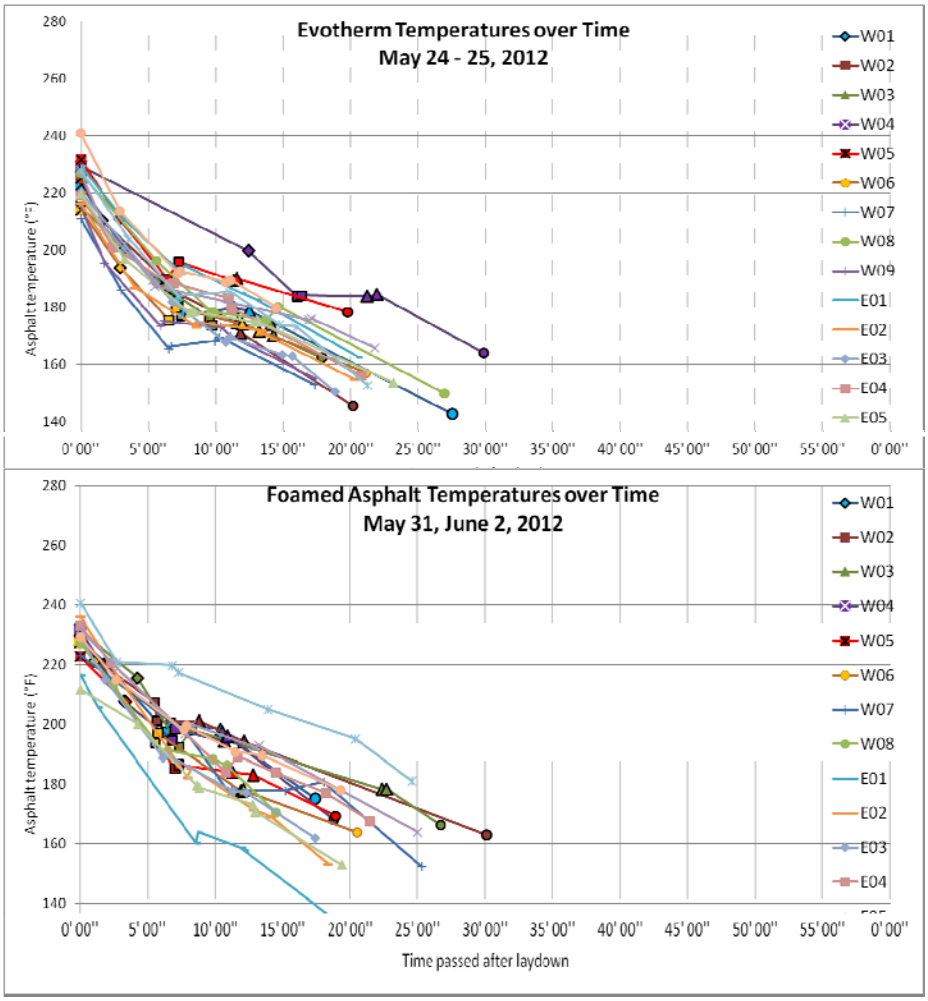

Figure 4. ND 15 WMA temperature change over time

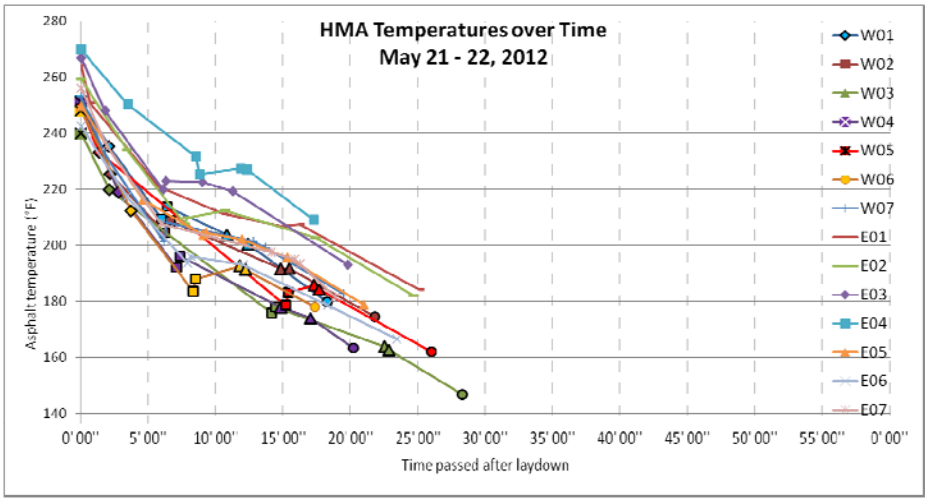

Figure 5. ND 15 HMA temperature change over time

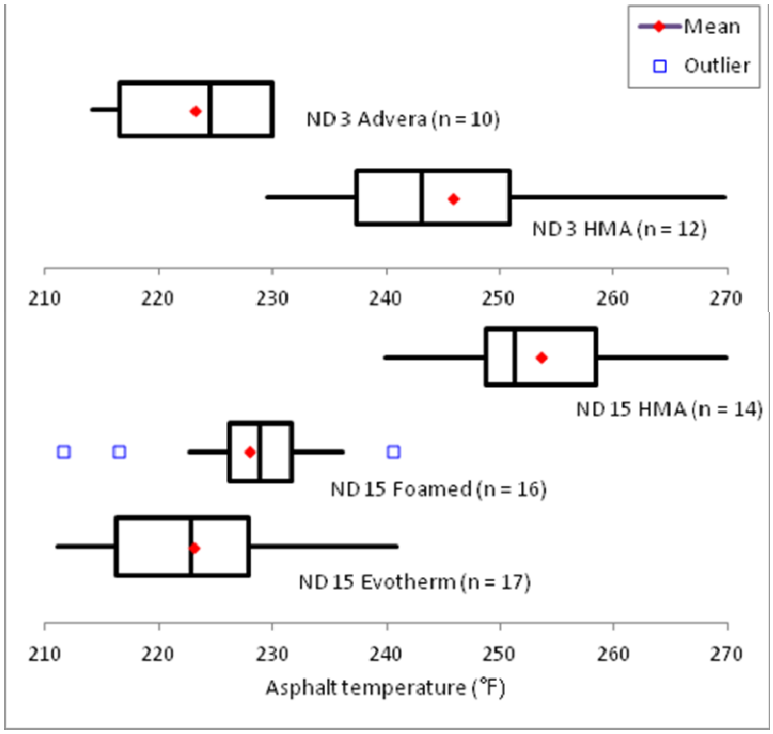

Figure 6. Distribution of asphalt temperature at laydown (*n* = sample size)

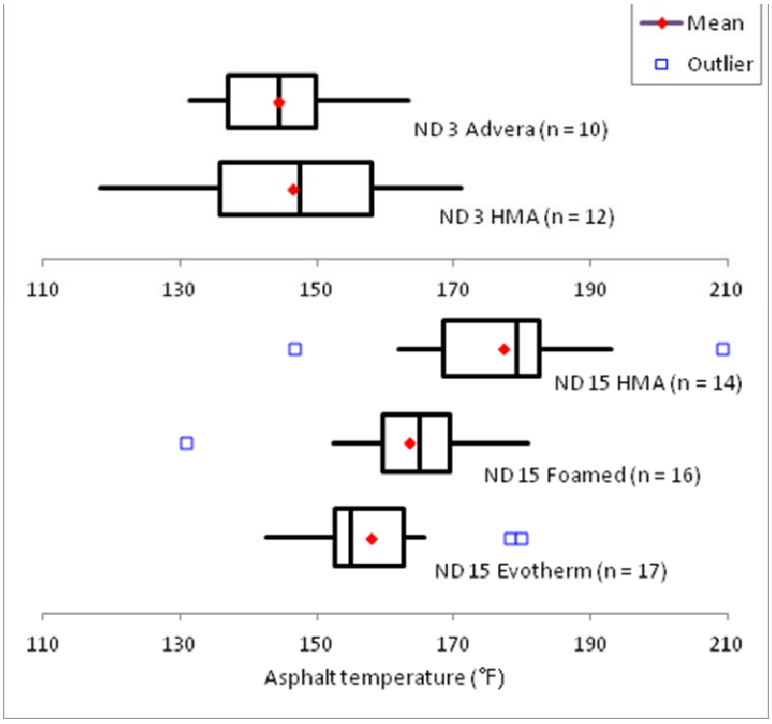

Figure 7. Distribution of asphalt temperature at finish (*n* = sample size)

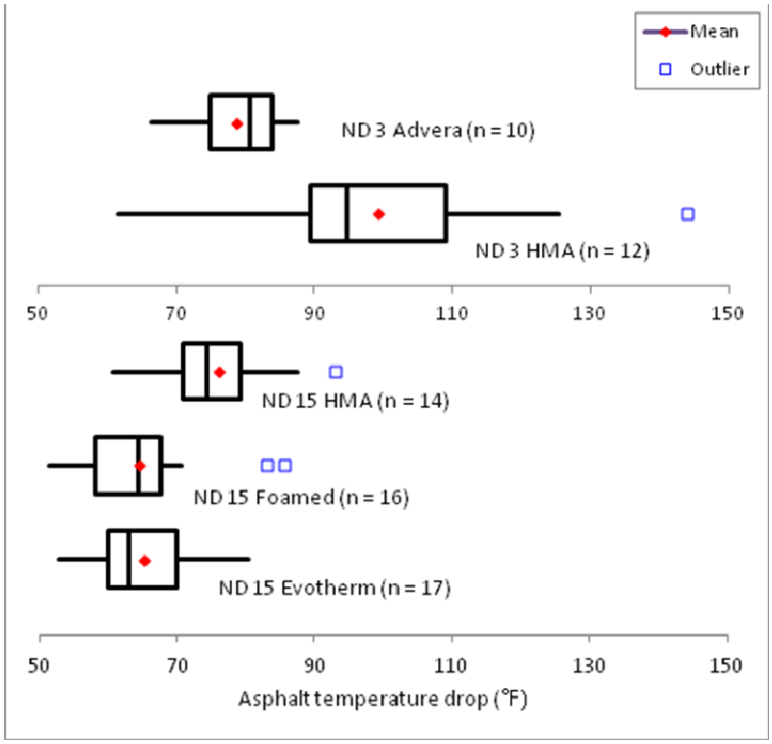

Figure 8. Distribution of temperature drop from laydown to finish (*n* = sample size)

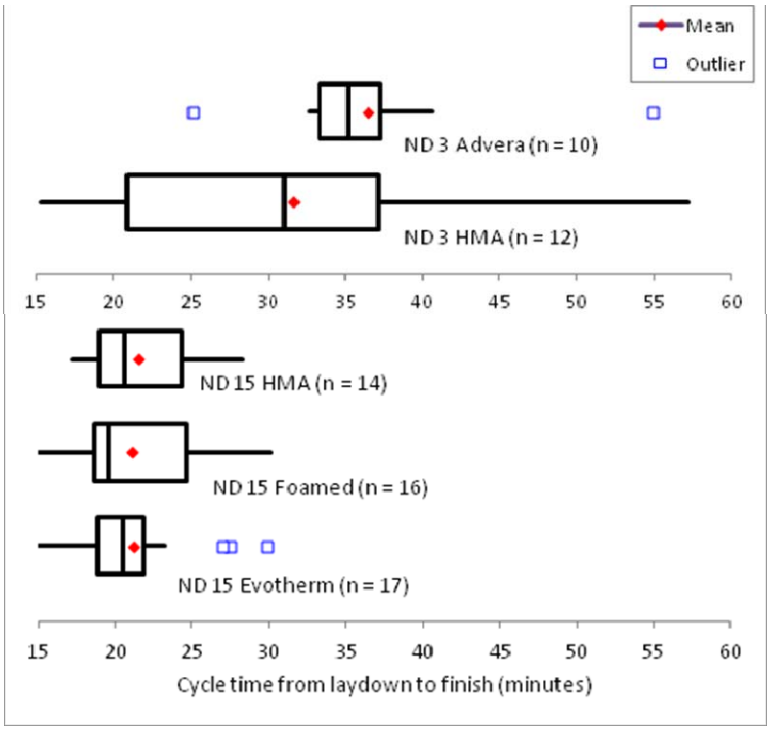

Figure 9. Paving cycle time from laydown to finish (*n* = sample size)

RELATING ASPHALT TEMPERATURES TO DENSITIES

Figure 10 shows that the correlation between core density and asphalt temperature recorded on ND 3 paving is very weak. This is also the case with ND 15 paving (see Figure 11). As such, field temperatures of asphalt mix, either WMA or HMA, are not a good indicator of the outcome of compaction – asphalt temperature alone cannot explain the resulting density. This conclusion is drawn based on density and temperature data from ten days of paving out of a total of twenty days of the entire paving. Also the density data used here for correlation analysis should be treated as an unbiased sample because core densities did not vary significantly from days of temperature recording to days with no temperature recording, as shown in Table 4 earlier. This means, for example, if asphalt temperature had been recorded on different dates and related to core densities from other days of paving than the present, any correlation may still be weak.

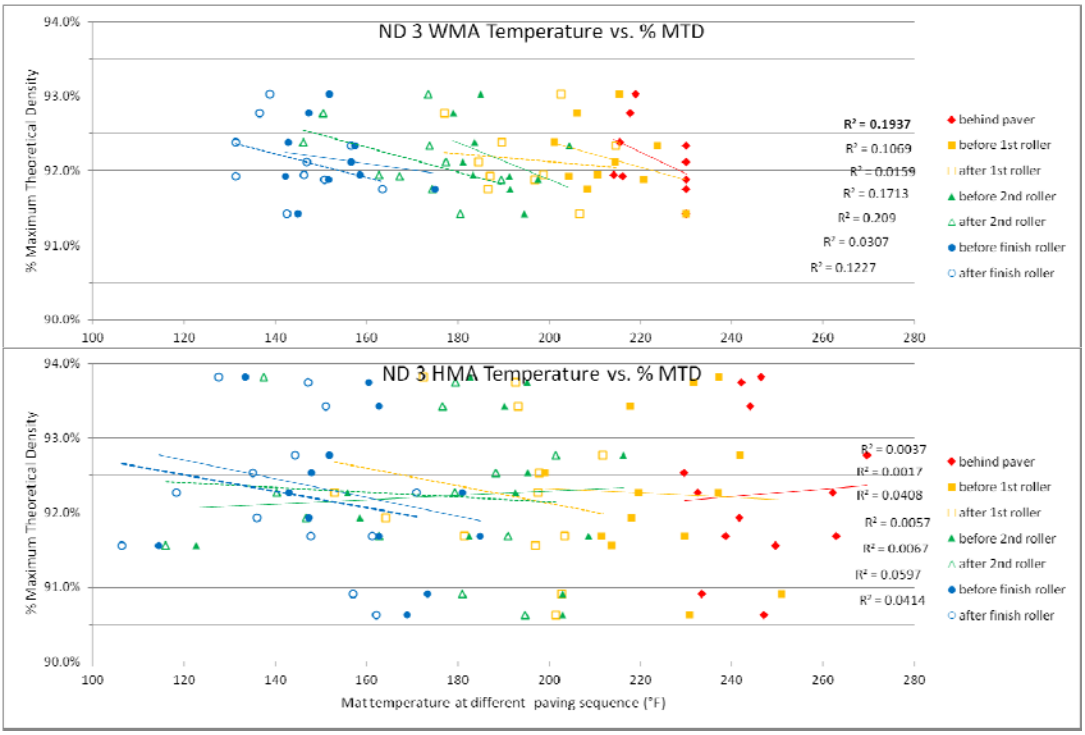

Figure 10. ND 3 asphalt temperature correlated to core density

However, the conclusion should be considered only interim that there is no correlation between field asphalt temperature and density. One reason for qualifying the conclusion is that the density and temperature data analyzed here originated not from identical locations, but from locations in the proximity ranging from tens of feet to hundreds of feet. From the investigator's experience in the previous research, it is conceivable that there does exist some correlation between asphalt temperature and density but it requires the "right" field data to substantiate that relationship. The investigator had previously found a strong correlation (R^2 of over 0.9) between asphalt temperature and core density sampled at eight identical locations. Thus, the possibility of asphalt temperature influencing the ability to attain desirable density should not completely be disregarded despite the conclusion from this research leaning in the other direction.

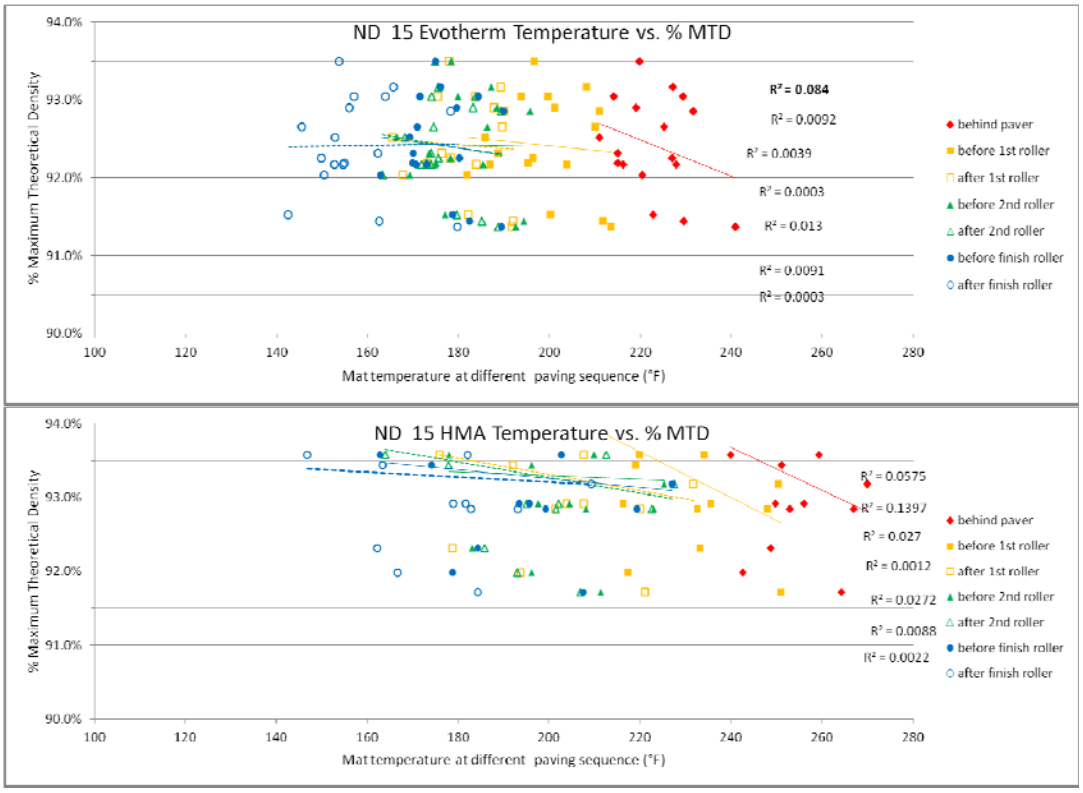

Figure 11. ND 15 asphalt temperature correlated to core density

CHAPTER 4. CONCLUSIONS

The research reported here conducted field investigation of WMA and HMA temperatures during paving operations. Thermal images of WMA and HMA were acquired for ten days during ND 3 and ND 15 paving, which overall lasted for a total of twenty days ranging from 2011 to 2012 construction seasons. Field temperatures of three different types of WMA additives or processes were compared to HMA temperatures: Advera, Evotherm, and foamed asphalt. Based on the observations from ND 3 and ND 15 paving that pointed to the consistent directions, it can be concluded that WMA was laid down at lower temperatures by 25 to 30 °F than HMA and that WMA temperatures were less variable for a given day of paving. WMA appeared to cool more slowly than HMA, but the amount of WMA temperature drop varied depending on the paving cycle time.

Although ND 15 paving involved 40 to 45 miles of haul, the densities achieved were similar to those of ND 3 paving. The use of pneumatic tire roller for intermediate rolling and completion of paving within approximately 21 minutes after laydown are also notable. However, the attempt to relate WMA and HMA temperatures to compacted density achieved during ND 3 and ND 15 paving led to only weak correlation. This may be partly due to the fact that core density and asphalt temperature data did not coincide in the sampling location. Thus, a conclusion is drawn on a preliminary basis that field temperatures of WMA or HMA at any stage in the paving process may not alone be used to predict the results of compaction. Considering the prevailing belief regarding the impact of field asphalt temperature, a working hypothesis is proposed: that asphalt temperature during paving has the potential to affect the ability to attain desirable density. Future efforts to quantify the potential effect on density will likely involve obtaining thermal pictures of asphalt concrete and in-place densities at the same sampling locations.

The findings from this investigation provide support for reduced rate of cooling of WMA temperatures. Future research is suggested to examine the potential of WMA for extending paving seasons. Specific efforts in support of the research objective may be focused on assessing through computer simulation WMA’s relative advantages of

lowering the risks associated with cool weather paving. For example, what are the risks of using WMA in late season paving and not having sufficient time available for effective compaction? Are all or some of those risks any lower than that with HMA? Required steps for answering related research questions may include estimating thermal diffusivity of WMA and HMA and predicting the available compaction time given environmental conditions of North Dakota projected from 20-year history. Existing asphalt pavement cooling models, such as CalCool, and thermal property values of HMA reported in the literature could serve as a starting point. Although it is not unreasonable that WMA possess somewhat different values of thermal properties than HMA, initially it may be necessary to assume no difference and test that null hypothesis against already available data.

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APPENDIX

A. THERMAL PICTURES FROM ND 3 PAVING

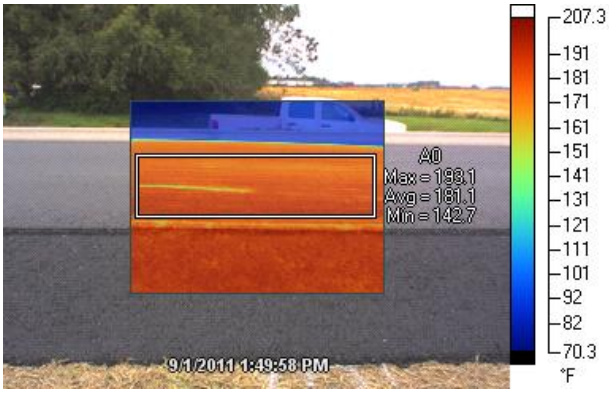
WMA ND 3 North Bound Lane N01 at STA 29+55 = RP 160

Unloading

Behind Paver

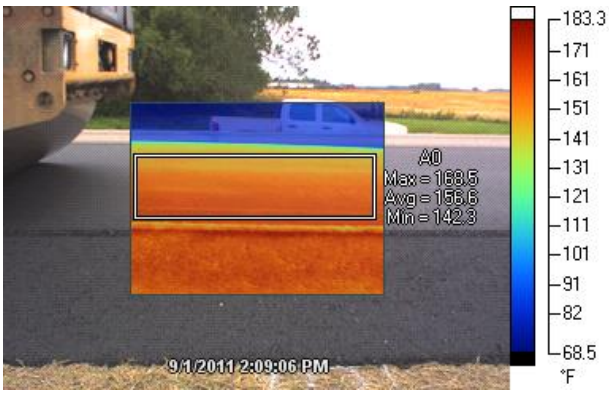
Before Breakdown Roller

After Breakdown Roller

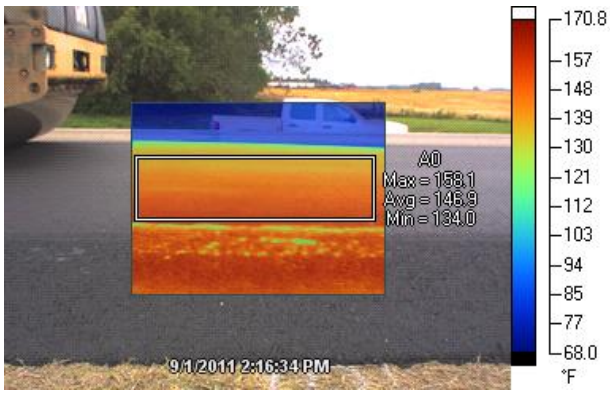


Before Intermediate Roller

After Intermediate Roller

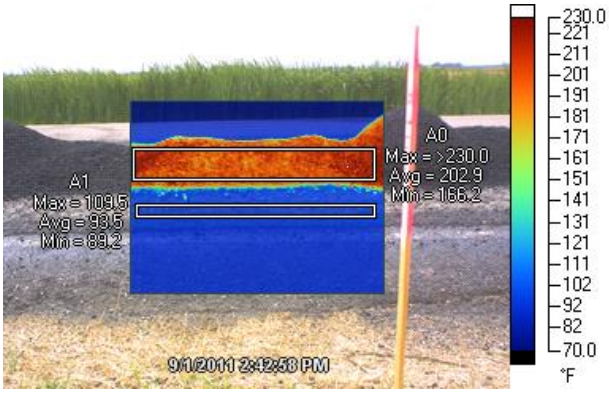


Before Finish Roller



After Finish Roller

WMA ND 3 North Bound Lane N02 at STA 54+00 = 2,445 ft north of RP 160



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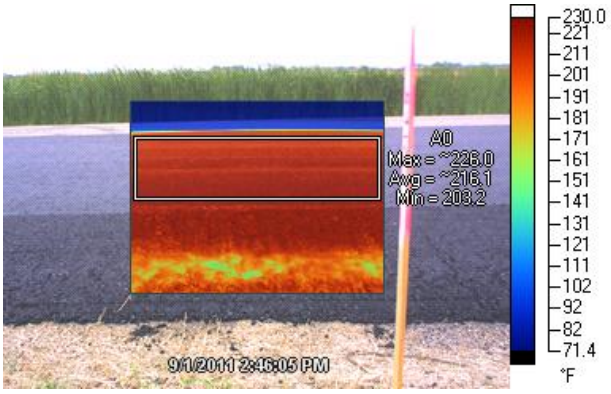
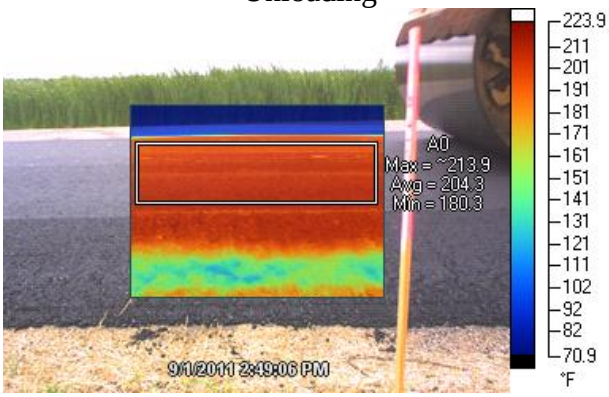


Behind Paver



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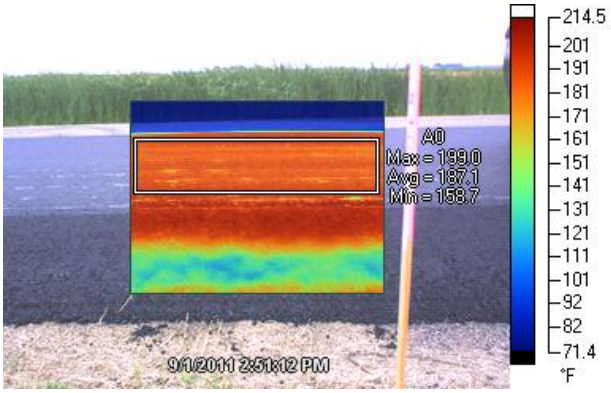
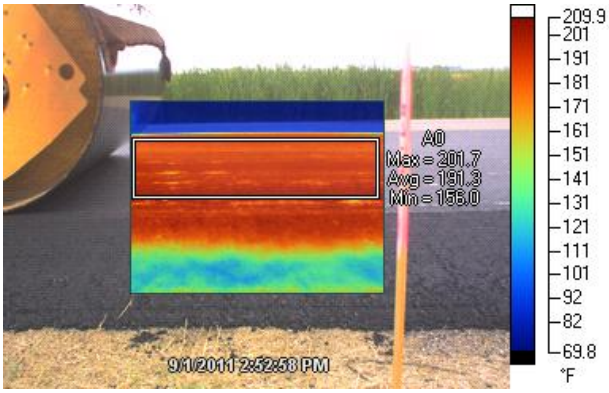
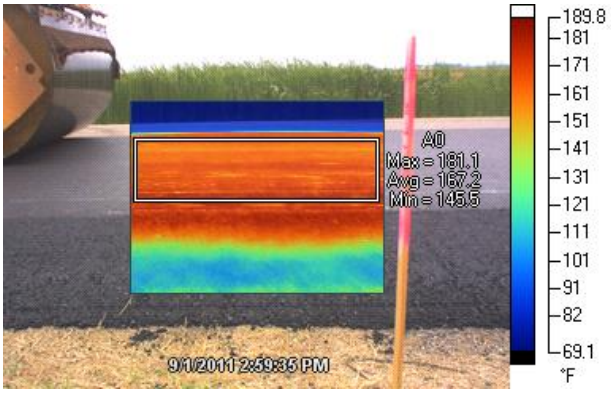


After Breakdown Roller



Before Intermediate Roller



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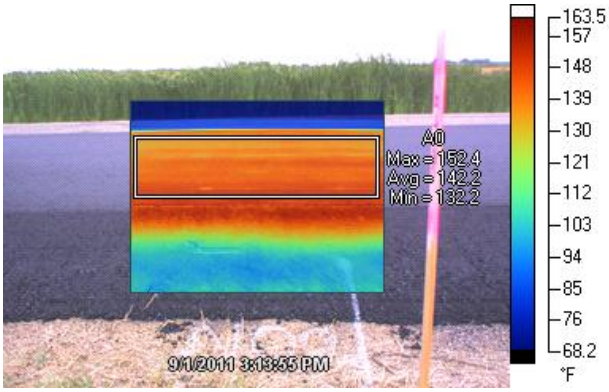
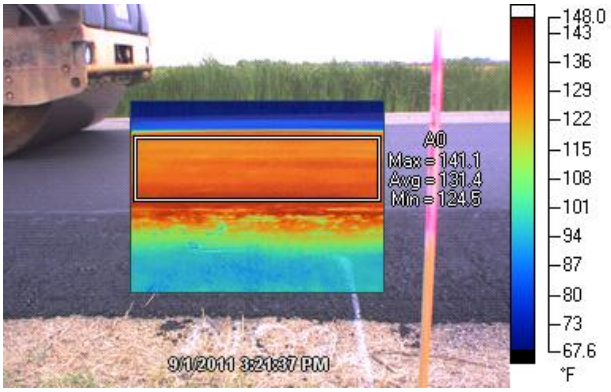
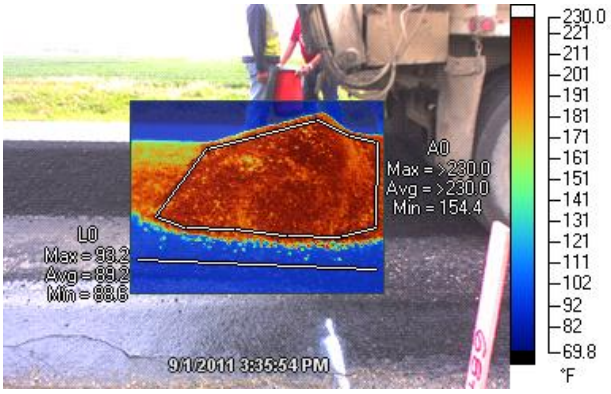


Before Finish Roller



After Finish Roller

WMA ND 3 North Bound Lane N03 at STA 68+00 = 3,845 ft north of RP 160



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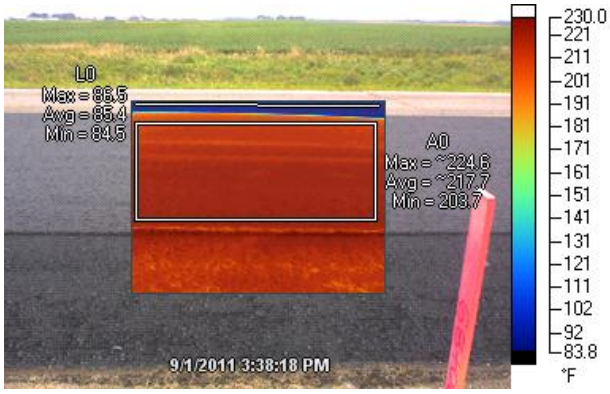
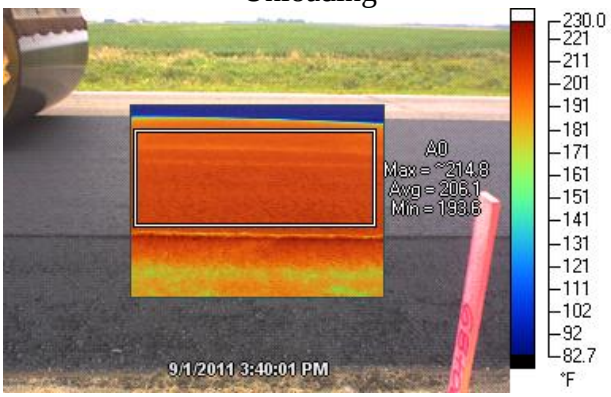


Behind Paver



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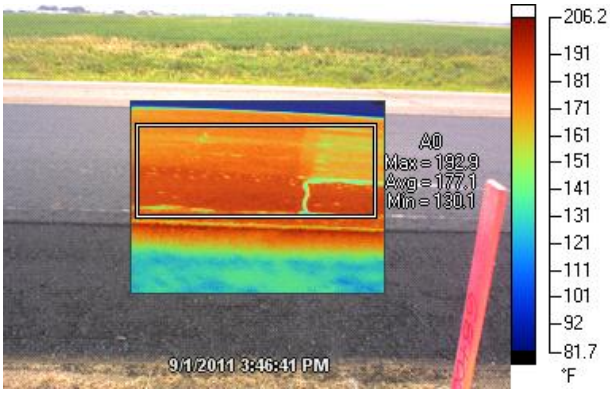

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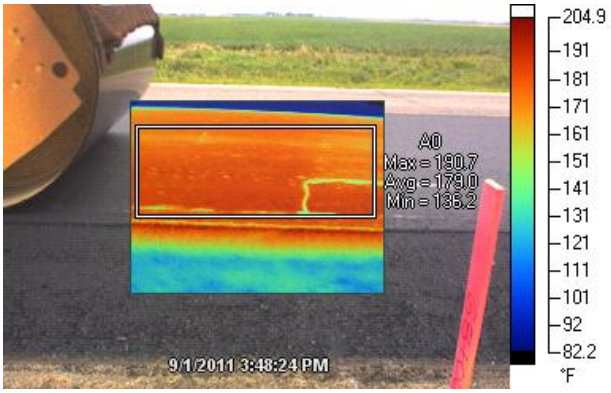
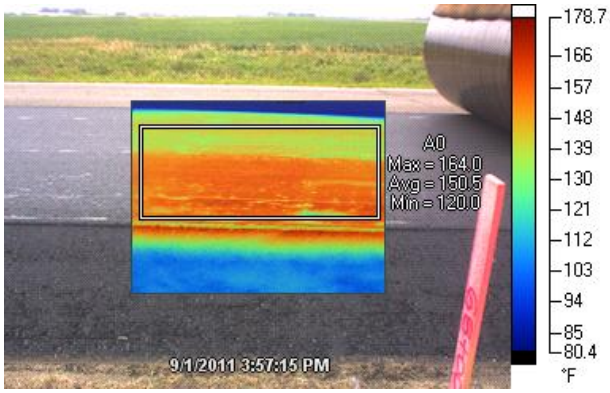


Before Intermediate Roller



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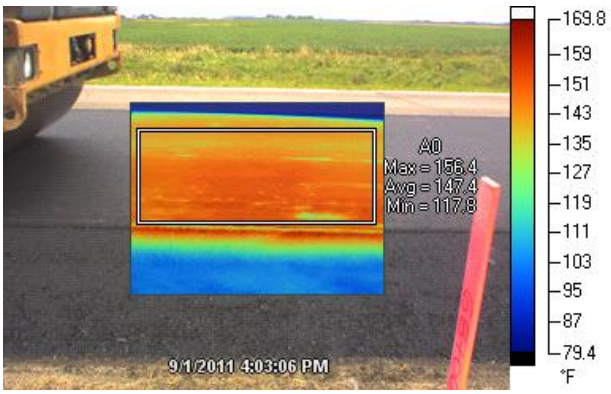

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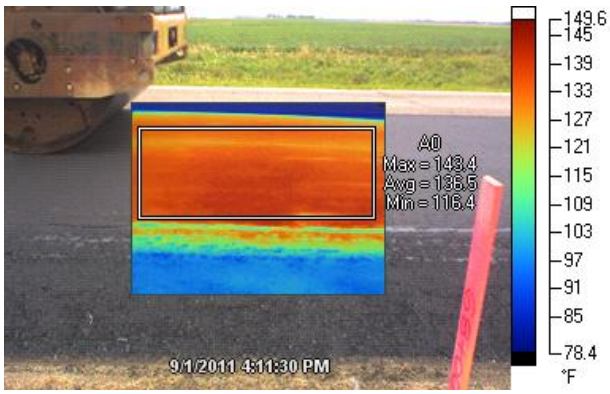
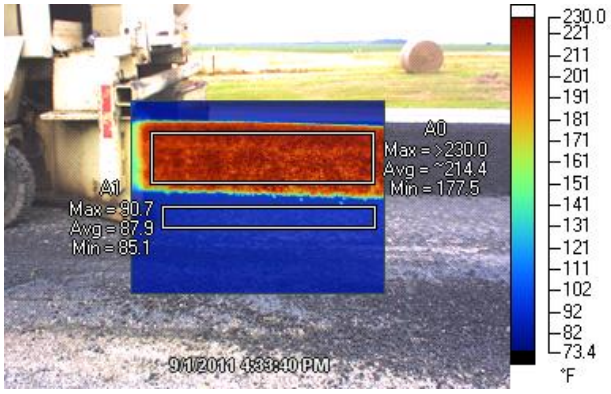


After Finish Roller

WMA ND 3 North Bound Lane N04 at STA 94+00 = 6,445 ft north of RP 160



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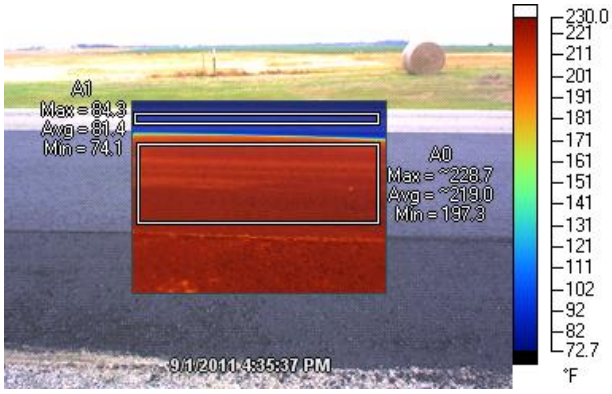

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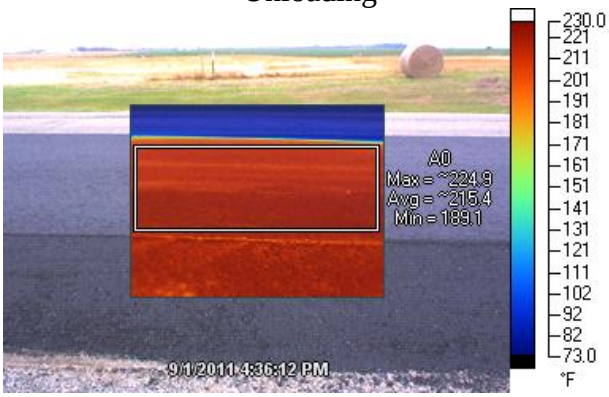

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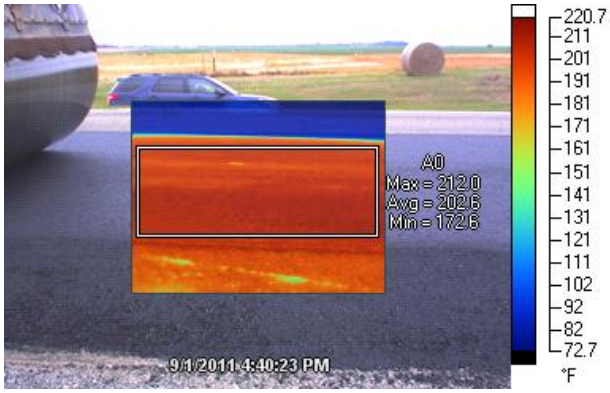

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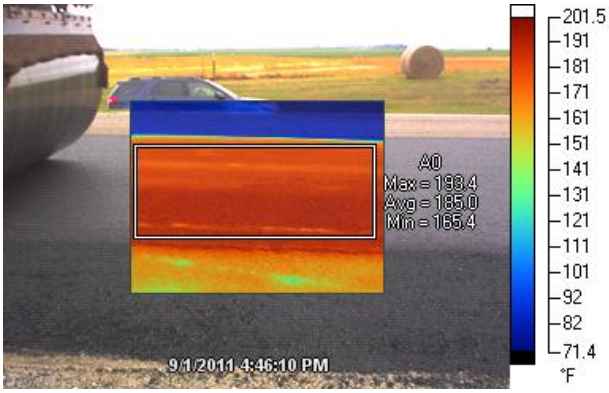

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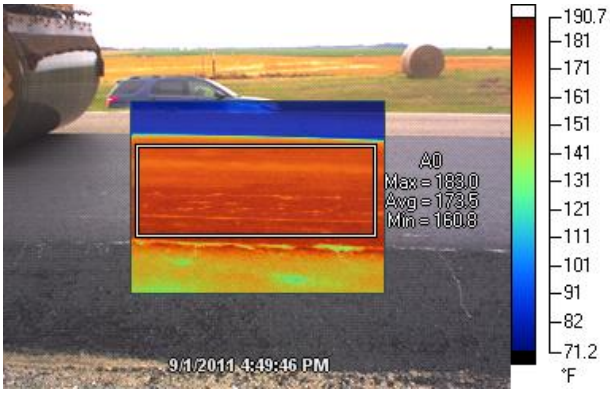

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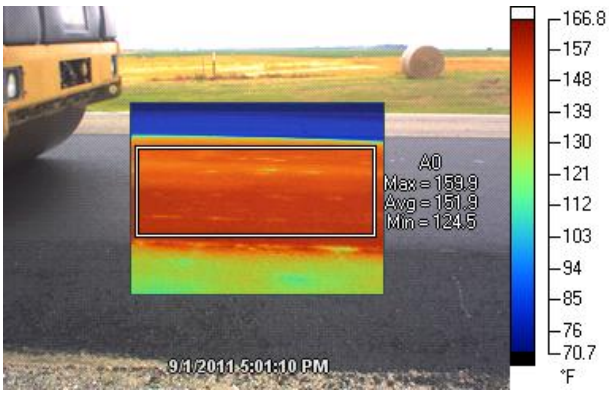

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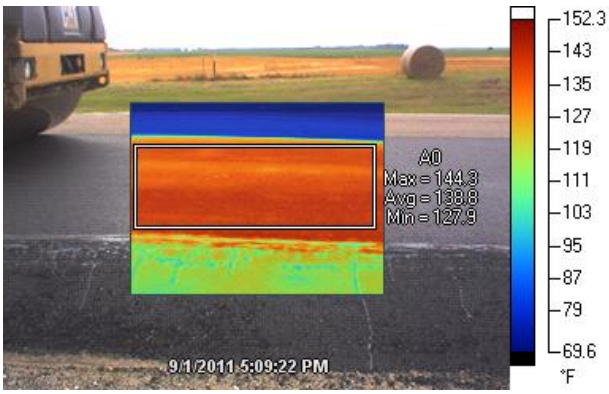
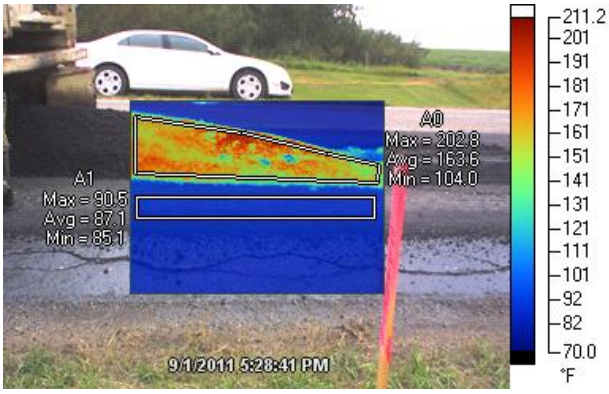


After Finish Roller

WMA ND 3 North Bound Lane N05 at STA 114+00 = 8,445 ft north of RP 160



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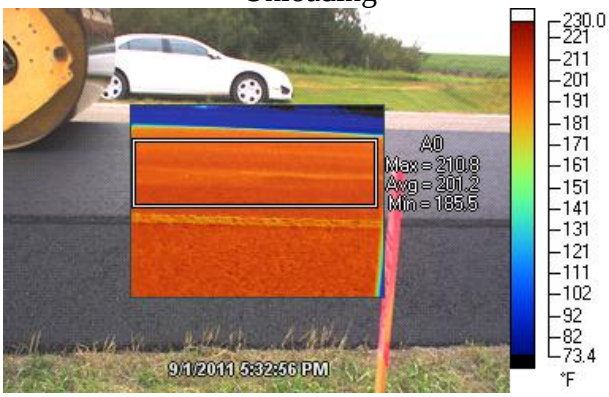

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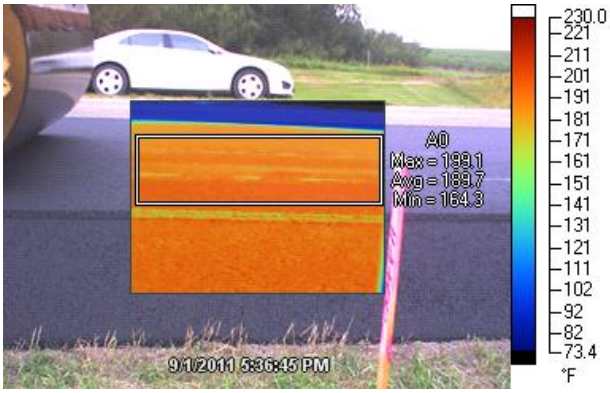

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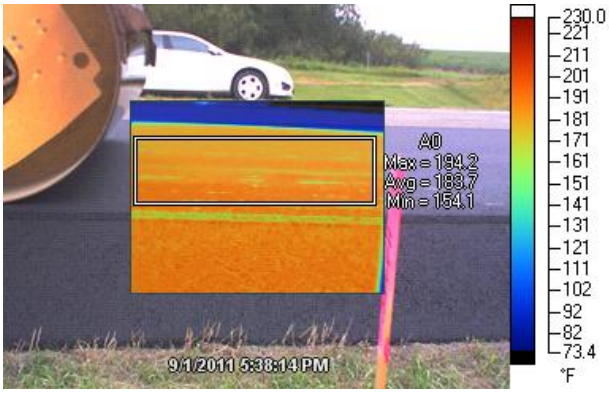

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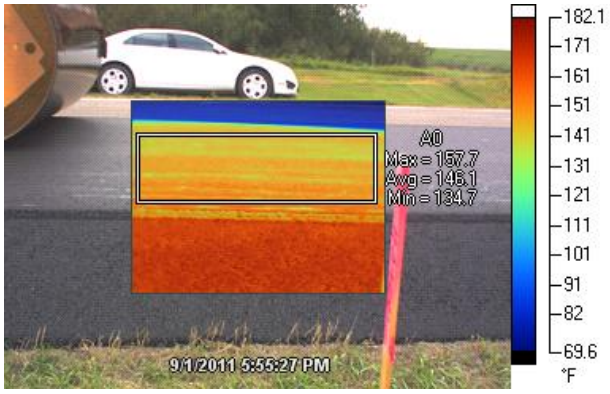

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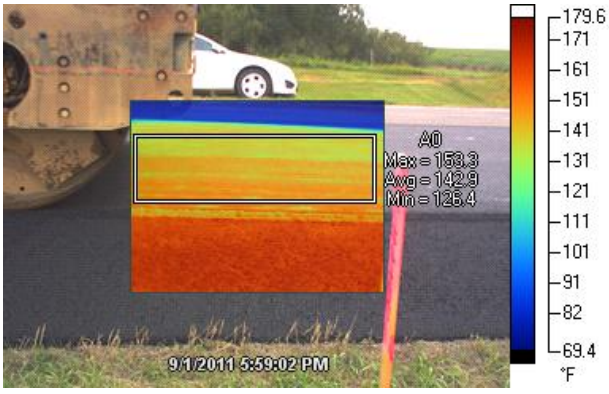

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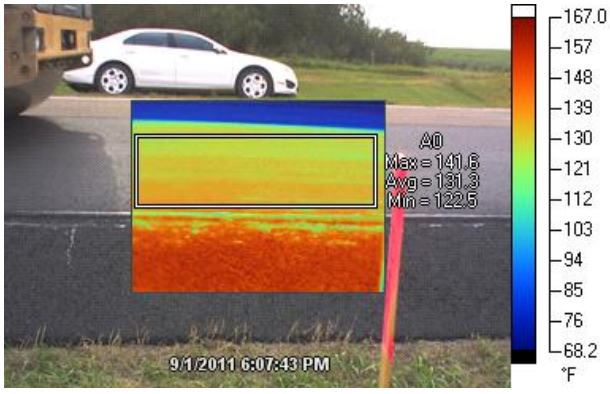


After Finish Roller

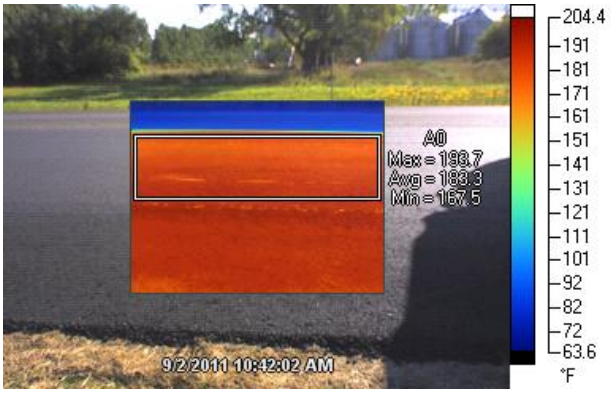
WMA ND 3 South Bound Lane S01 at STA 29+55 = RP 160

Unloading

Behind Paver

Before Breakdown Roller

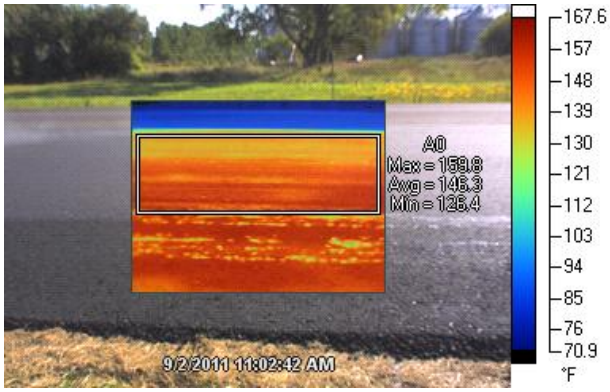
After Breakdown Roller



Before Intermediate Roller

After Intermediate Roller

Before Finish Roller



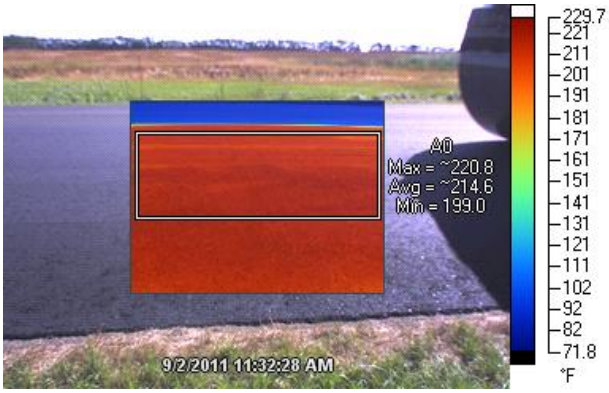
After Finish Roller

WMA ND 3 South Bound Lane S02 at STA 58+00 = 2,845 ft north of RP 160

Unloading

Behind Paver

Before Breakdown Roller



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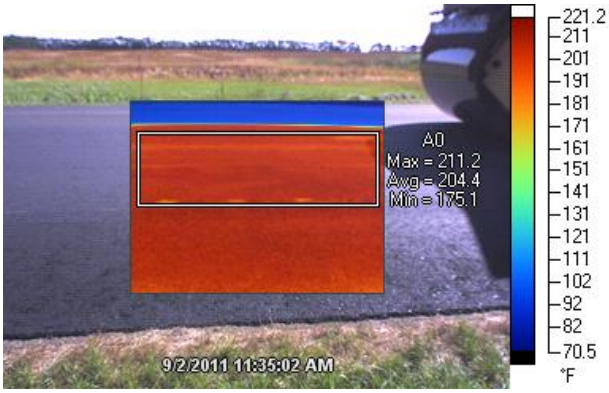

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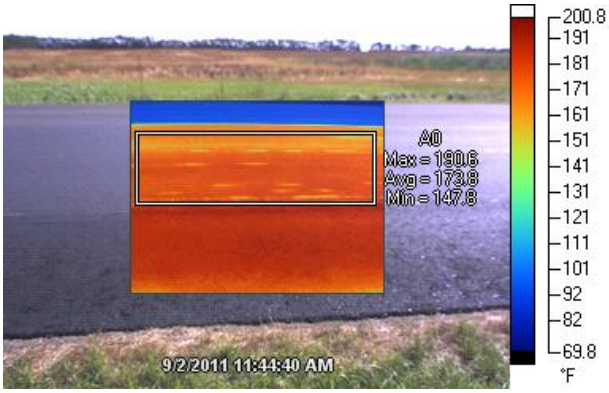
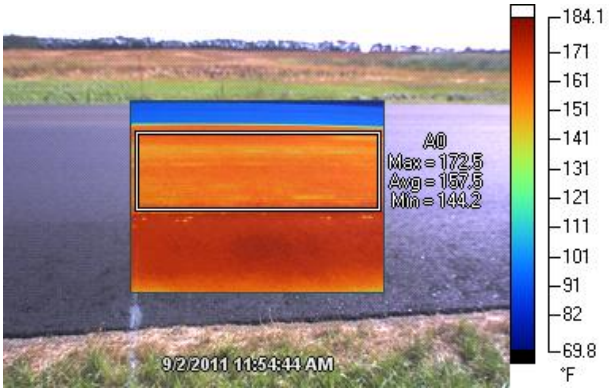


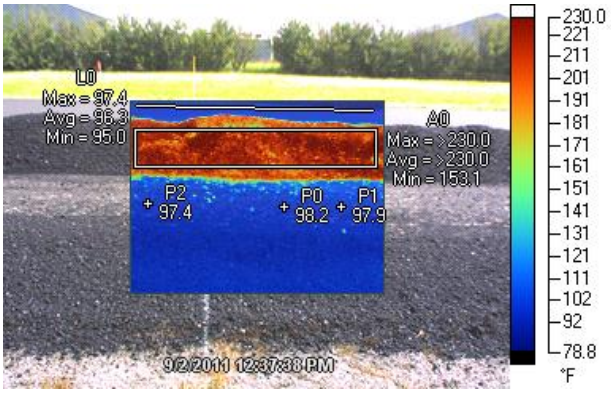
After Intermediate Roller



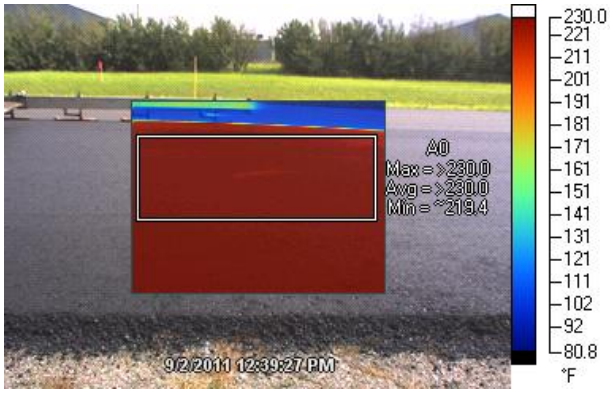
Before Finish Roller

After Finish Roller

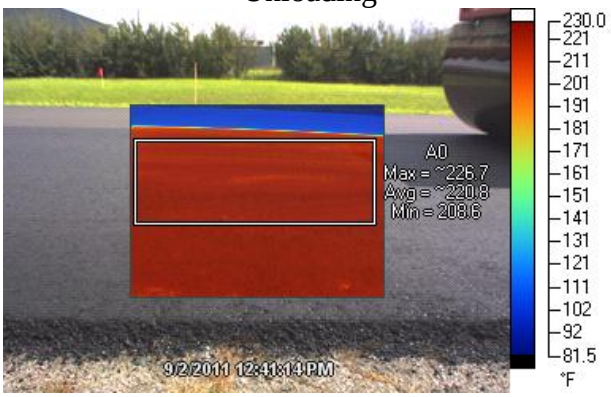
WMA ND 3 South Bound Lane S03 at STA 84+00 = 5,445 ft north of RP 160



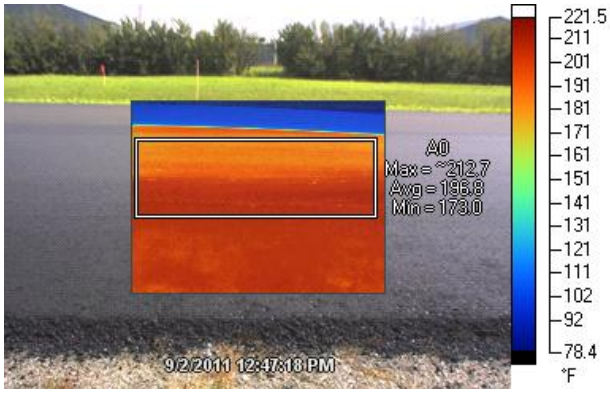
Unloading



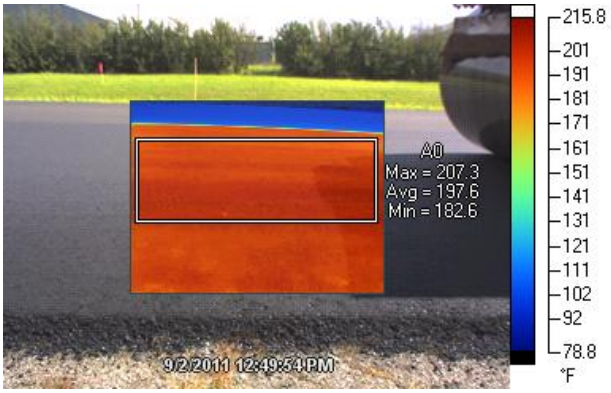
Behind Paver



Before Breakdown Roller



After Breakdown Roller



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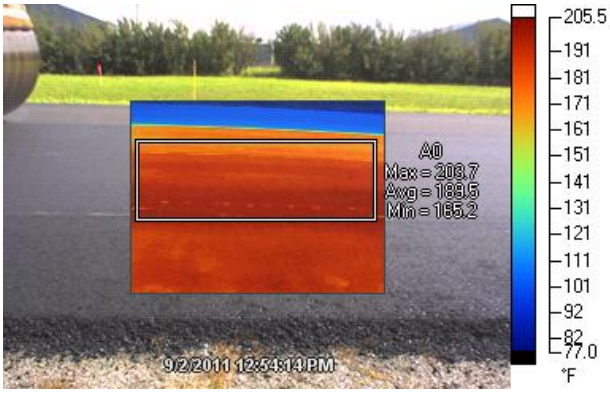
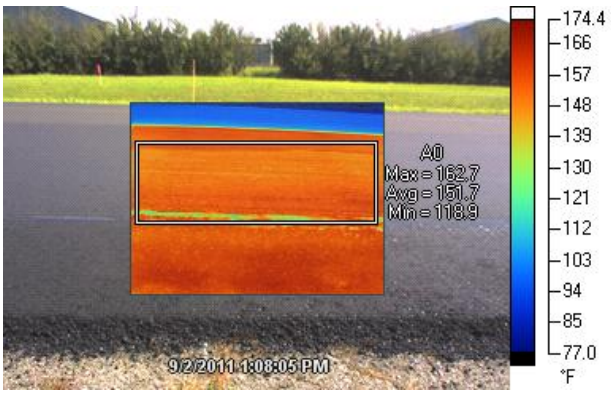
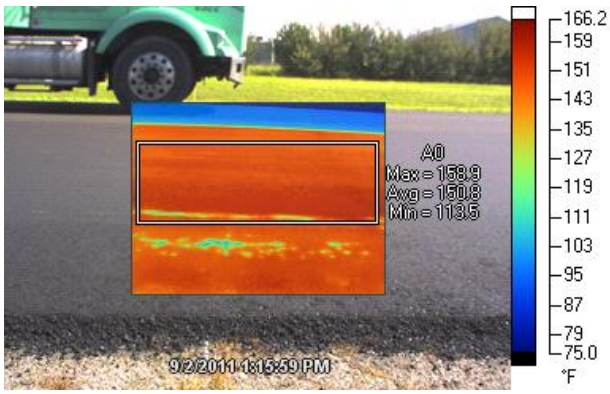


After Intermediate Roller

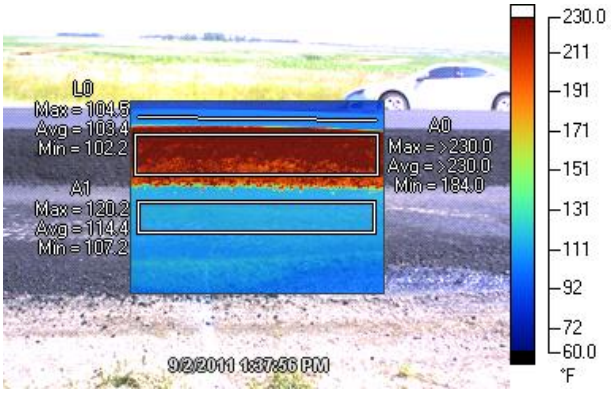


Before Finish Roller

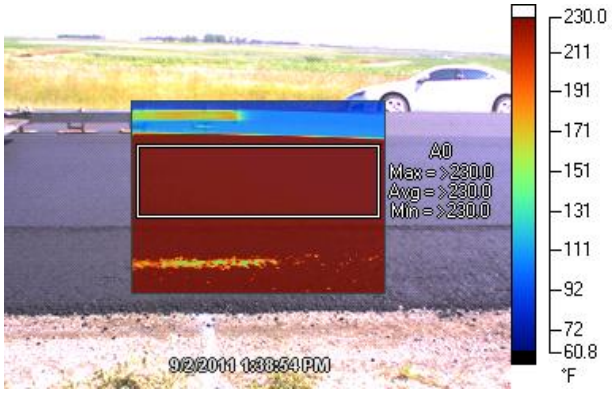


After Finish Roller

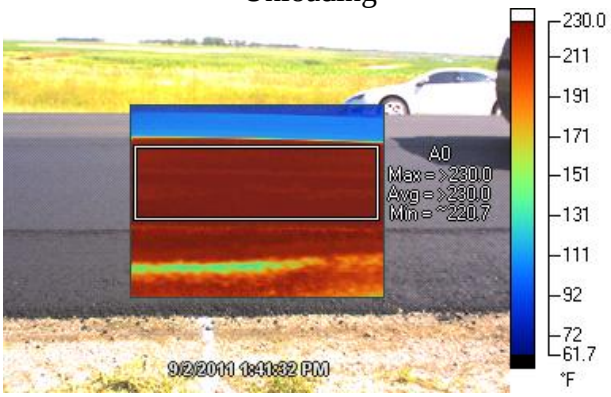
WMA ND 3 South Bound Lane S04 at STA 112+00 = 8,245 ft north of RP 160



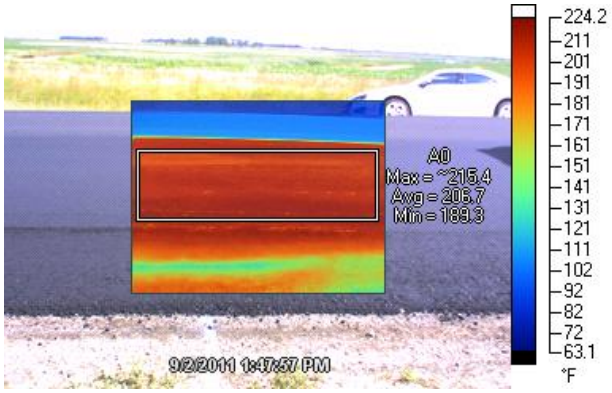
Unloading



Behind Paver

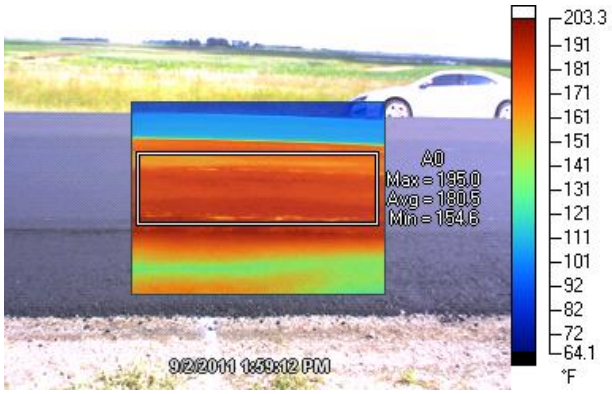


Before Breakdown Roller

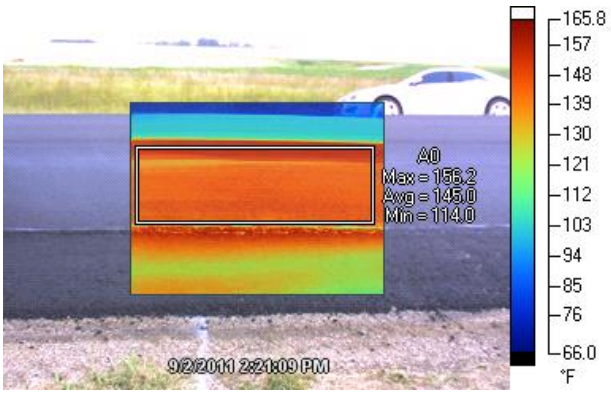


After Breakdown Roller

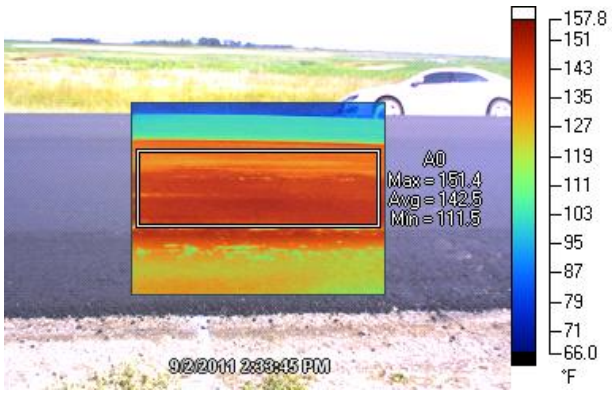
Before Intermediate Roller



After Intermediate Roller

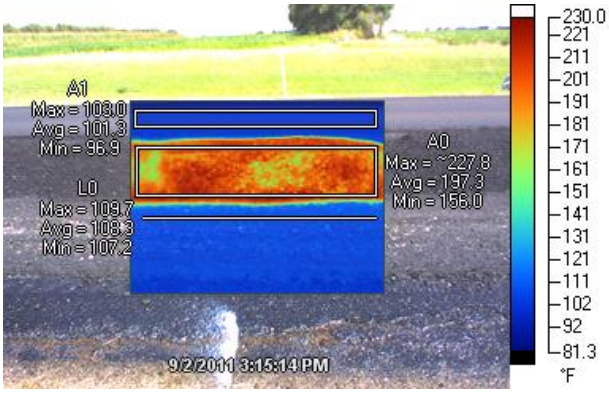


Before Finish Roller



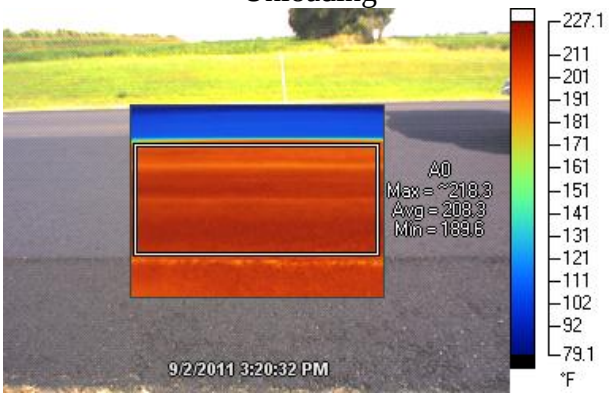
After Finish Roller

WMA ND 3 South Bound Lane S05 at STA 156+00 = 12,645 ft north of RP 160



Unloading

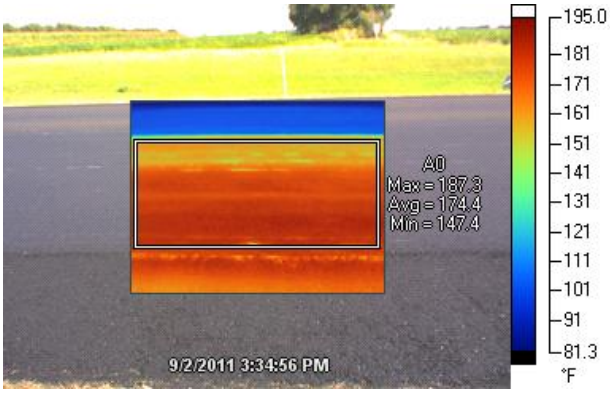
Behind Paver



Before Breakdown Roller

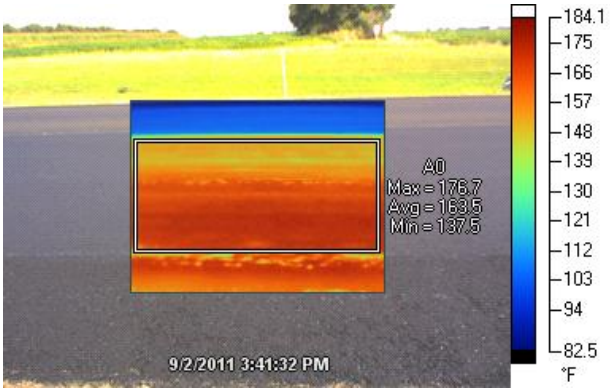
After Breakdown Roller

Before Intermediate Roller



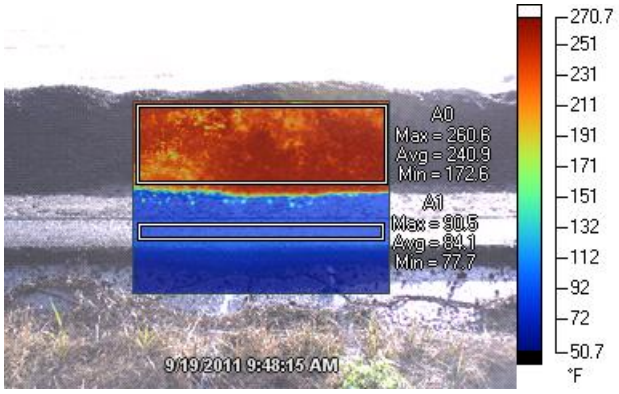
After Intermediate Roller

Before Finish Roller

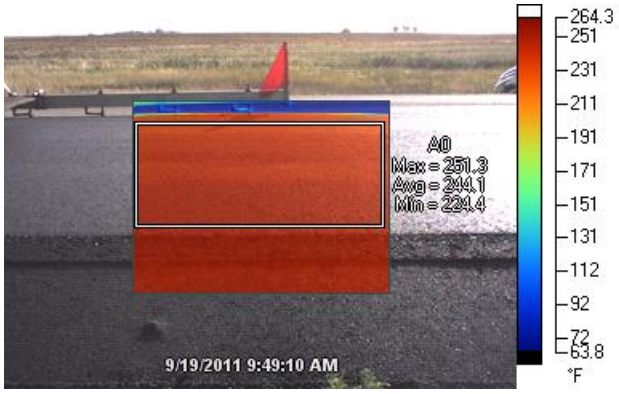


After Finish Roller

HMA ND 3 South Bound Lane S01 at STA 286+00 = 905 ft north of RP 165

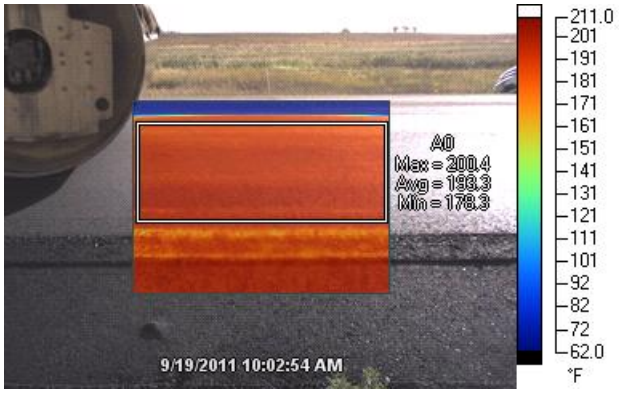


Unloading



Behind Paver

Before Breakdown Roller



After Breakdown Roller

Before Intermediate Roller

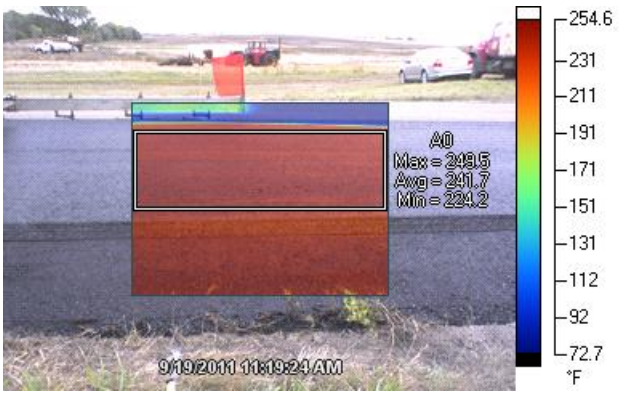
After Intermediate Roller

Before Finish Roller

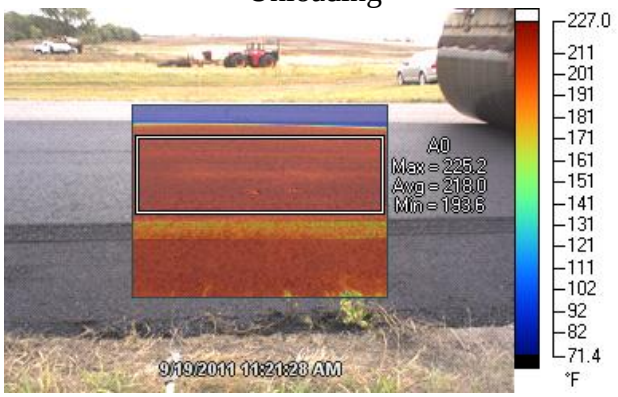
After Finish Roller

HMA ND 3 South Bound Lane S02 at STA 310+00 = 4,505 ft north of RP 165

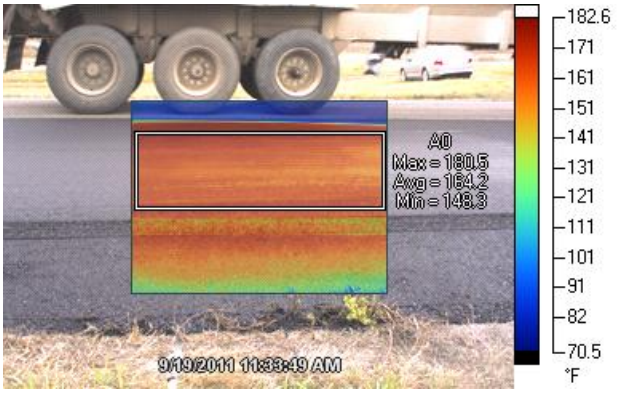
Unloading



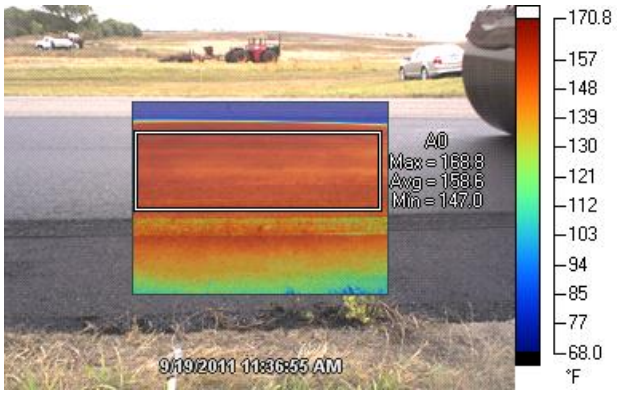
Behind Paver



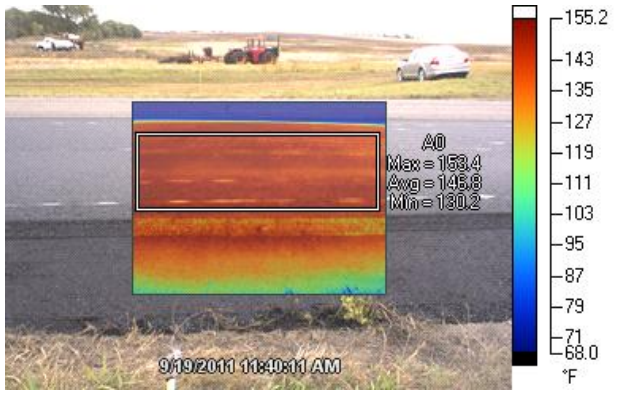
Before Breakdown Roller



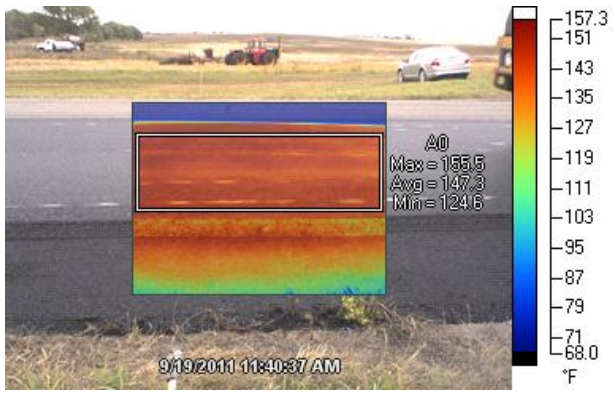
After Breakdown Roller



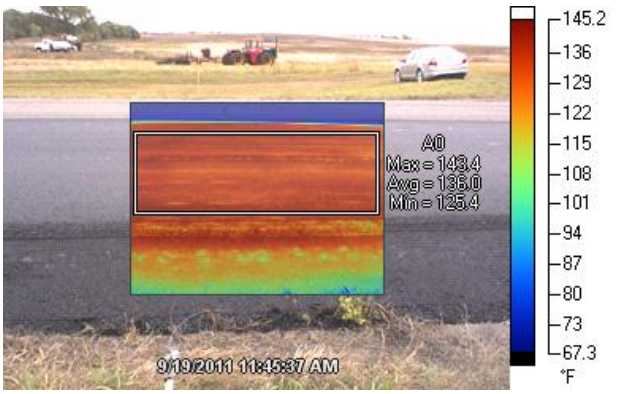
Before Intermediate Roller



After Intermediate Roller

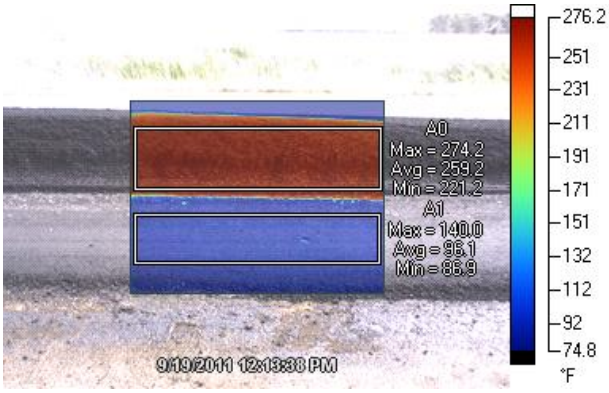


Before Finish Roller

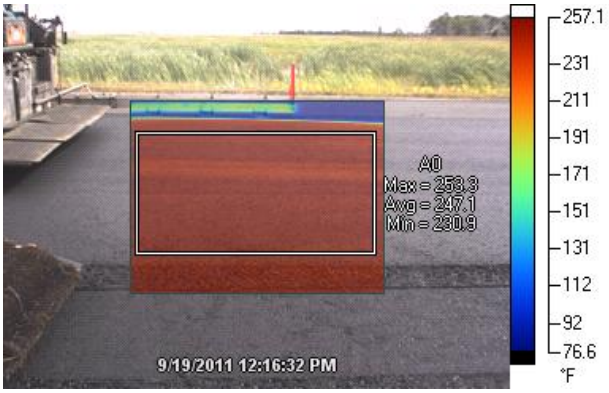


After Finish Roller

HMA ND 3 South Bound Lane S03 at STA 334+00 = 6,905 ft north of RP 165

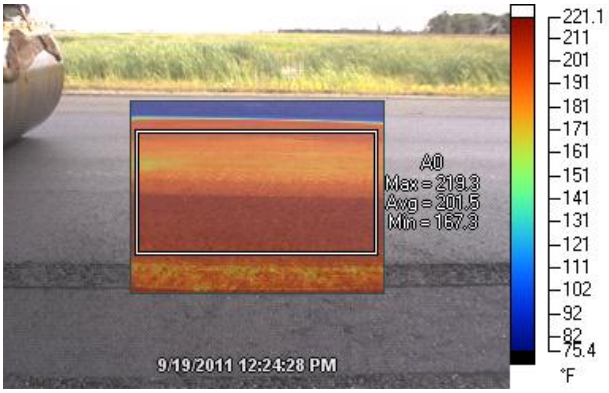


Unloading



Behind Paver

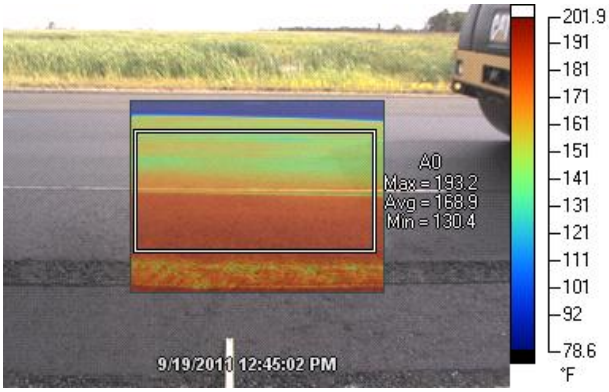
Before Breakdown Roller



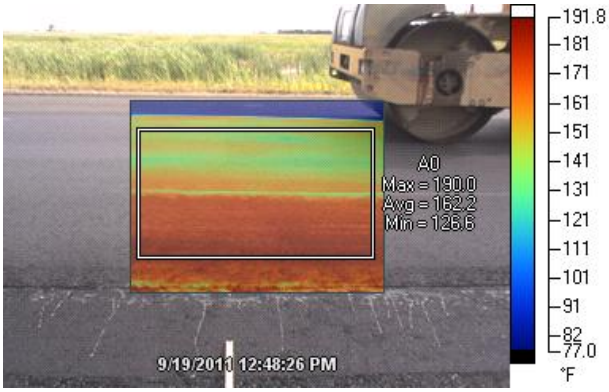
After Breakdown Roller

Before Intermediate Roller

After Intermediate Roller

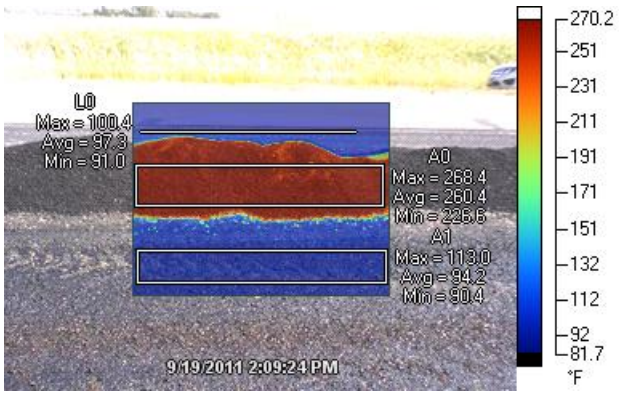


Before Finish Roller



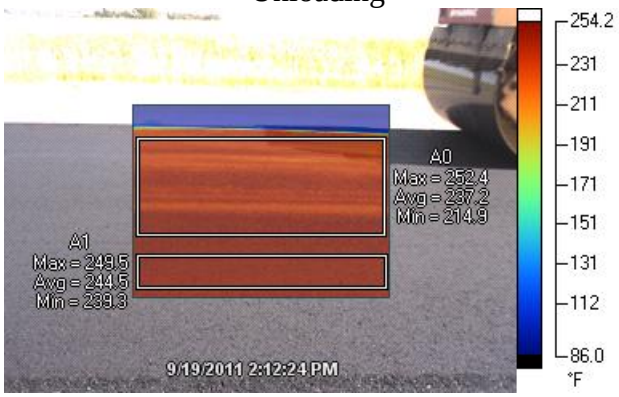
After Finish Roller

HMA ND 3 South Bound Lane S04 at STA 364+00 = 9,905 ft north of RP 165



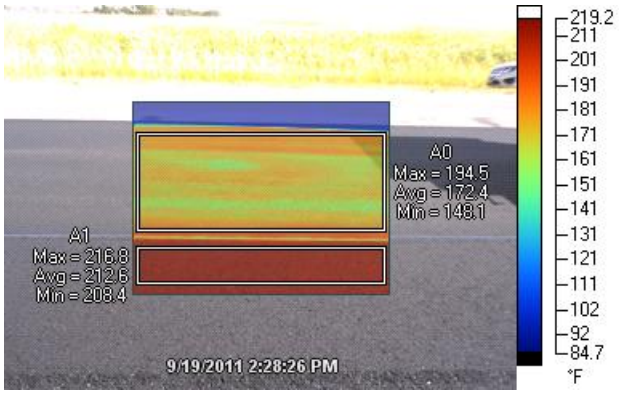
Unloading

Behind Paver

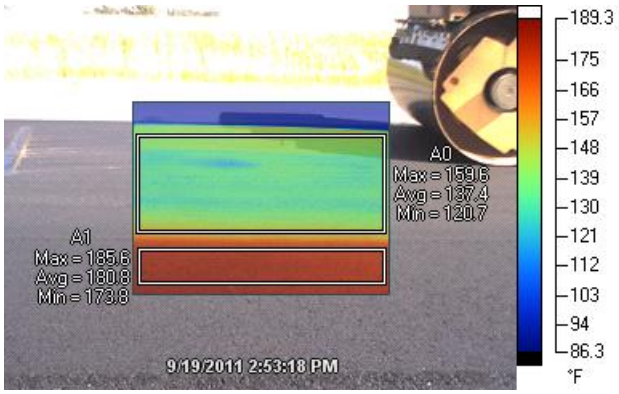


Before Breakdown Roller

After Breakdown Roller



Before Intermediate Roller

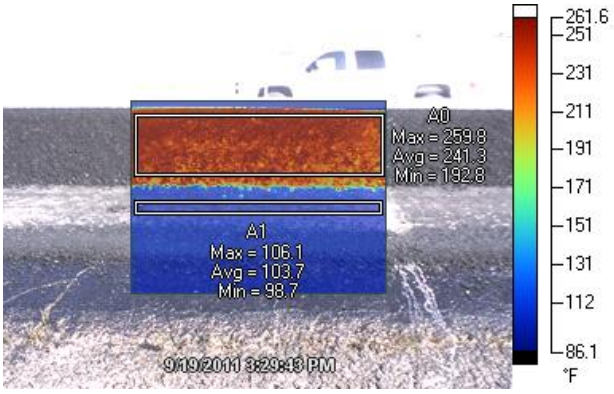


After Intermediate Roller

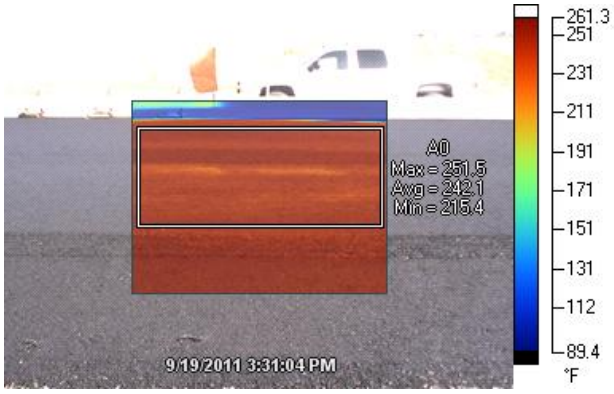
Before Finish Roller

After Finish Roller

HMA ND 3 South Bound Lane S05 at STA 394+00 = 12,905 ft north of RP 165

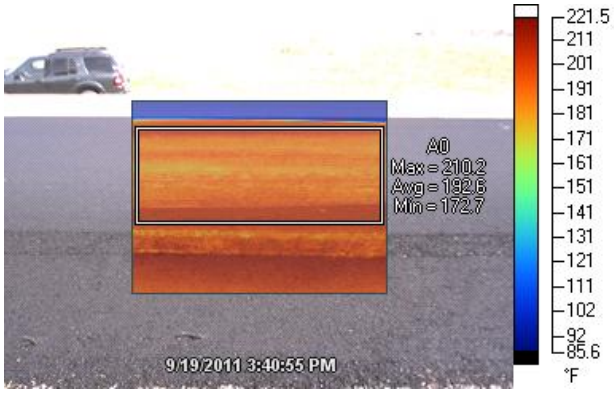


Unloading



Behind Paver

Before Breakdown Roller

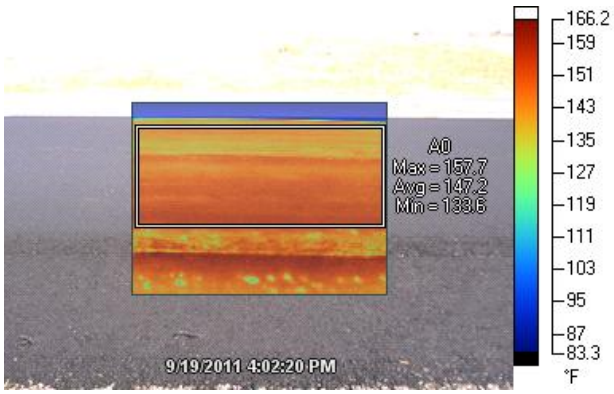


After Breakdown Roller

Before Intermediate Roller

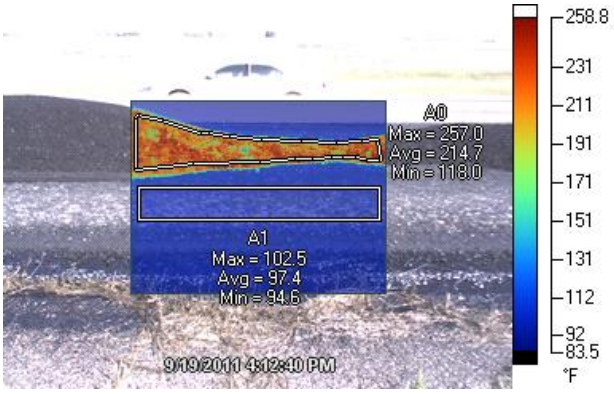
After Intermediate Roller

Before Finish Roller

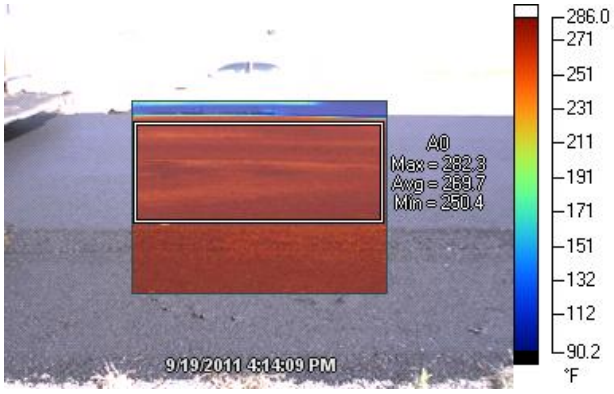


After Finish Roller

HMA ND 3 South Bound Lane S06 at STA 414+00 = 14,905 ft north of RP 165



Unloading



Behind Paver

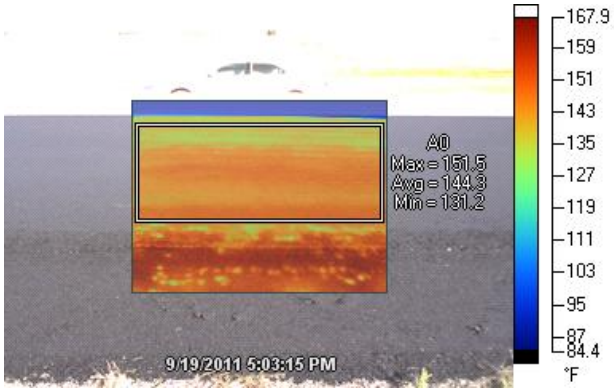
Before Breakdown Roller

After Breakdown Roller

Before Intermediate Roller

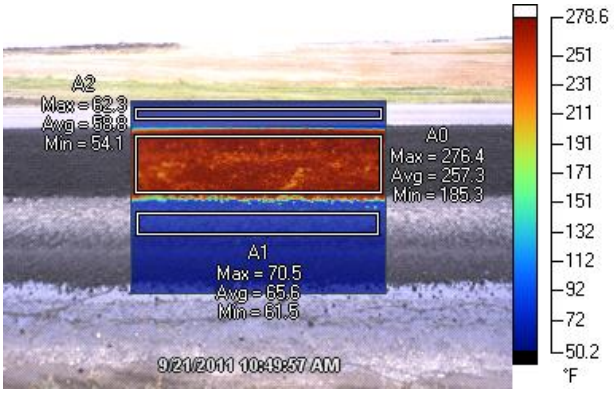
After Intermediate Roller

Before Finish Roller

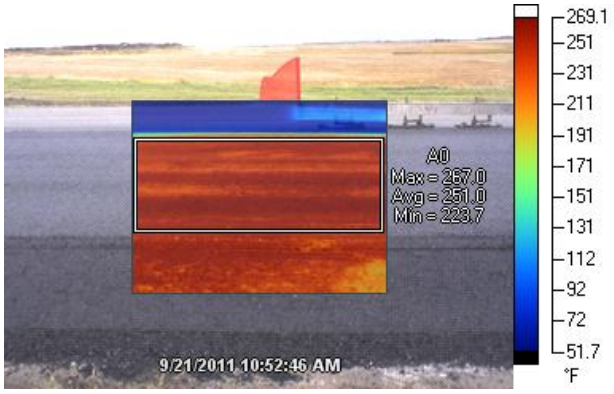


After Finish Roller

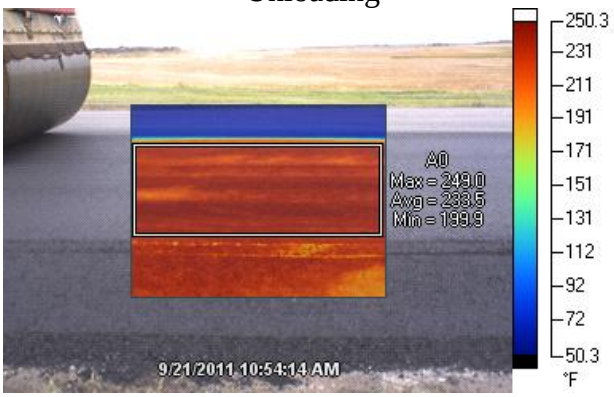
HMA ND 3 North Bound Lane N01 at RP 165 = STA 276+95



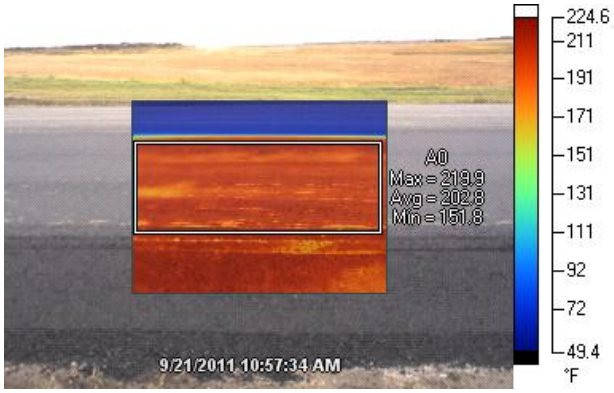
Unloading



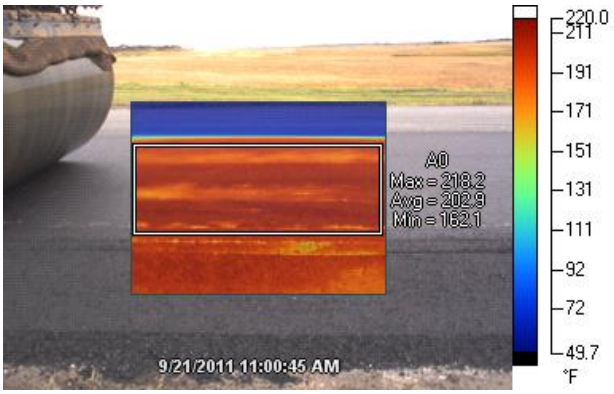
Behind Paver



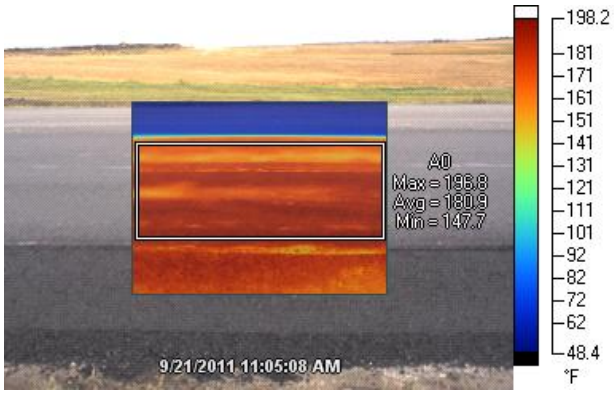
Before Breakdown Roller



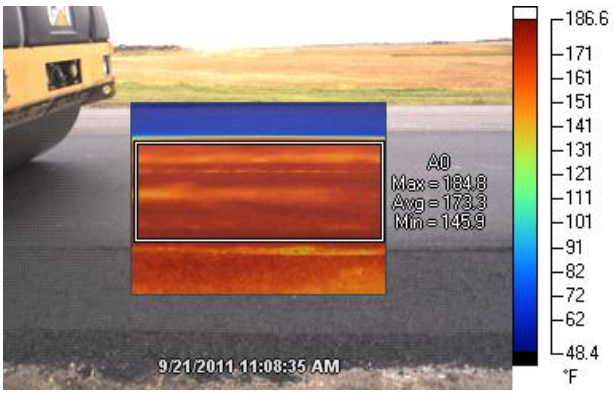
After Breakdown Roller



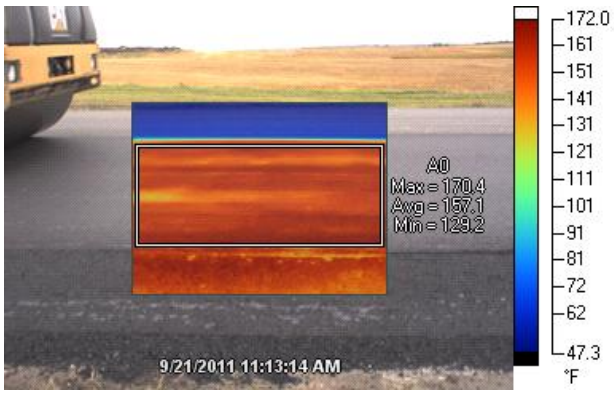
Before Intermediate Roller



After Intermediate Roller

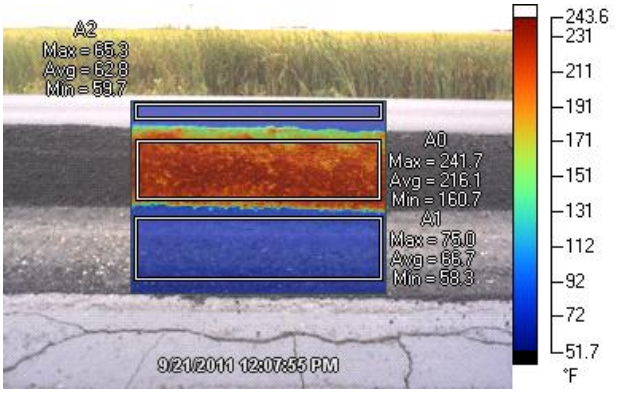


Before Finish Roller



After Finish Roller

HMA ND 3 North Bound Lane N02 at STA 292+00 = 1,505 ft north of RP 165

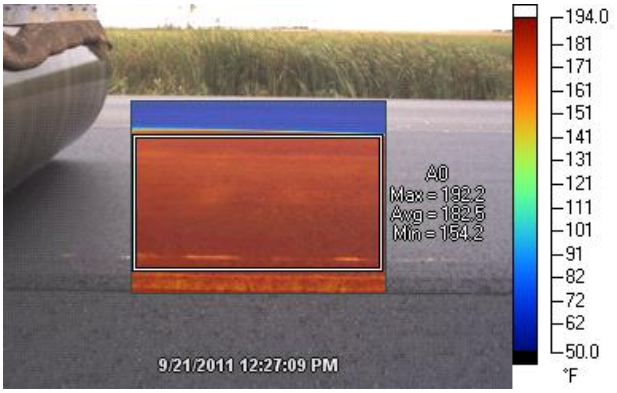


Unloading

Behind Paver

Before Breakdown Roller

After Breakdown Roller



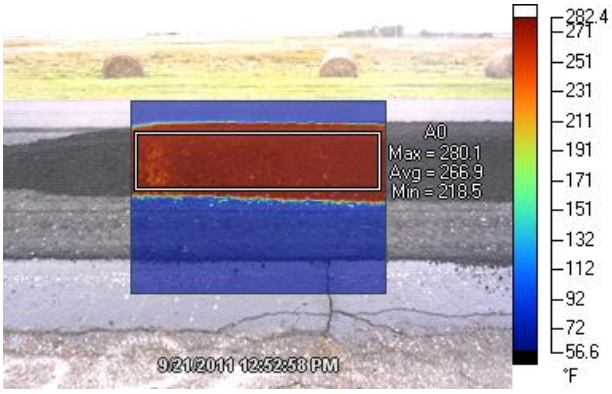
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

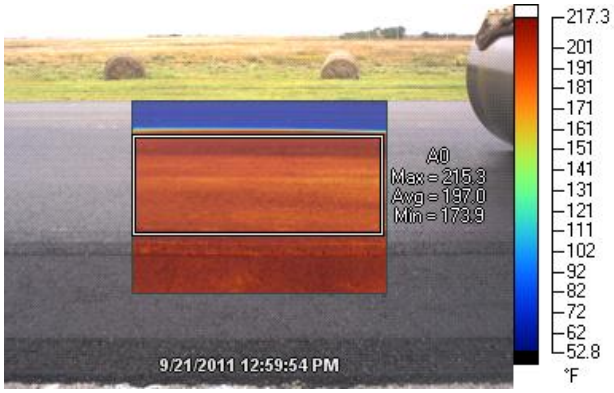
HMA ND 3 North Bound Lane N03 at STA 304+00 = 2,705 ft north of RP 165



Unloading

Behind Paver

Before Breakdown Roller

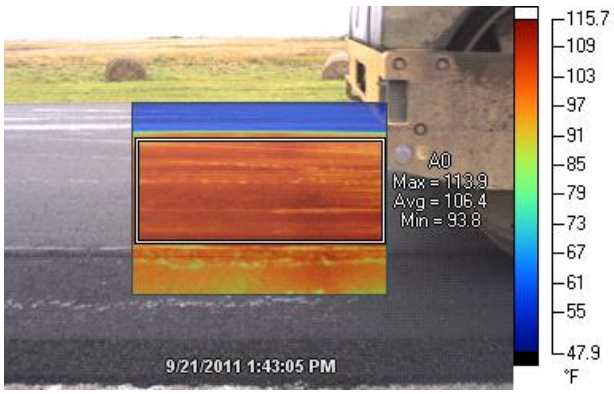


After Breakdown Roller

Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

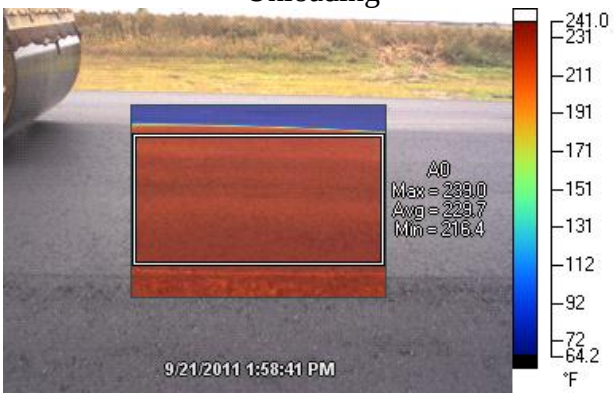


After Finish Roller

HMA ND 3 North Bound Lane N04 at STA 319+42 = 4,247.5 ft north of RP 165

Unloading

Behind Paver



Before Breakdown Roller

After Breakdown Roller

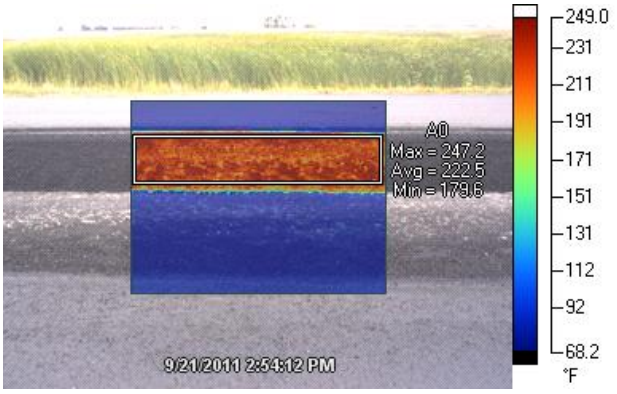
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

HMA ND 3 North Bound Lane N05 at STA 332+53 = 5,558 ft north of RP 165

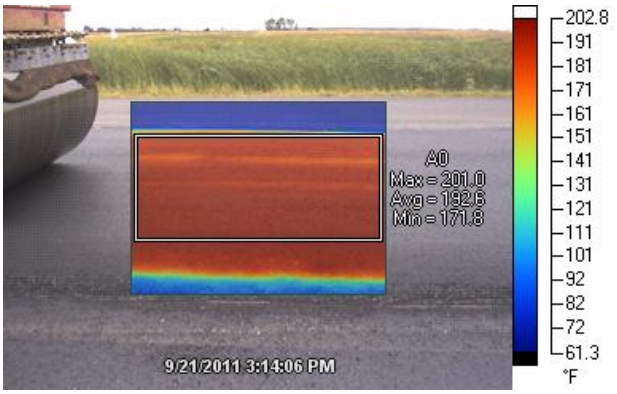


Unloading

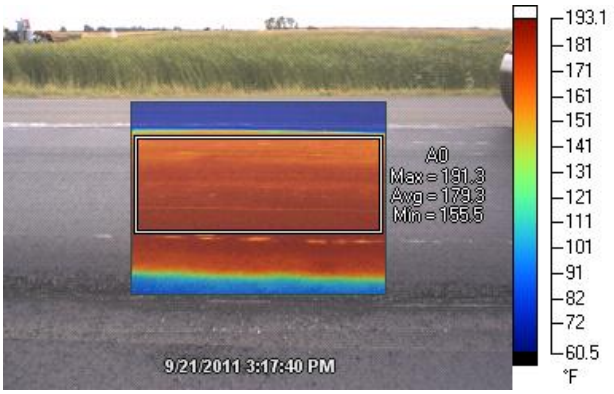
Behind Paver

Before Breakdown Roller

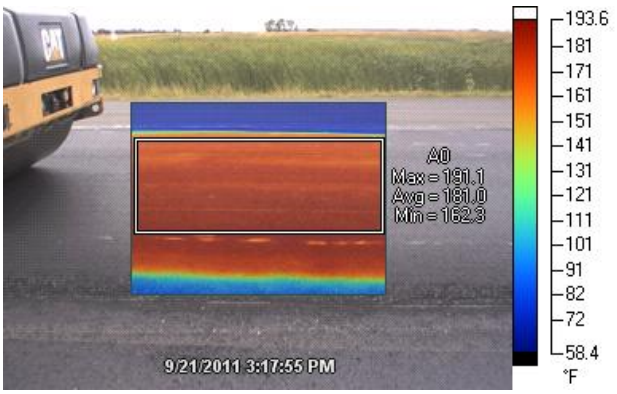
After Breakdown Roller



Before Intermediate Roller



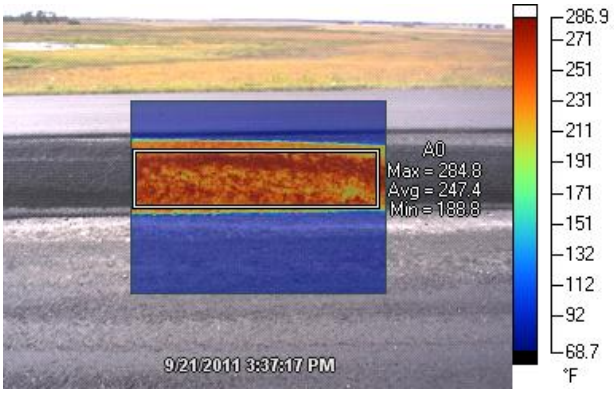
After Intermediate Roller



Before Finish Roller

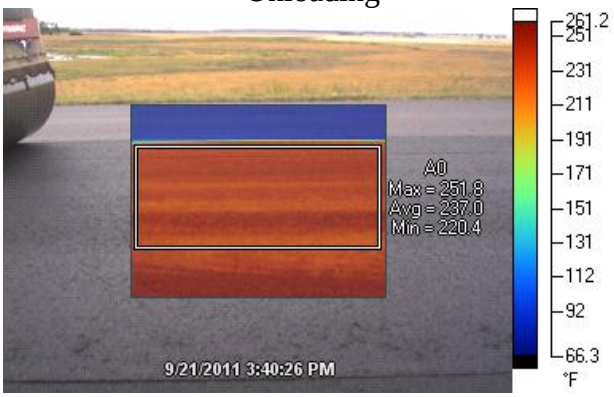
After Finish Roller

HMA ND 3 North Bound Lane N06 at STA 342+00 = 6,505 ft north of RP 165

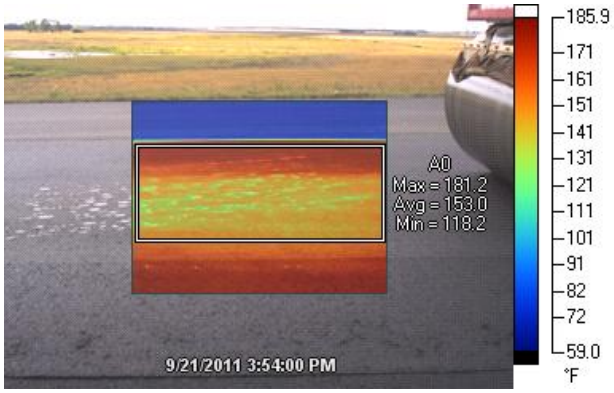


Unloading

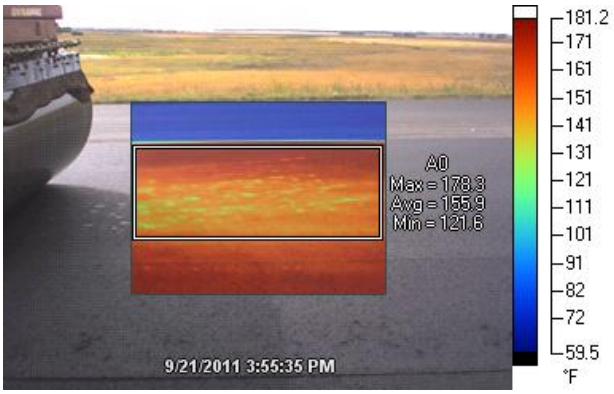
Behind Paver



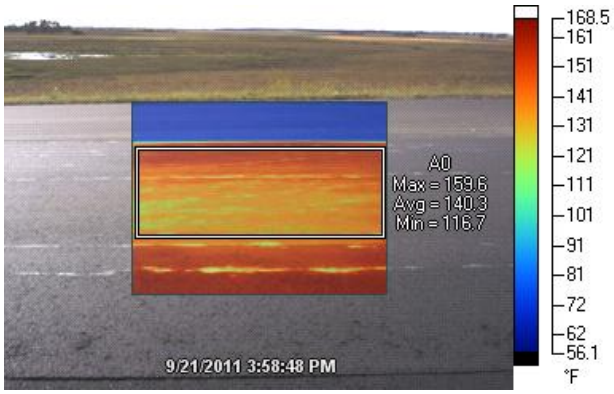
Before Breakdown Roller



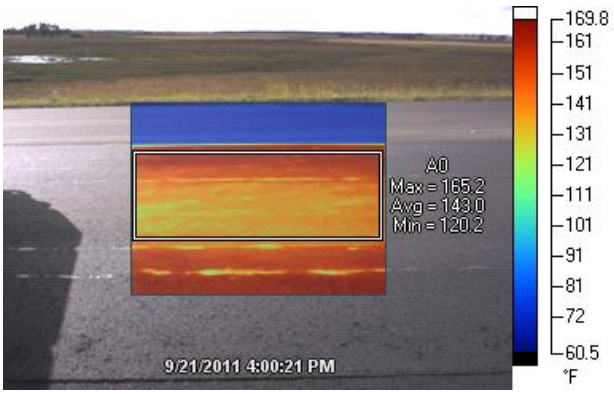
After Breakdown Roller



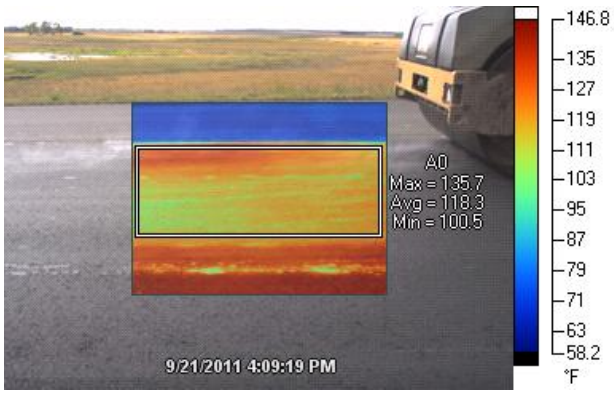
Before Intermediate Roller



After Intermediate Roller



Before Finish Roller



After Finish Roller

HMA ND 3 North Bound Lane N07 at STA 362+00 = 8,505 ft north of RP 165

Unloading

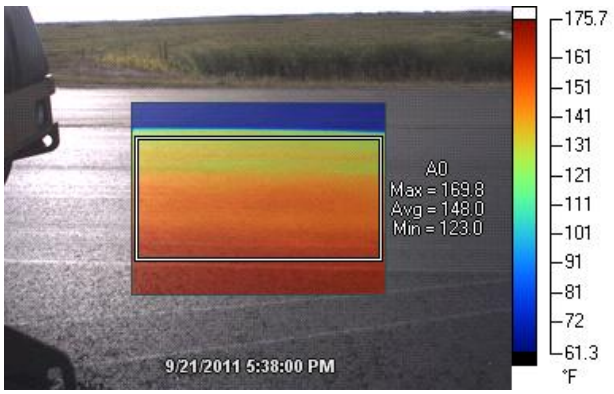
Behind Paver

Before Breakdown Roller

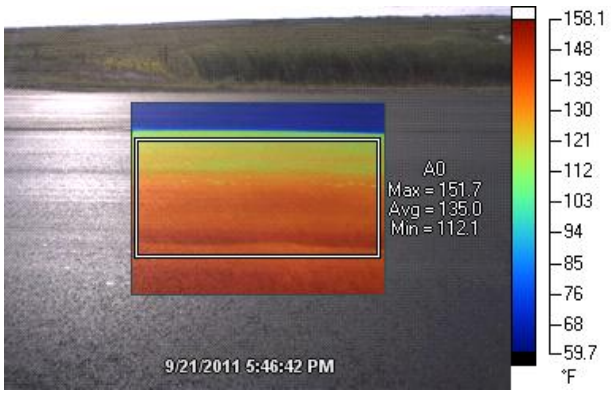
After Breakdown Roller

Before Intermediate Roller

After Intermediate Roller



Before Finish Roller

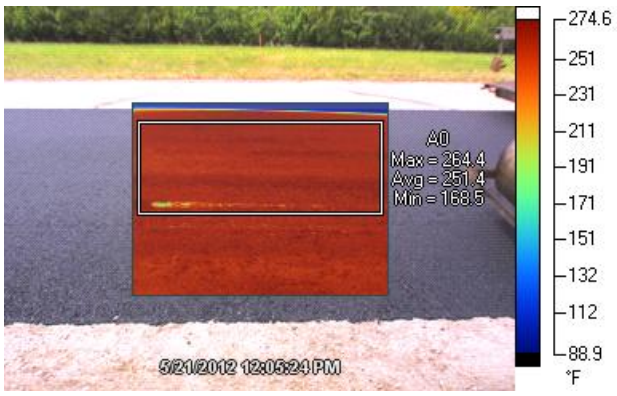


After Finish Roller

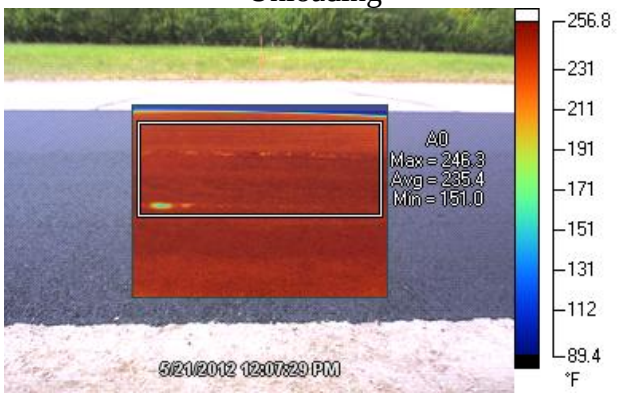
B. THERMAL PICTURES FROM ND 15 PAVING

ND 15 HMA West bound lane W01 at STA 330+00

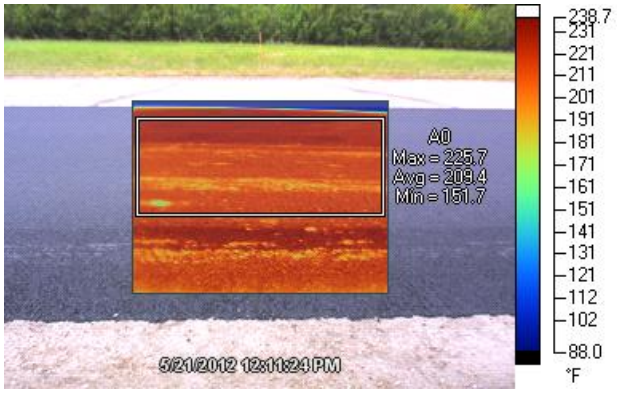
Unloading



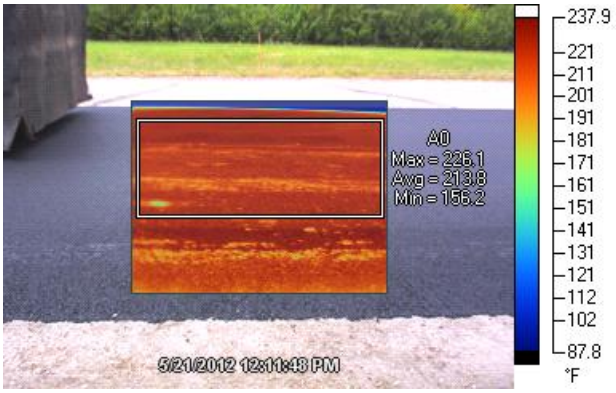
Behind Paver



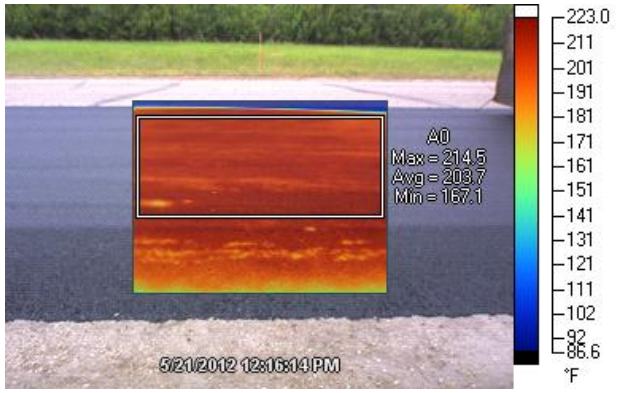
Before Breakdown Roller



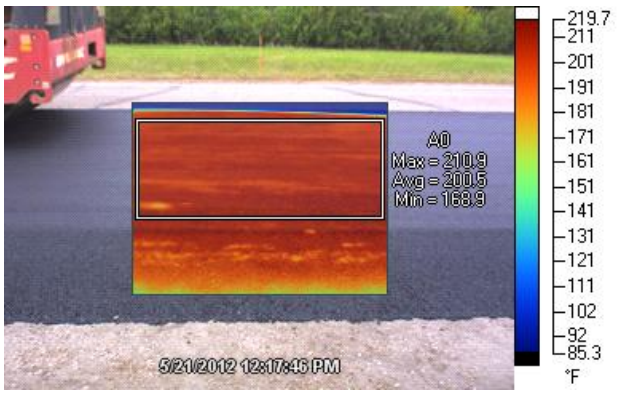
After Breakdown Roller



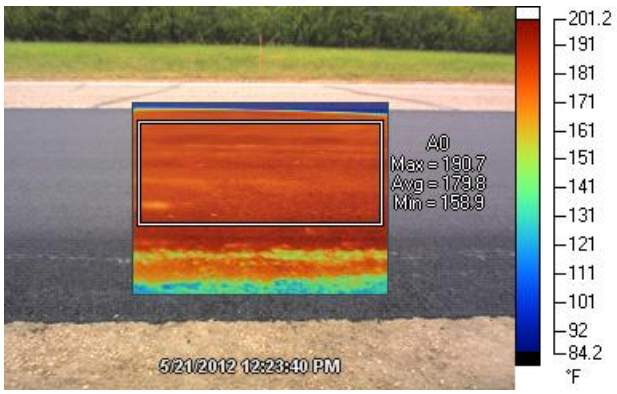
Before Intermediate Roller



After Intermediate Roller

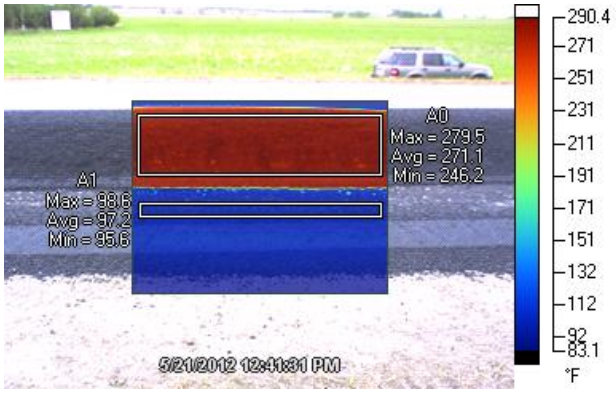


Before Finish Roller

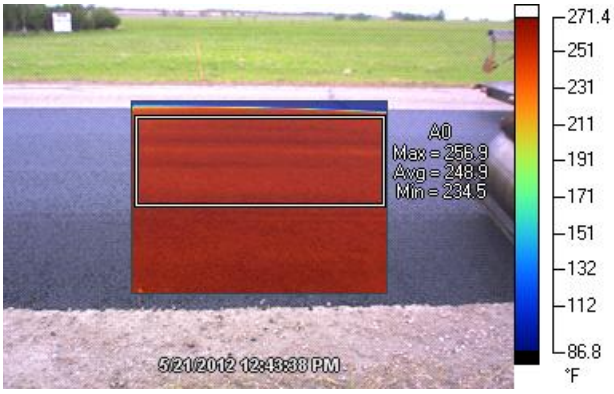


After Finish Roller

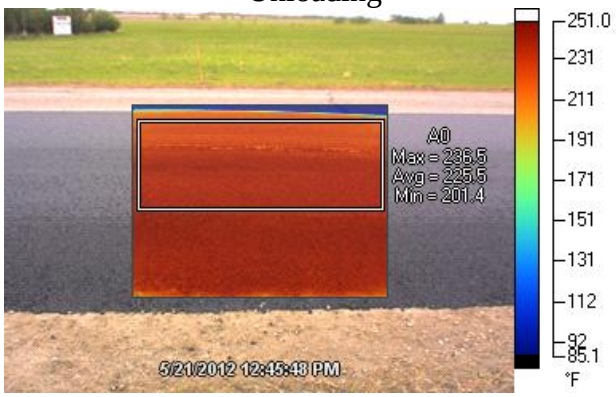
ND 15 HMA West bound lane W02 at STA 320+00



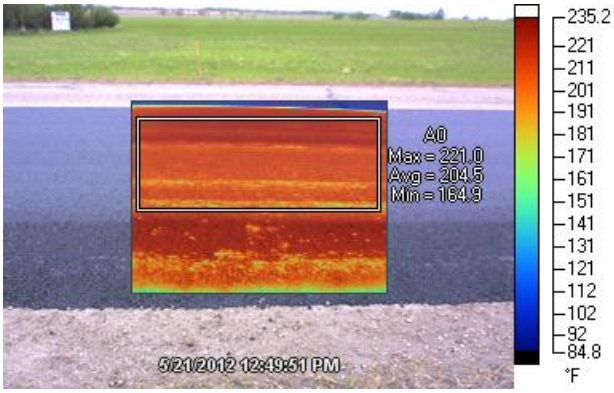
Unloading



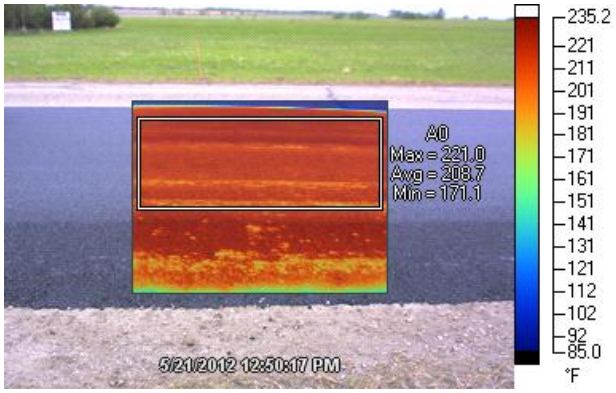
Behind Paver



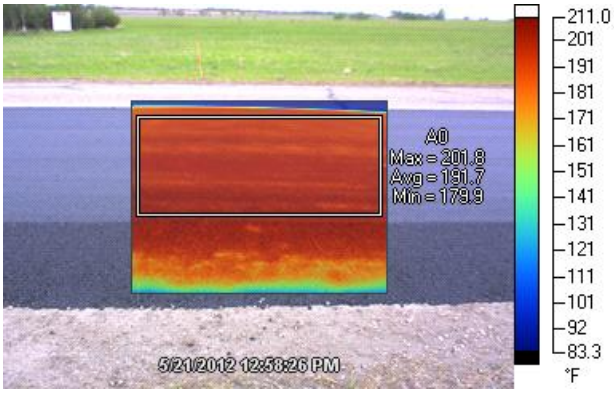
Before Breakdown Roller



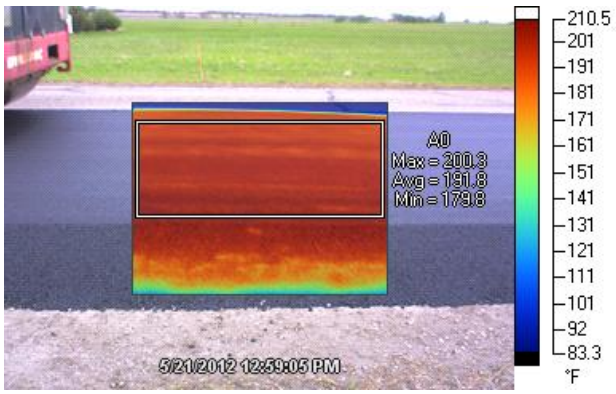
After Breakdown Roller



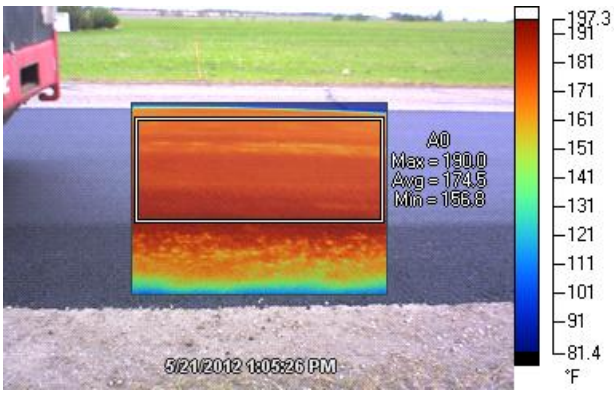
Before Intermediate Roller



After Intermediate Roller

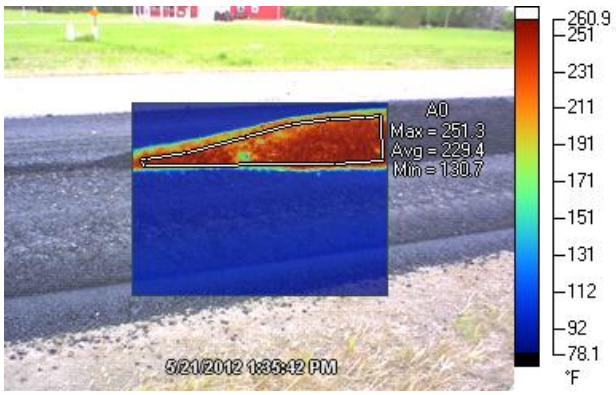


Before Finish Roller



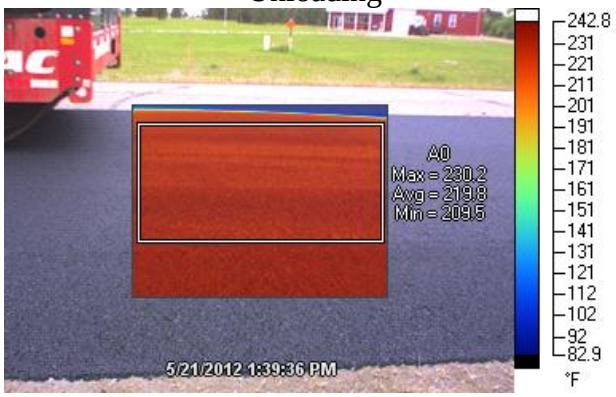
After Finish Roller

ND 15 HMA West bound lane W03 at STA 300+00



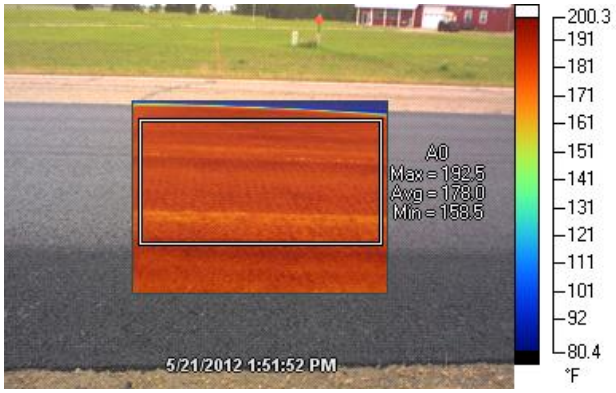
Unloading

Behind Paver



Before Breakdown Roller

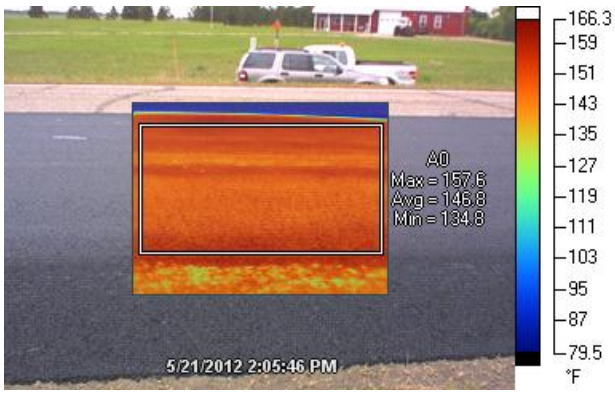
After Breakdown Roller



Before Intermediate Roller

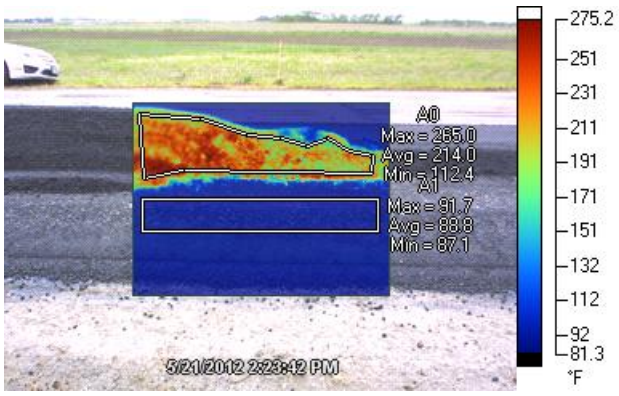
After Intermediate Roller

Before Finish Roller

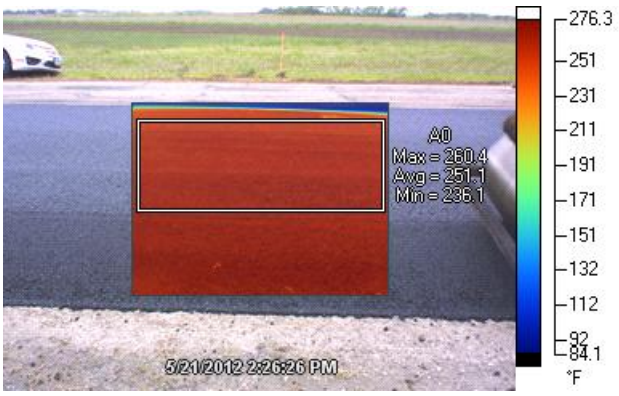


After Finish Roller

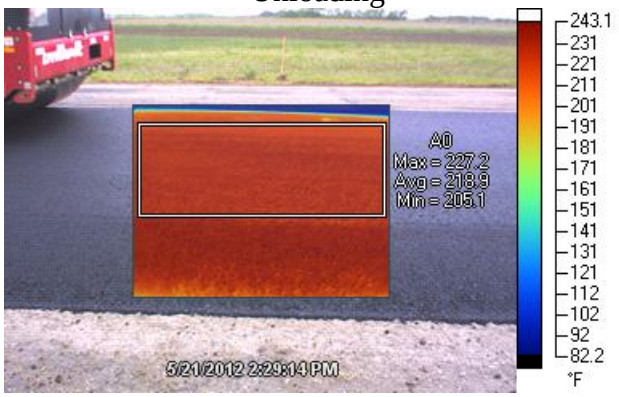
ND 15 HMA West bound lane W04 at STA 270+00



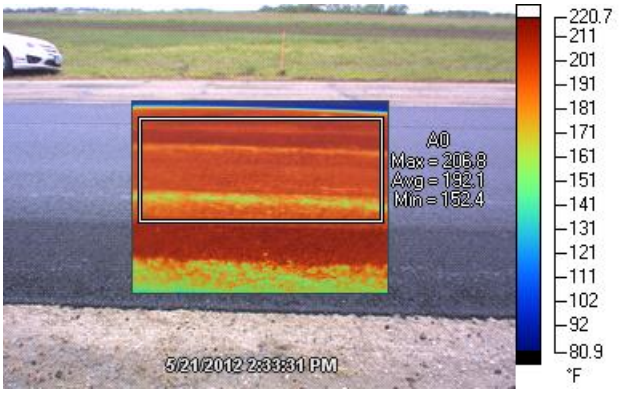
Unloading



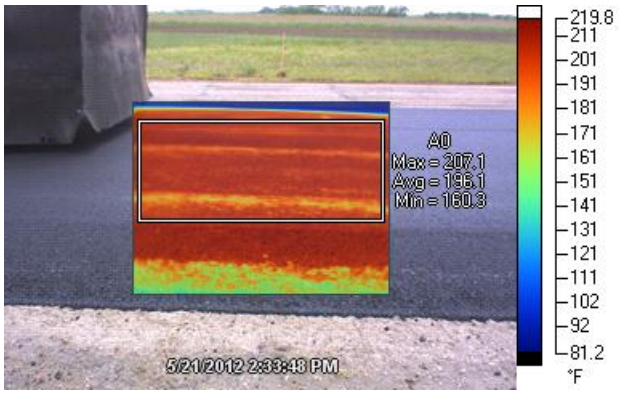
Behind Paver



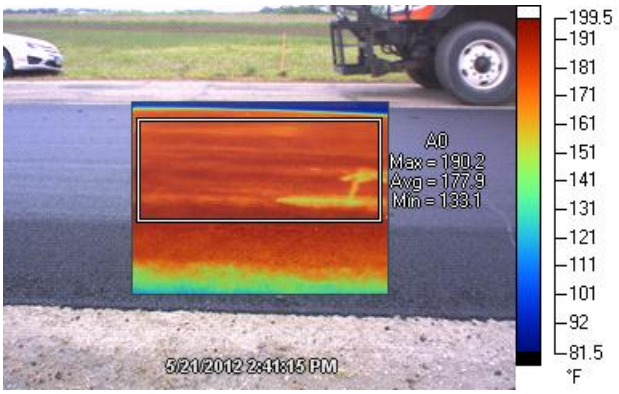
Before Breakdown Roller



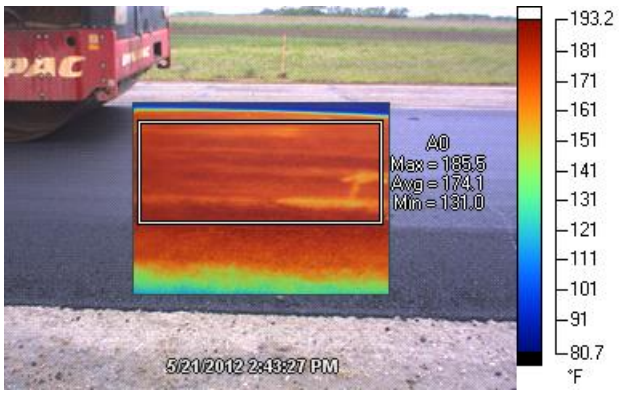
After Breakdown Roller



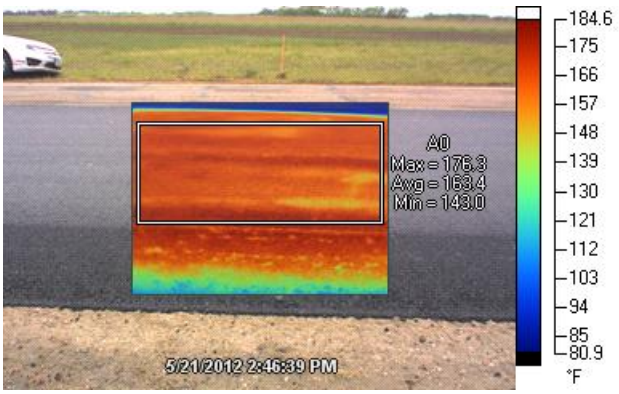
Before Intermediate Roller



After Intermediate Roller

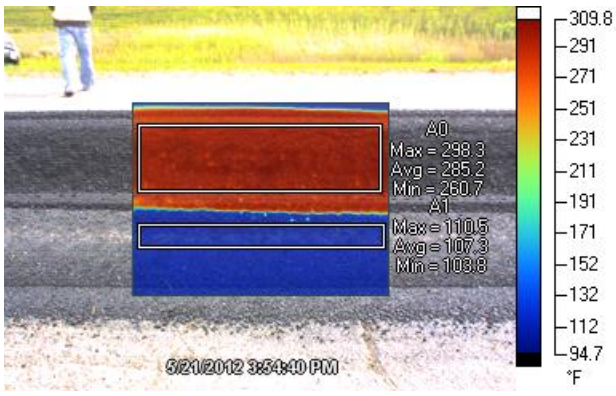


Before Finish Roller



After Finish Roller

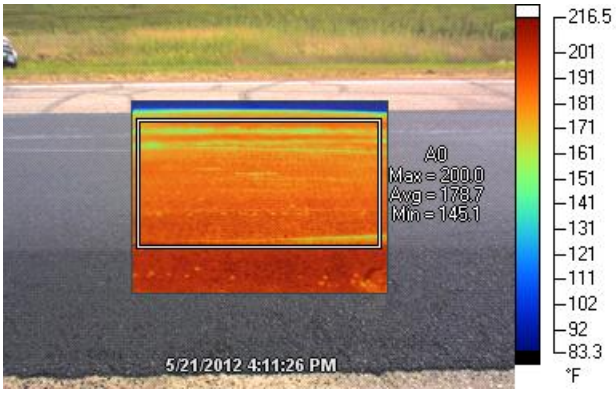
ND 15 HMA West bound lane W05 at STA 240+00



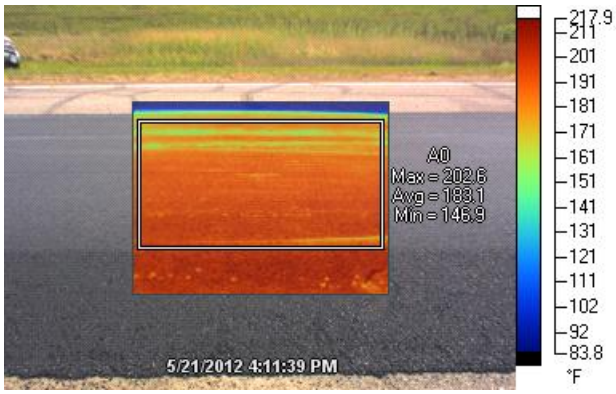
Unloading

Behind Paver

Before Breakdown Roller

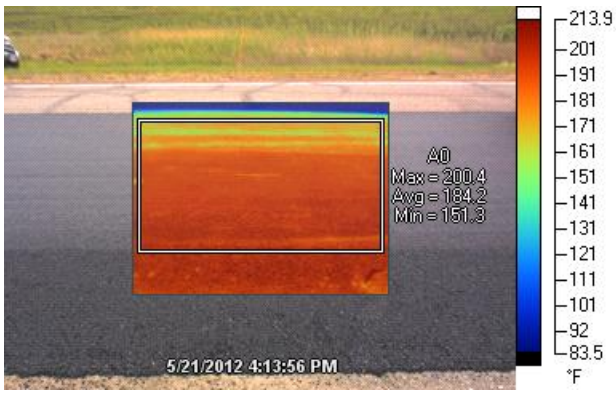


After Breakdown Roller

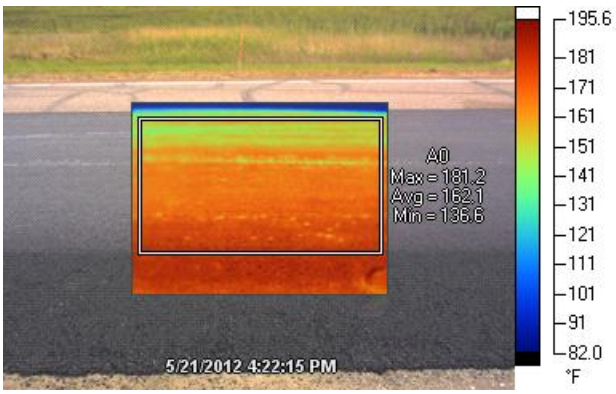


Before Intermediate Roller

After Intermediate Roller

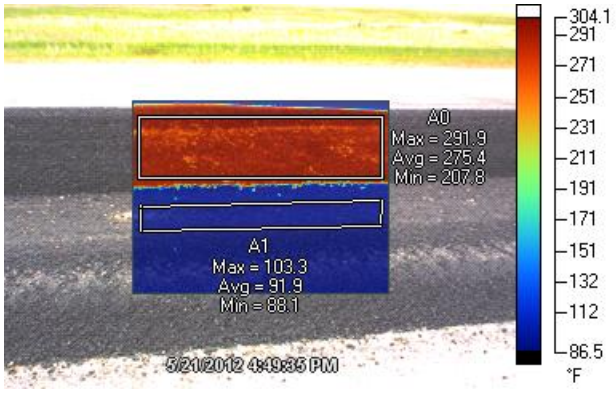


Before Finish Roller



After Finish Roller

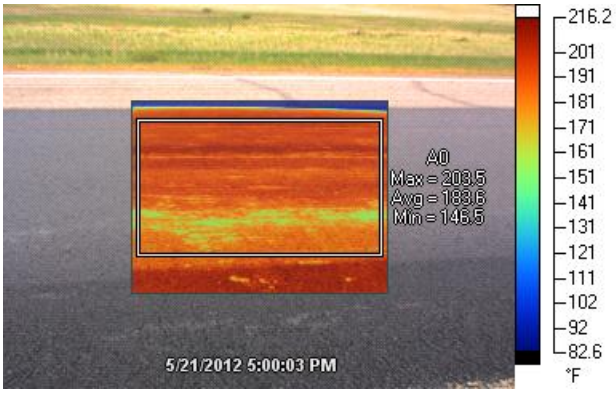
ND 15 HMA West bound lane W06 at STA 220+00



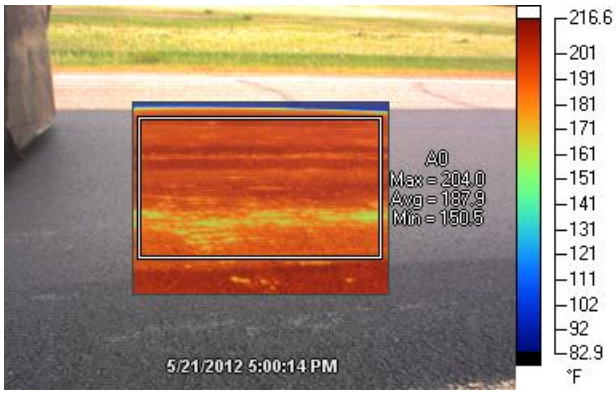
Unloading

Behind Paver

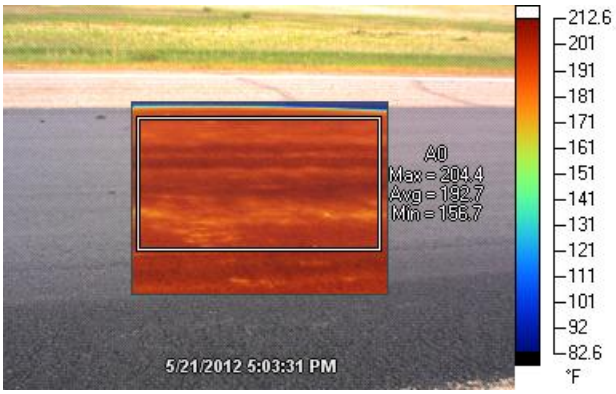
Before Breakdown Roller



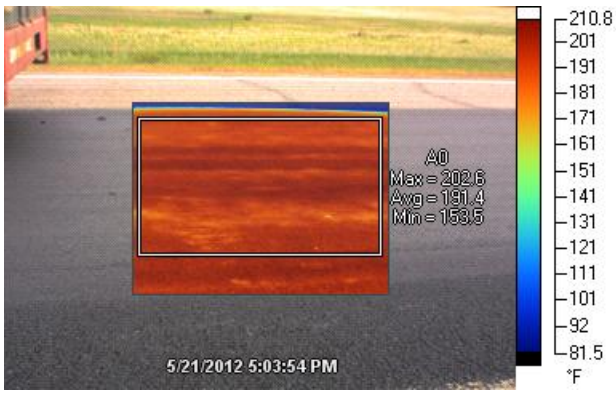
After Breakdown Roller



Before Intermediate Roller



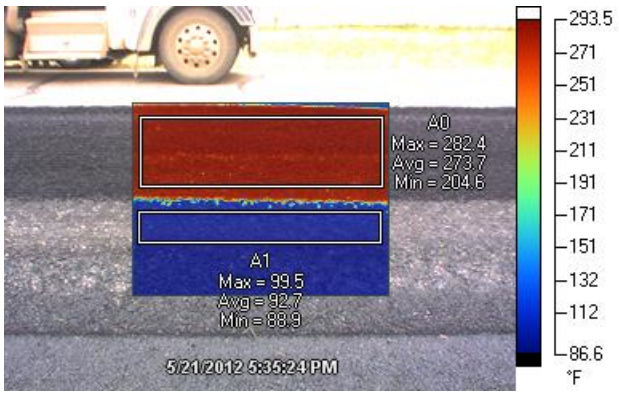
After Intermediate Roller



Before Finish Roller

After Finish Roller

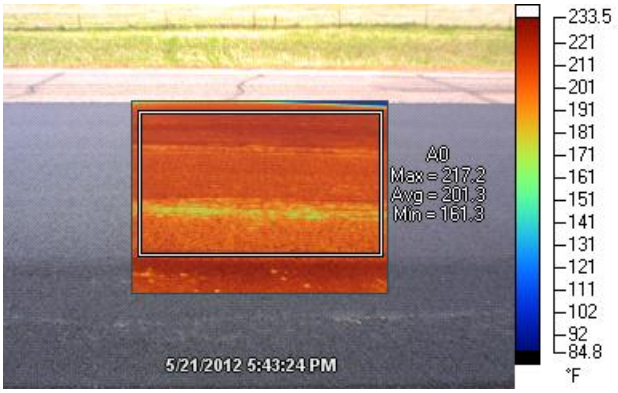
ND 15 HMA West bound lane W07 at STA 200+00



Unloading

Behind Paver

Before Breakdown Roller

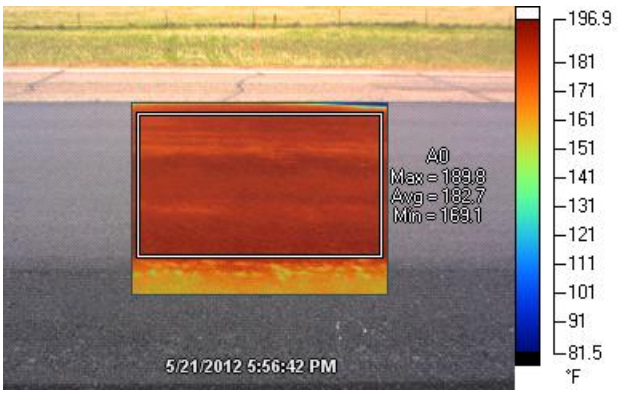


After Breakdown Roller

Before Intermediate Roller

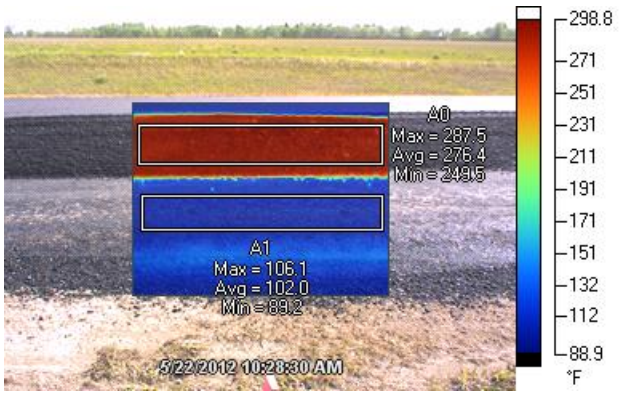
After Intermediate Roller

Before Finish Roller

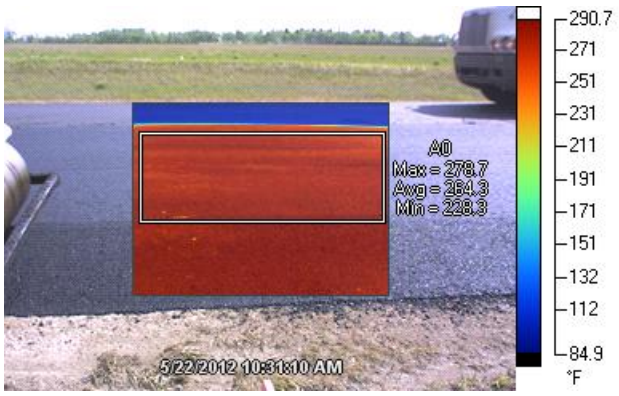


After Finish Roller

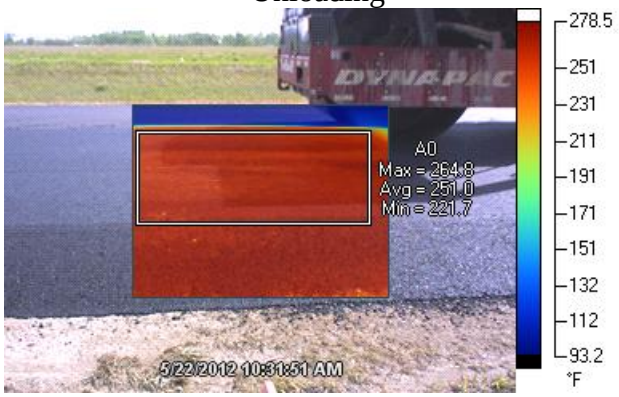
ND 15 HMA East bound lane E01 at STA 339+50



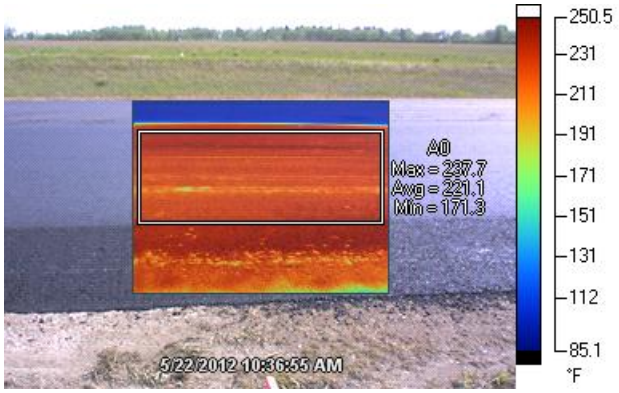
Unloading



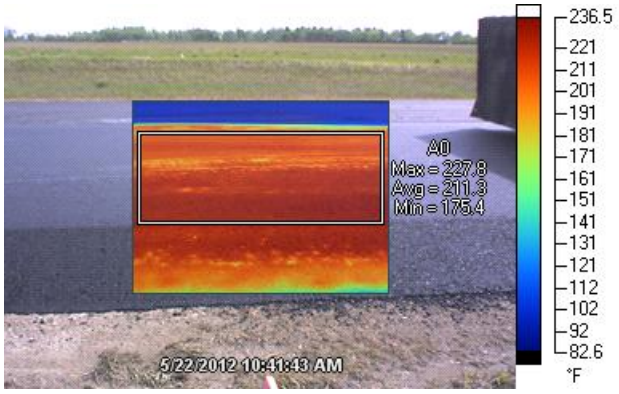
Behind Paver



Before Breakdown Roller

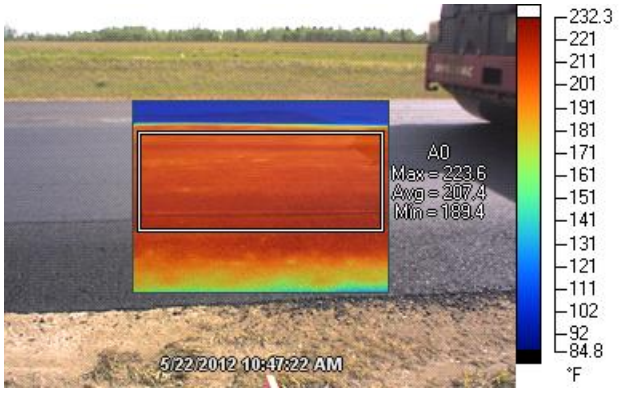


After Breakdown Roller

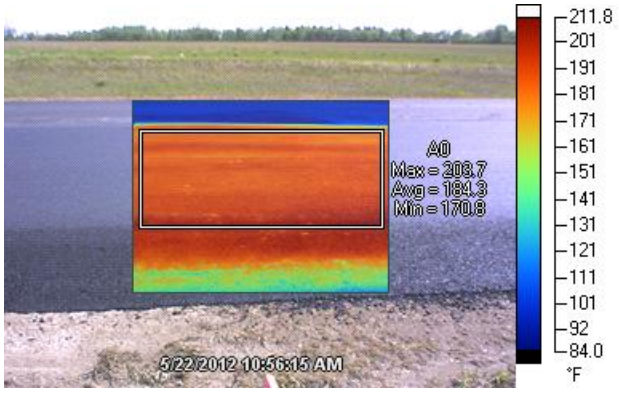


Before Intermediate Roller

After Intermediate Roller

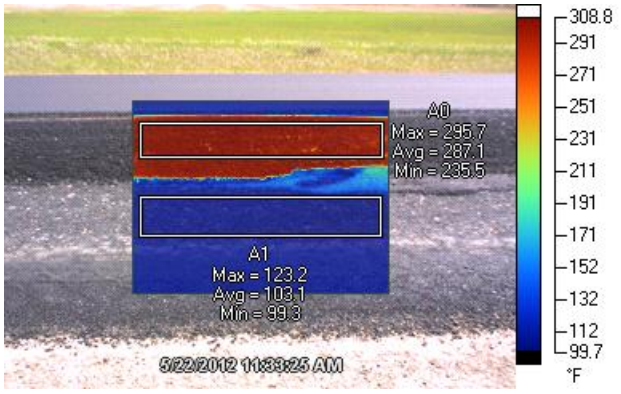


Before Finish Roller



After Finish Roller

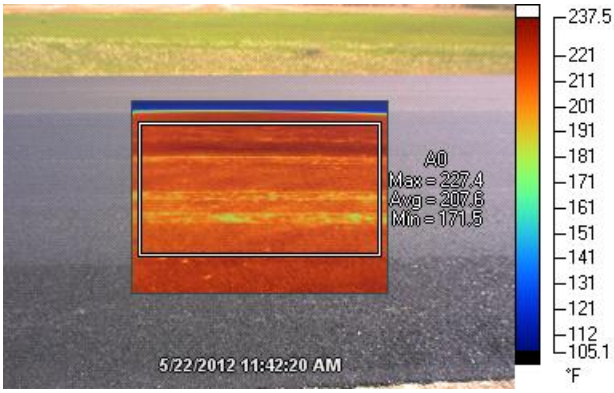
ND 15 HMA East bound lane E02 at STA 310+00



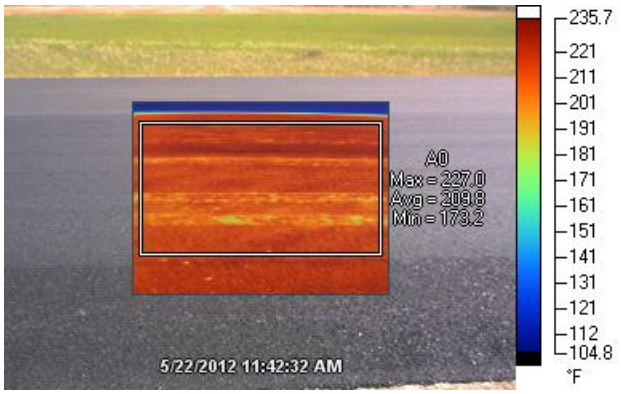
Unloading

Behind Paver

Before Breakdown Roller

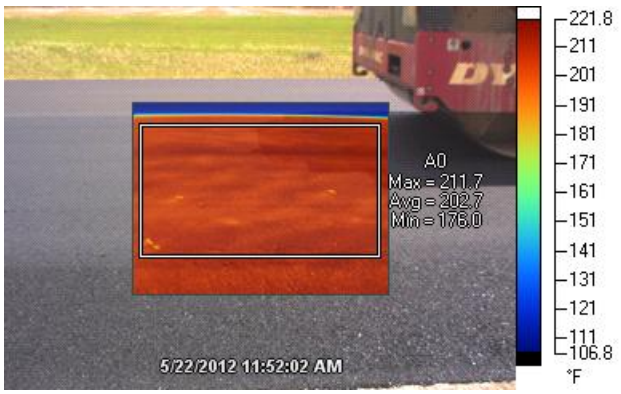


After Breakdown Roller

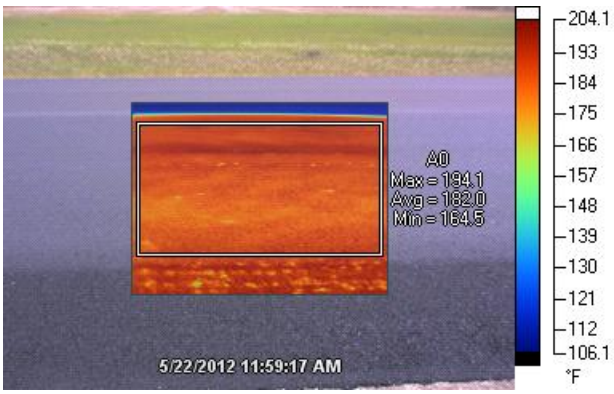


Before Intermediate Roller

After Intermediate Roller

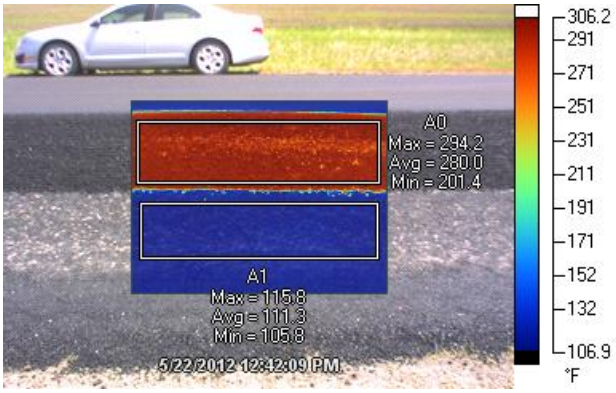


Before Finish Roller



After Finish Roller

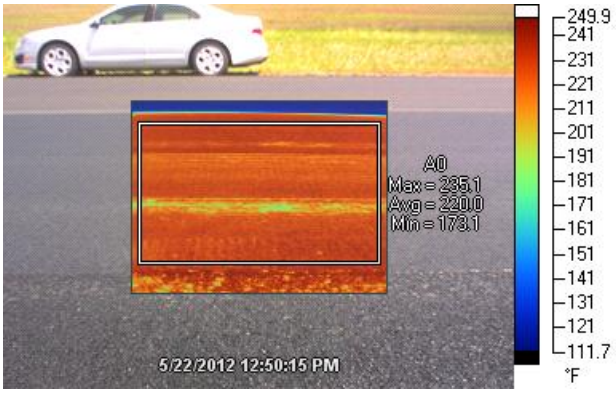
ND 15 HMA East bound lane E03 at STA 280+00



Unloading

Behind Paver

Before Breakdown Roller



After Breakdown Roller

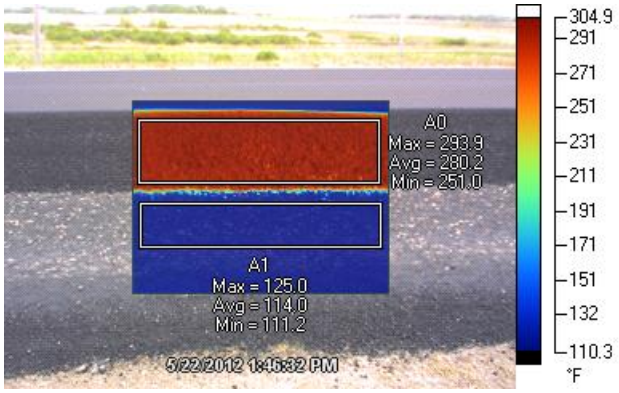
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

ND 15 HMA East bound lane E04 at STA 250+00



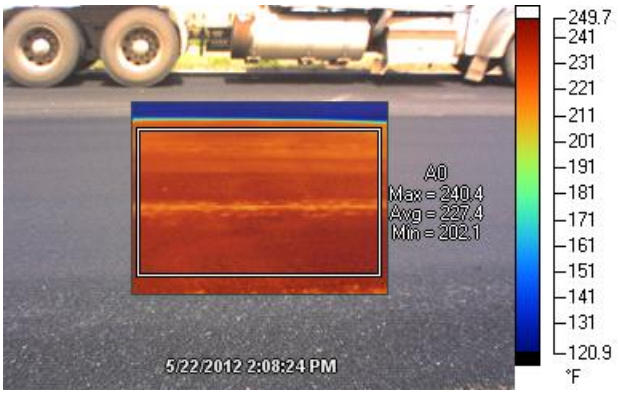
Unloading

Behind Paver

Before Breakdown Roller

After Breakdown Roller

Before Intermediate Roller

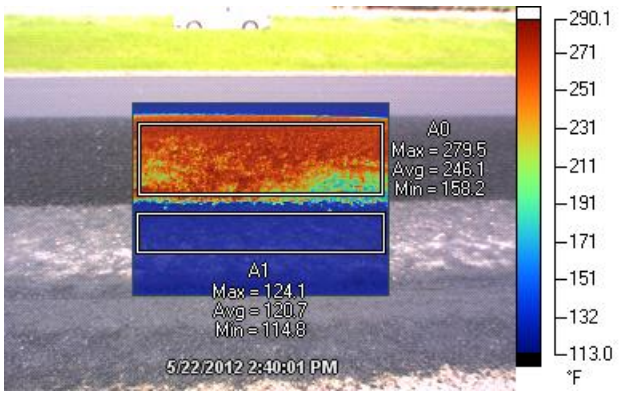


After Intermediate Roller

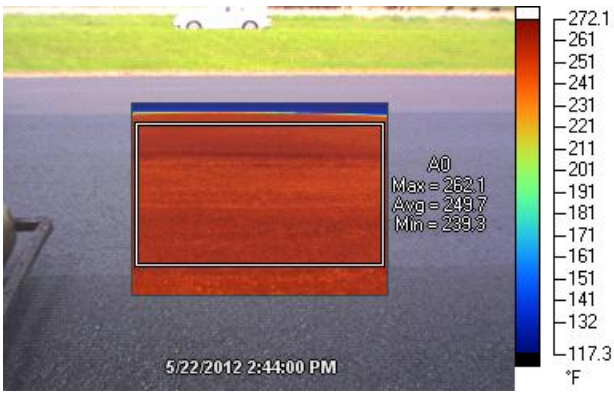
Before Finish Roller

After Finish Roller

ND 15 HMA East bound lane E05 at STA 230+00

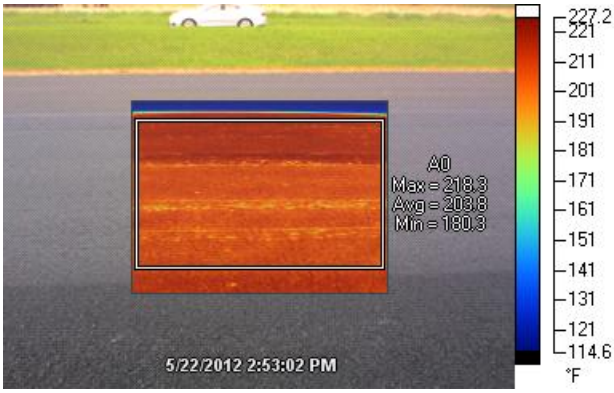


Unloading

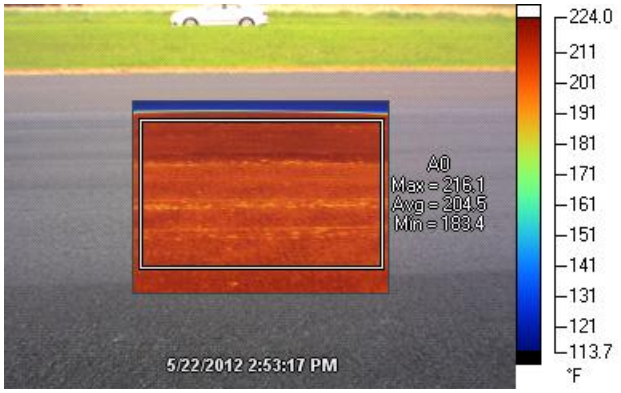


Behind Paver

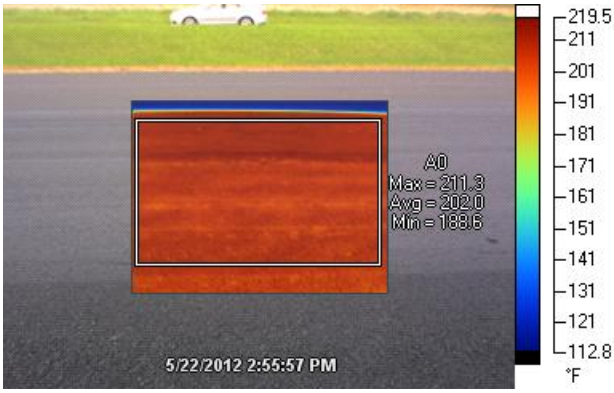
Before Breakdown Roller



After Breakdown Roller



Before Intermediate Roller

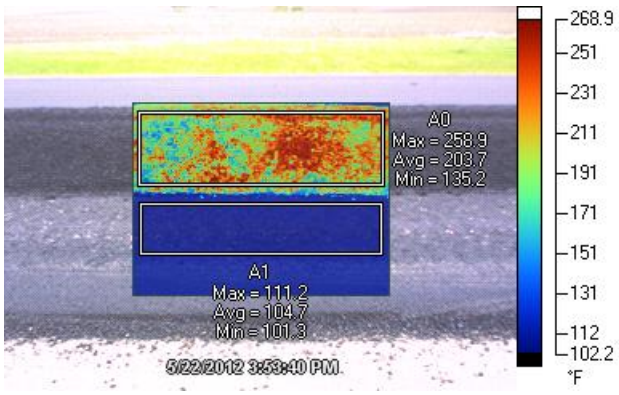


After Intermediate Roller

Before Finish Roller

After Finish Roller

ND 15 HMA East bound lane E06 at STA 199+41

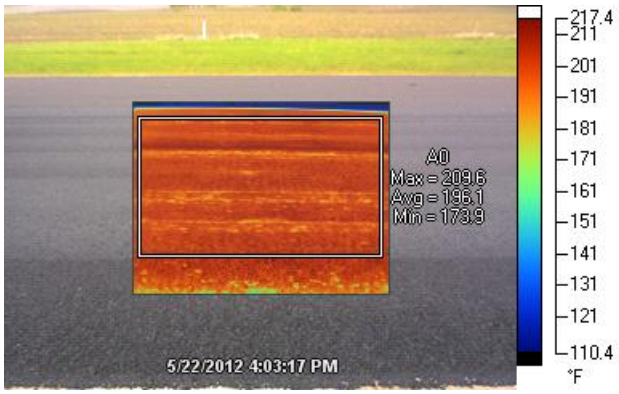


Unloading

Behind Paver

Before Breakdown Roller

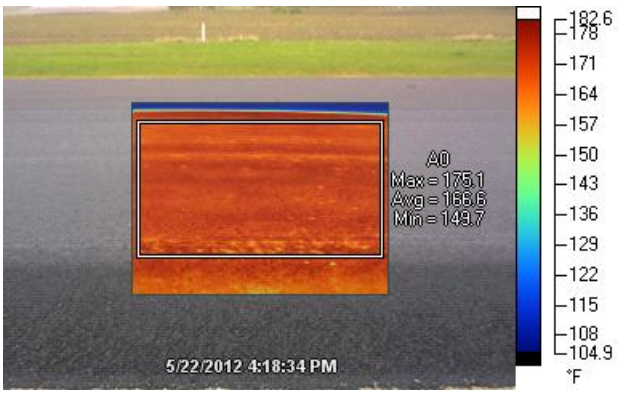
After Breakdown Roller



Before Intermediate Roller

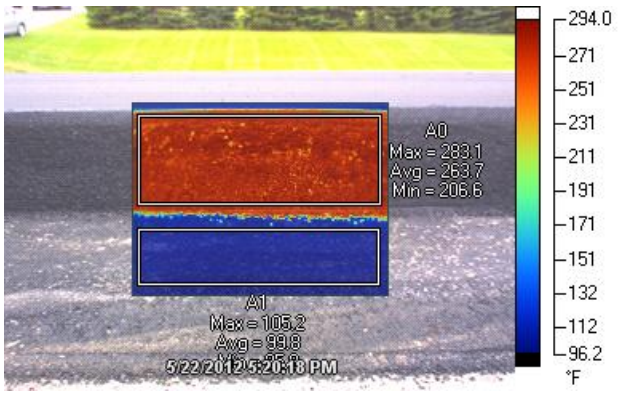
After Intermediate Roller

Before Finish Roller

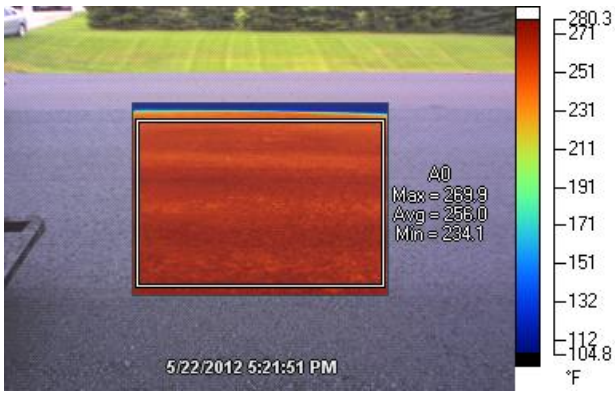


After Finish Roller

ND 15 HMA East bound lane E07 at STA 160+00

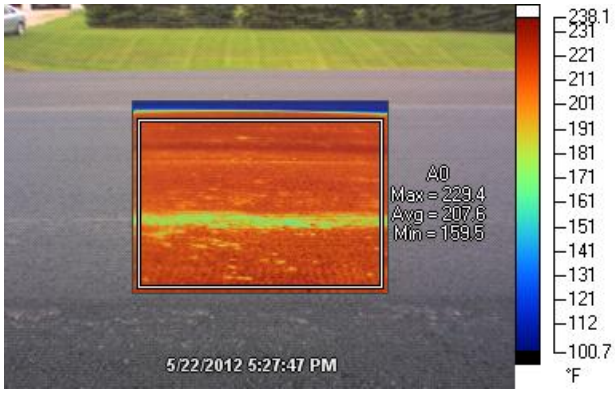


Unloading

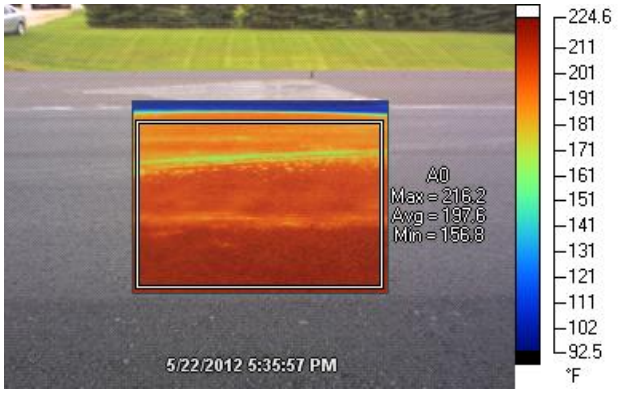


Behind Paver

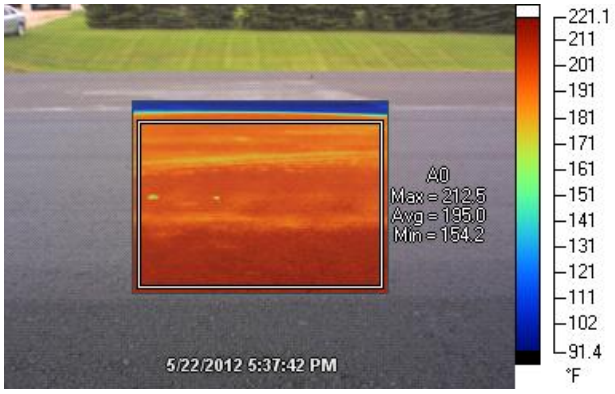
Before Breakdown Roller



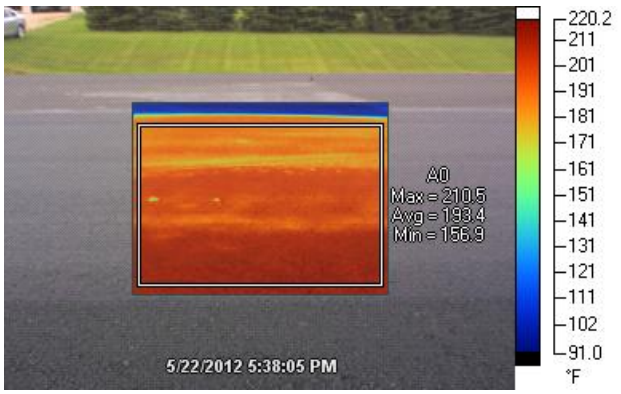
After Breakdown Roller



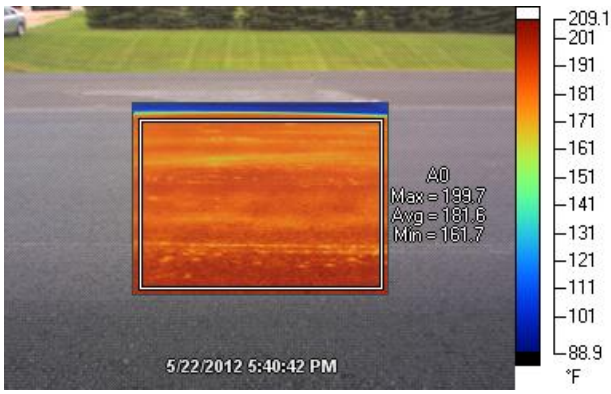
Before Intermediate Roller



After Intermediate Roller



Before Finish Roller



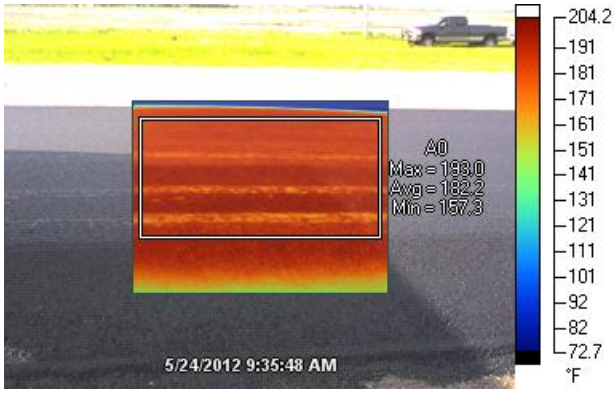
After Finish Roller

ND 15 WMA (Evotherm) West bound lane W01 at STA 680+00

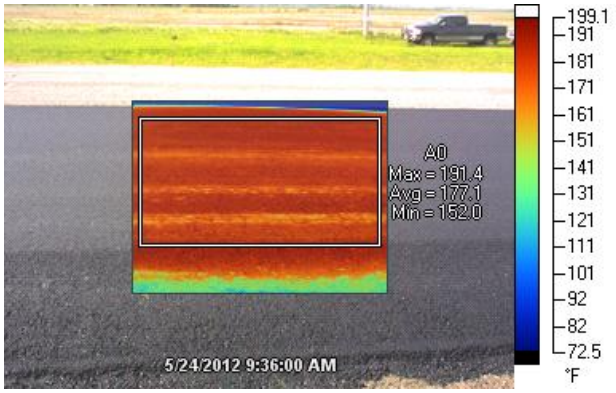
Unloading

Behind Paver

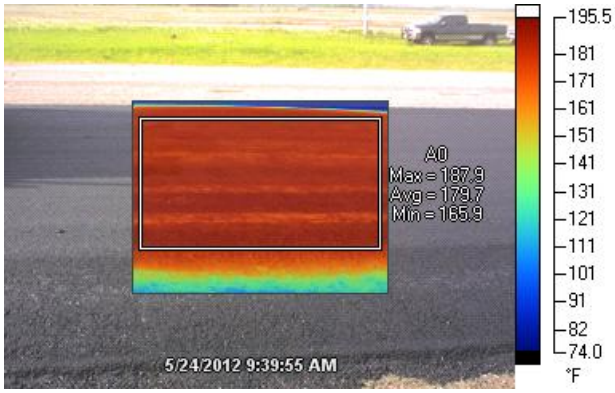
Before Breakdown Roller



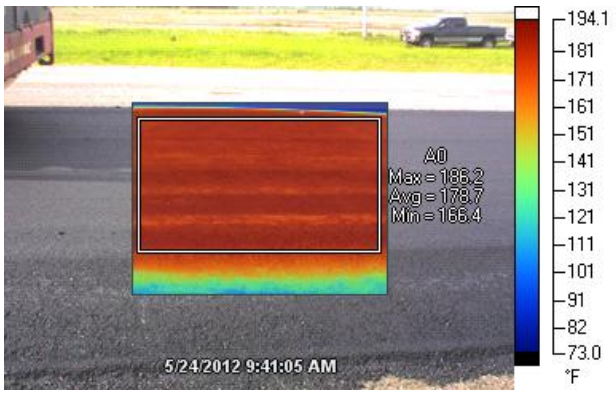
After Breakdown Roller



Before Intermediate Roller



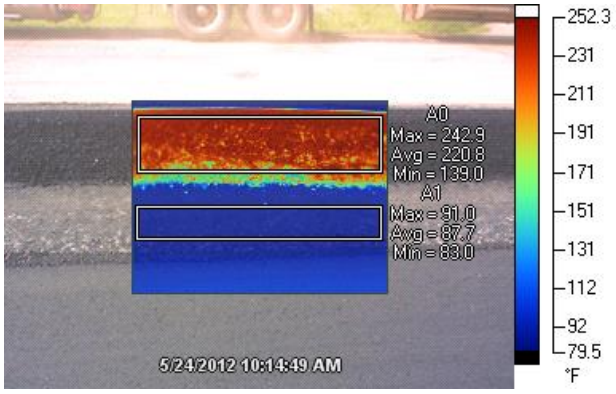
After Intermediate Roller



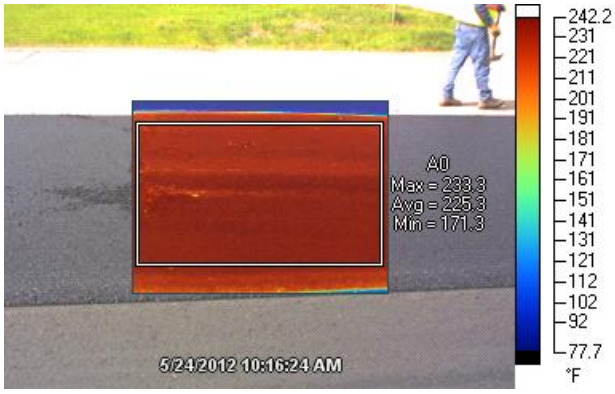
Before Finish Roller

After Finish Roller

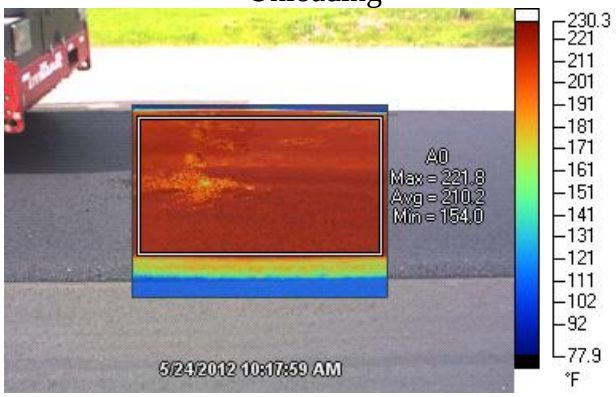
ND 15 WMA (Evotherm) West bound lane W02 at STA 650+00



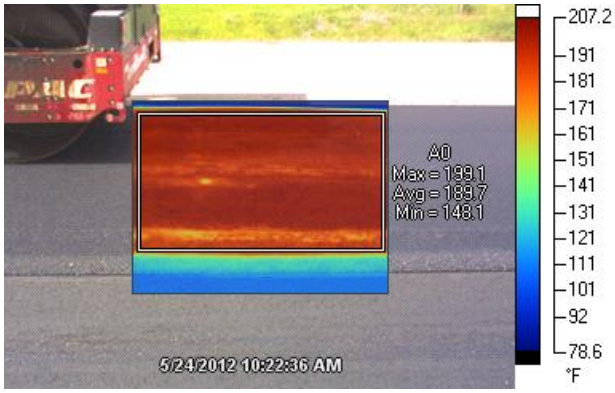
Unloading



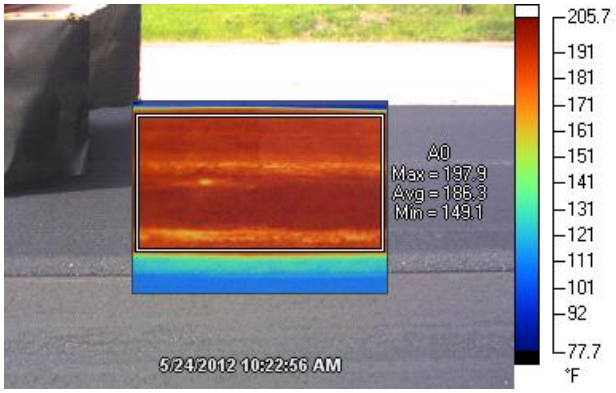
Behind Paver



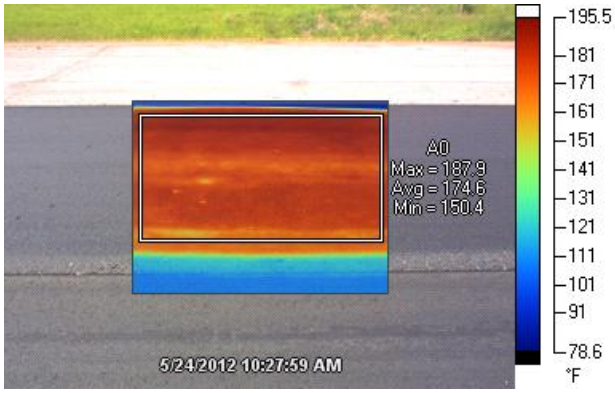
Before Breakdown Roller



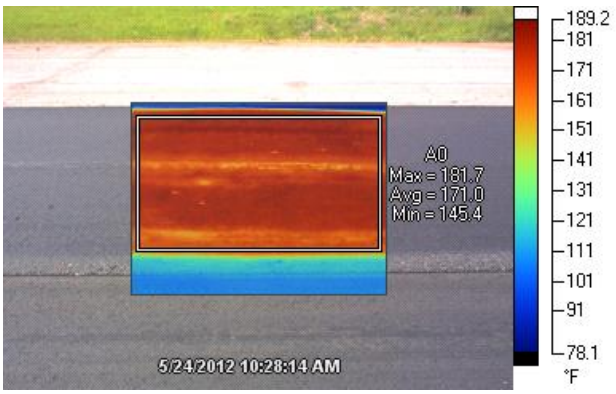
After Breakdown Roller



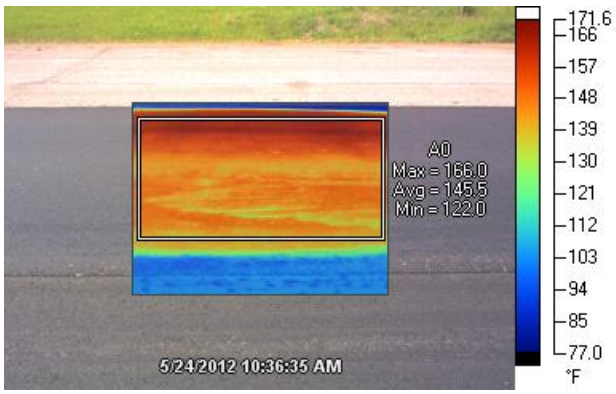
Before Intermediate Roller



After Intermediate Roller

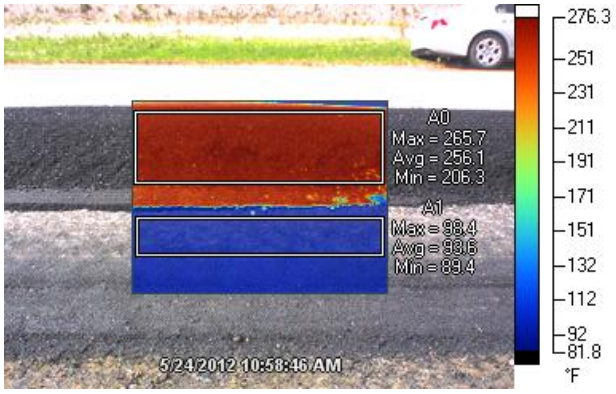


Before Finish Roller



After Finish Roller

ND 15 WMA (Evotherm) West bound lane W03 at STA 630+00



Unloading

Behind Paver

Before Breakdown Roller

After Breakdown Roller

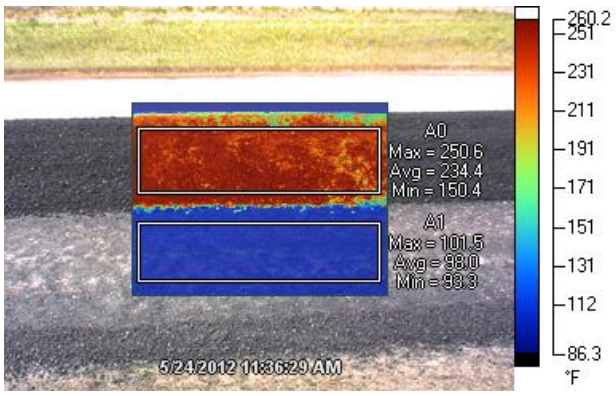
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

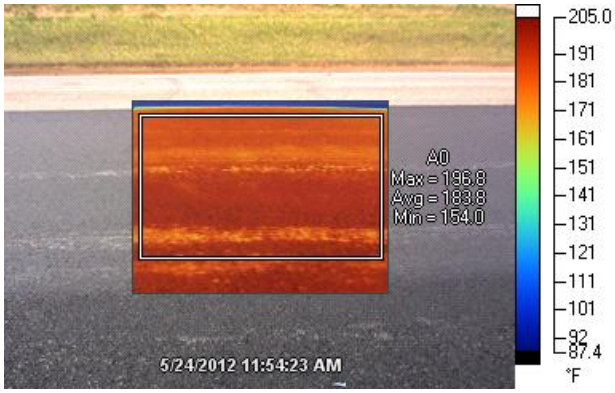
ND 15 WMA (Evotherm) West bound lane W04 at STA 620+00



Unloading

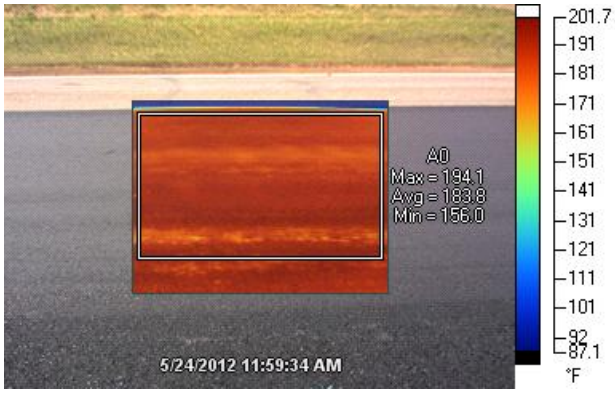
Behind Paver

Before Breakdown Roller

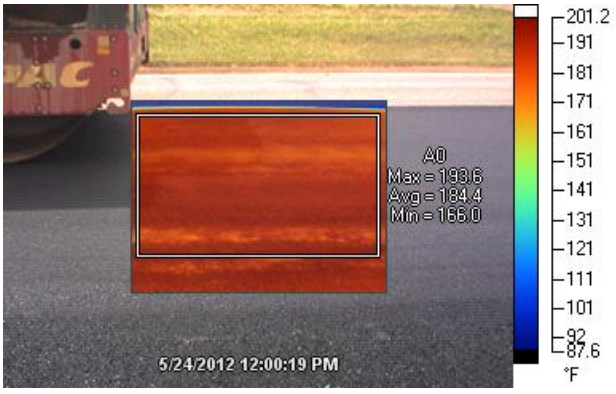


After Breakdown Roller

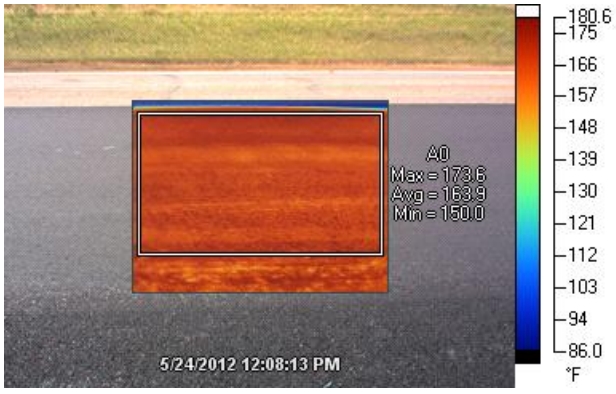
Before Intermediate Roller



After Intermediate Roller

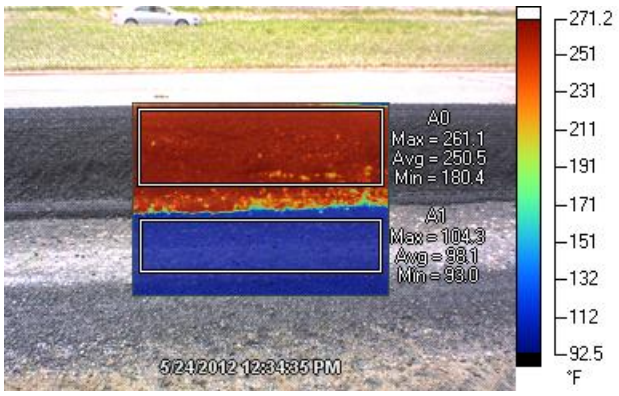


Before Finish Roller



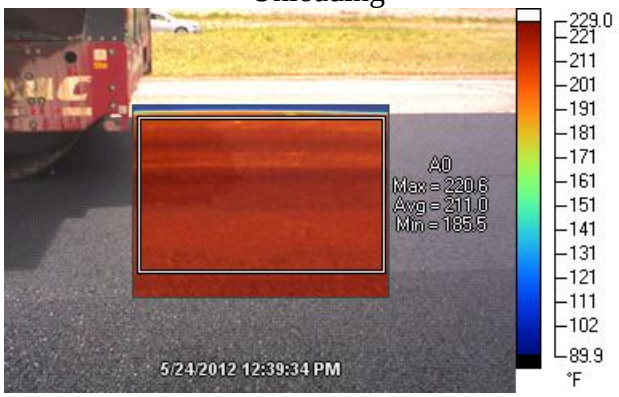
After Finish Roller

ND 15 WMA (Evotherm) West bound lane W05 at STA 600+00

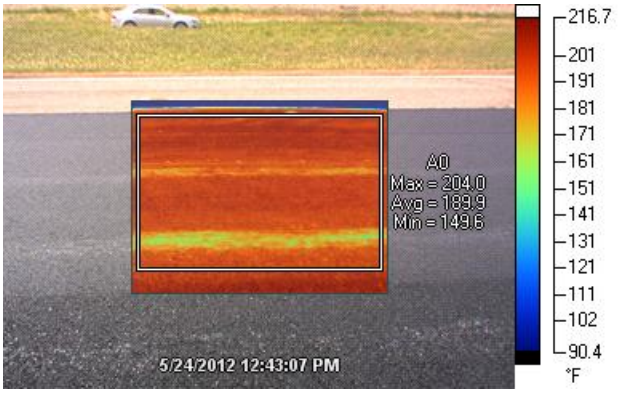


Unloading

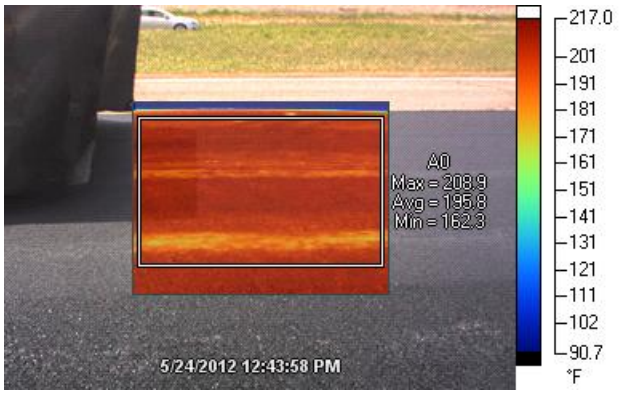
Behind Paver



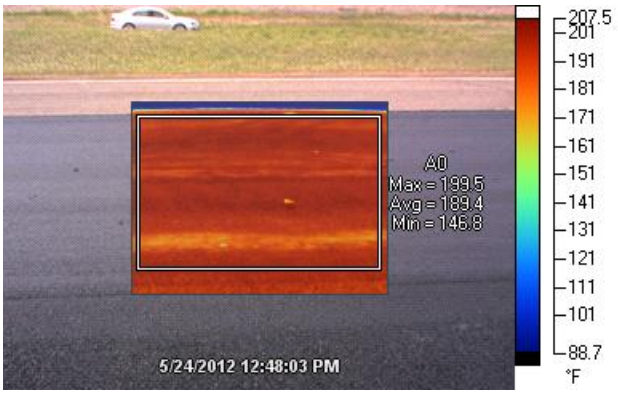
Before Breakdown Roller



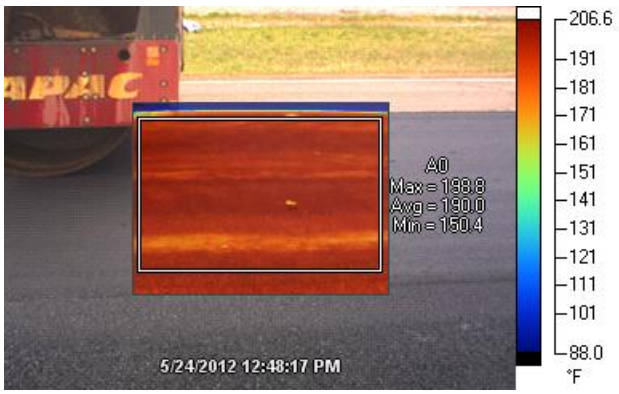
After Breakdown Roller



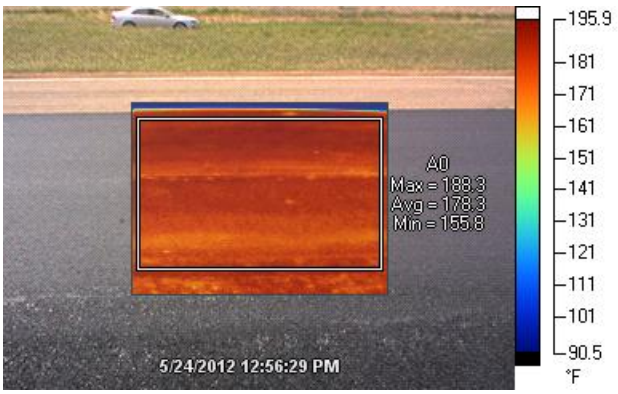
Before Intermediate Roller



After Intermediate Roller

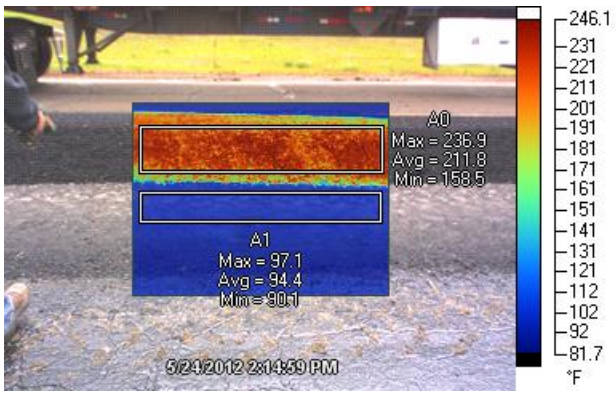


Before Finish Roller

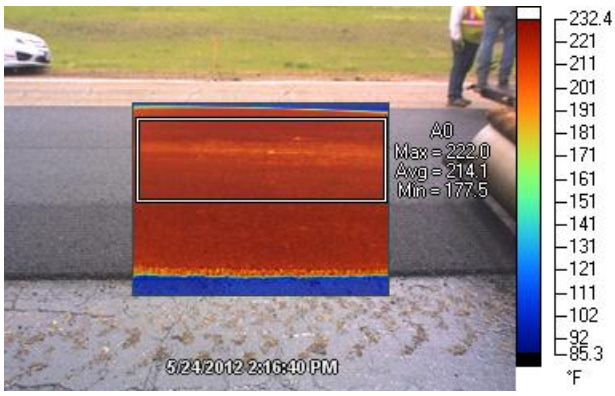


After Finish Roller

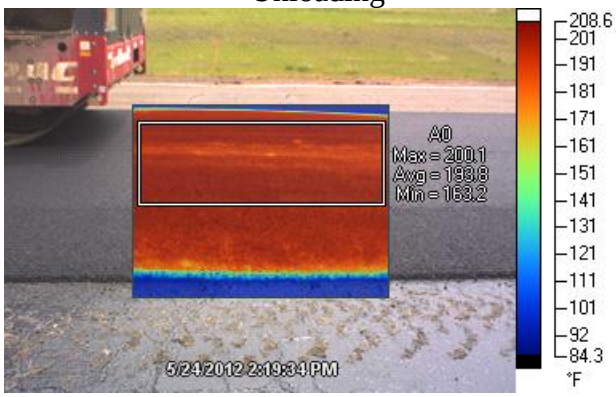
ND 15 WMA (Evotherm) West bound lane W06 at STA 560+00



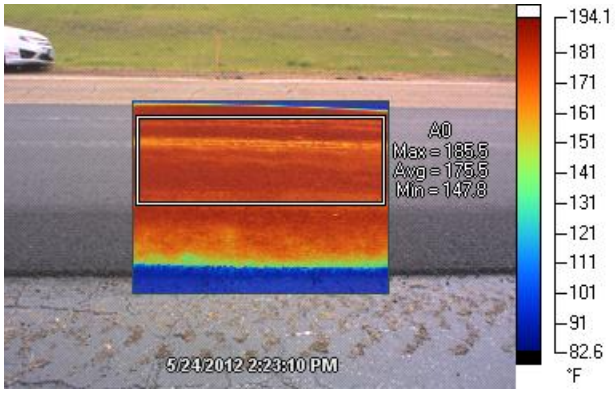
Unloading



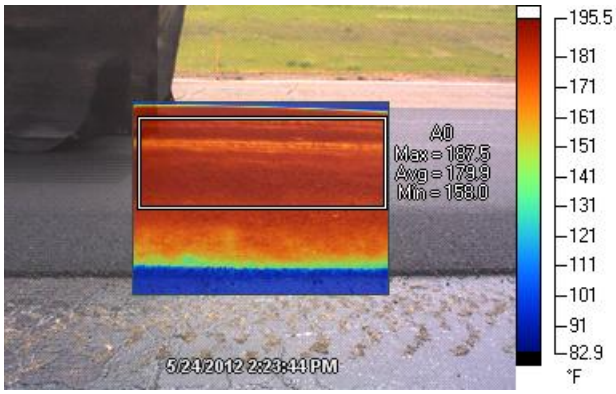
Behind Paver



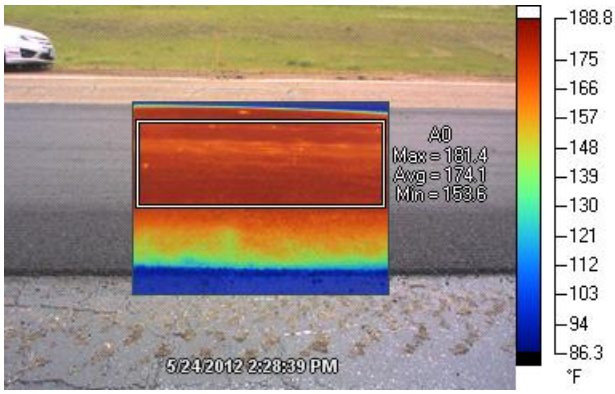
Before Breakdown Roller



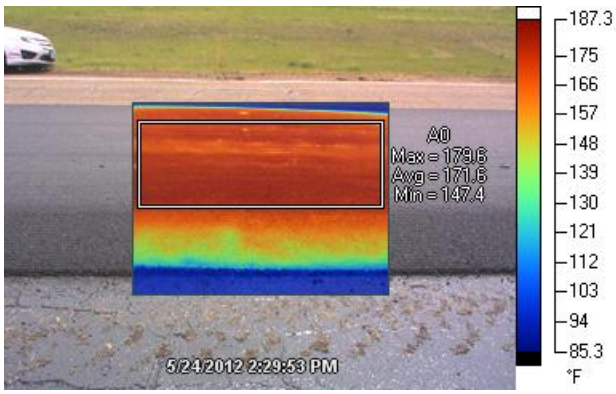
After Breakdown Roller



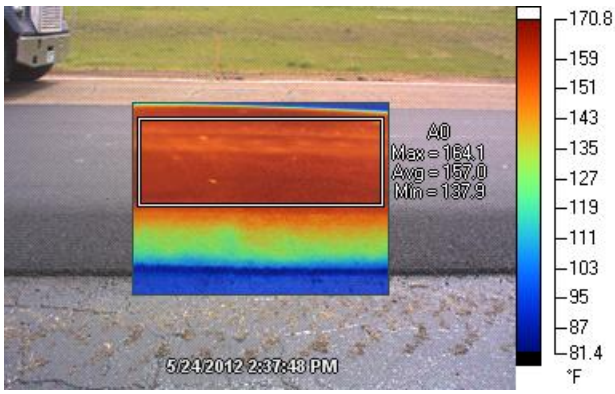
Before Intermediate Roller



After Intermediate Roller

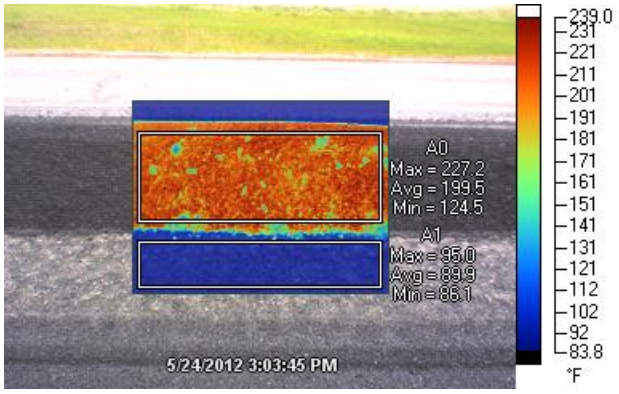


Before Finish Roller

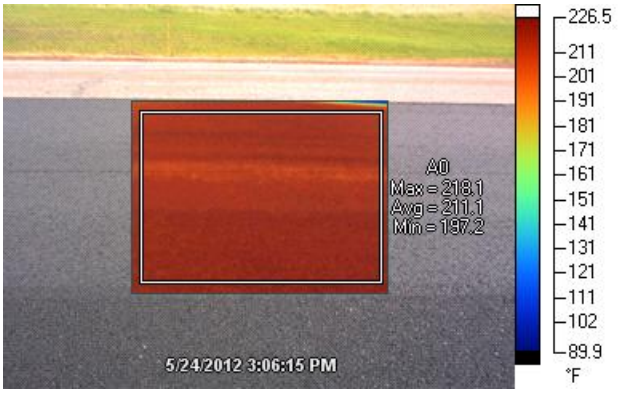


After Finish Roller

ND 15 WMA (Evotherm) West bound lane W07 at STA 540+00

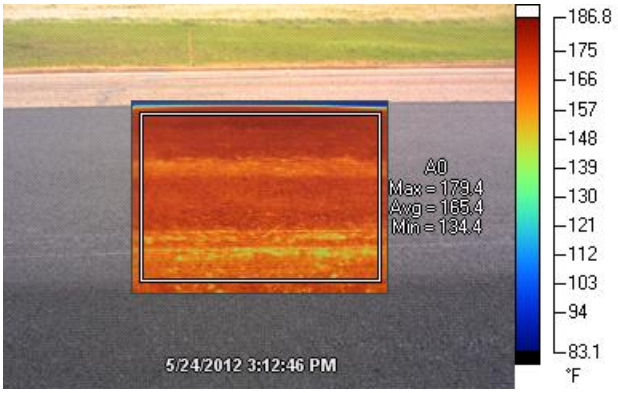


Unloading

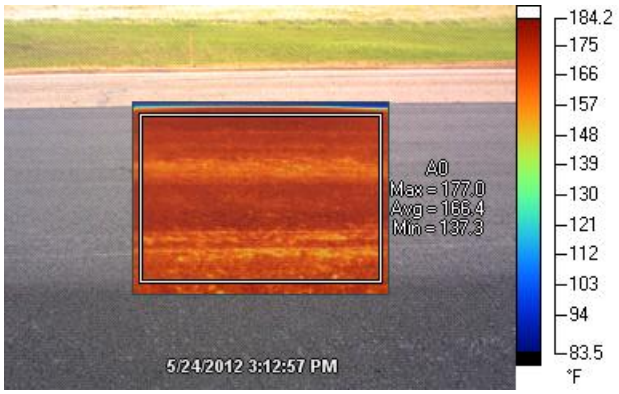


Behind Paver

Before Breakdown Roller

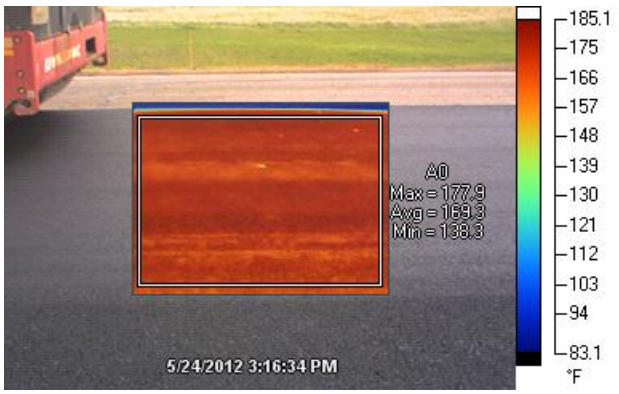


After Breakdown Roller

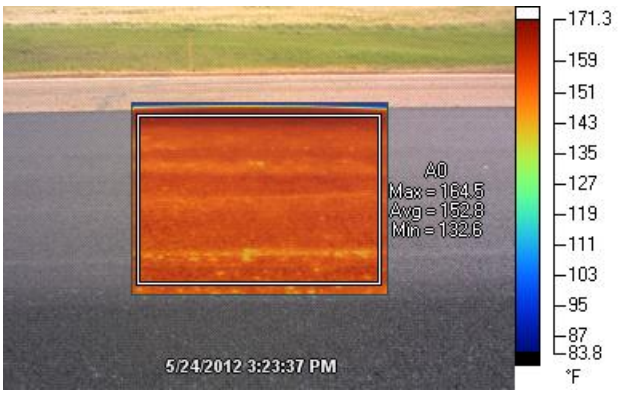


Before Intermediate Roller

After Intermediate Roller

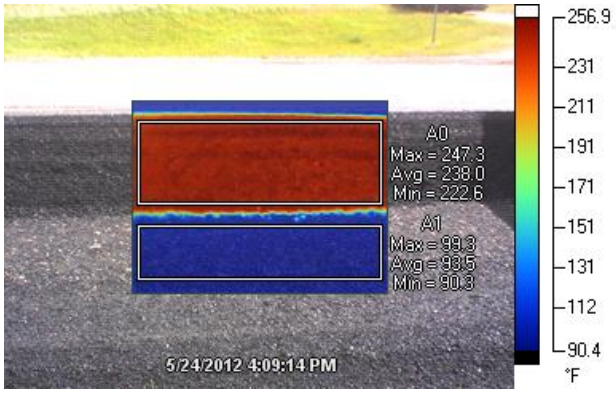


Before Finish Roller



After Finish Roller

ND 15 WMA (Evotherm) West bound lane W08 at STA 520+00

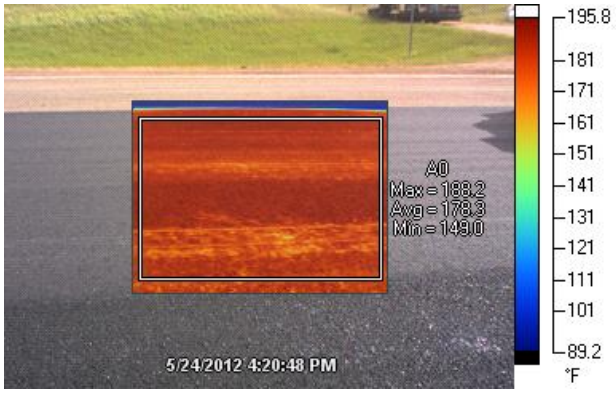


Unloading

Behind Paver

Before Breakdown Roller

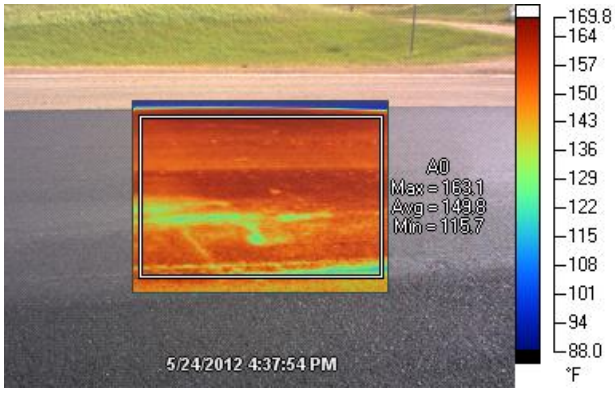
After Breakdown Roller



Before Intermediate Roller

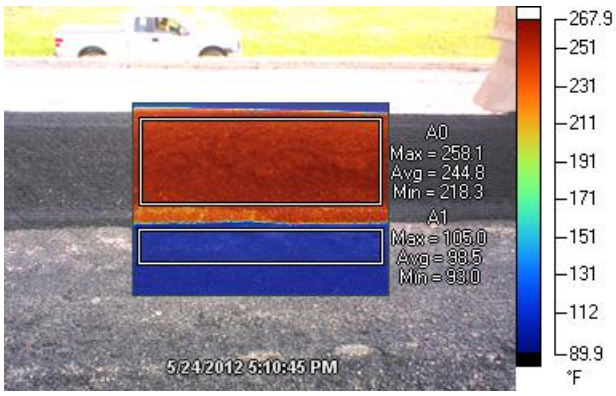
After Intermediate Roller

Before Finish Roller



After Finish Roller

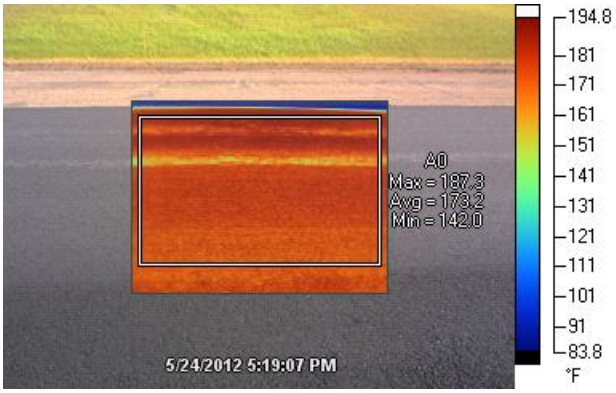
ND 15 WMA (Evotherm) West bound lane W09 at STA 500+00



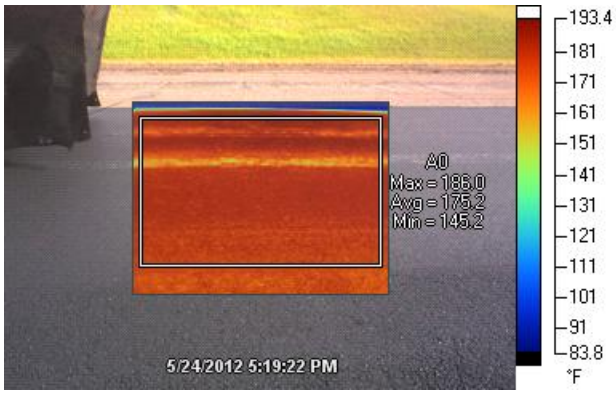
Unloading

Behind Paver

Before Breakdown Roller

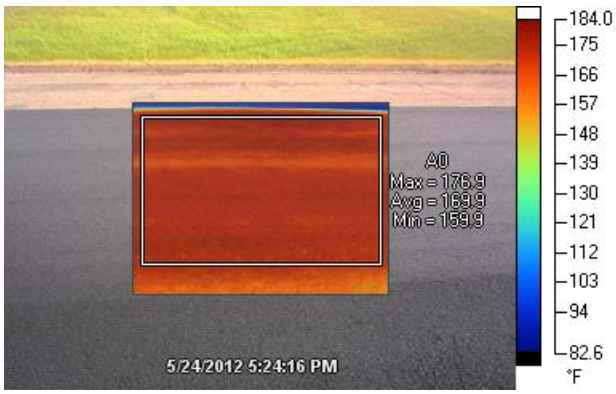


After Breakdown Roller



Before Intermediate Roller

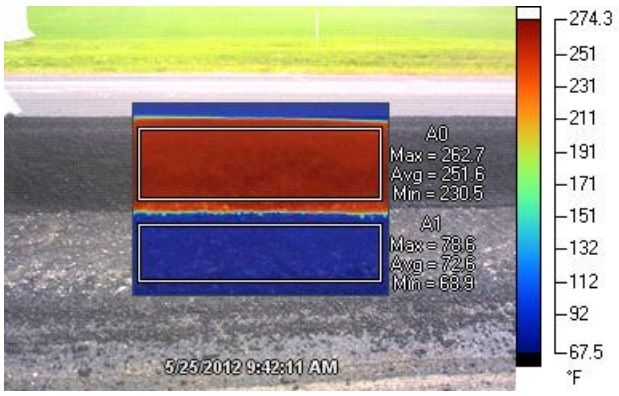
After Intermediate Roller



Before Finish Roller

After Finish Roller

ND 15 WMA (Evotherm) East bound lane E01 at STA 679+69

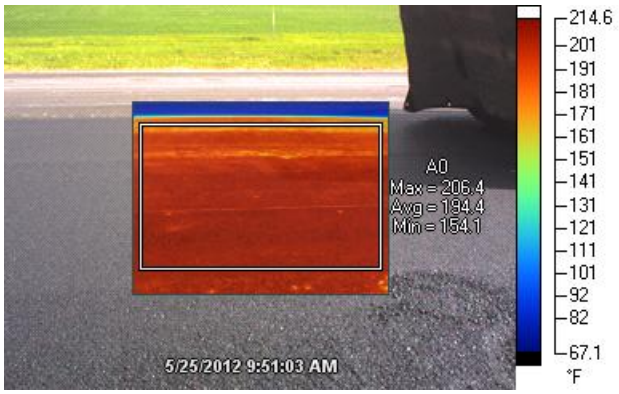


Unloading

Behind Paver

Before Breakdown Roller

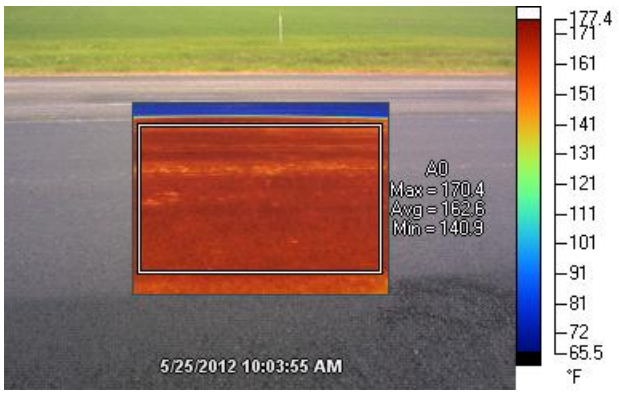
After Breakdown Roller



Before Intermediate Roller

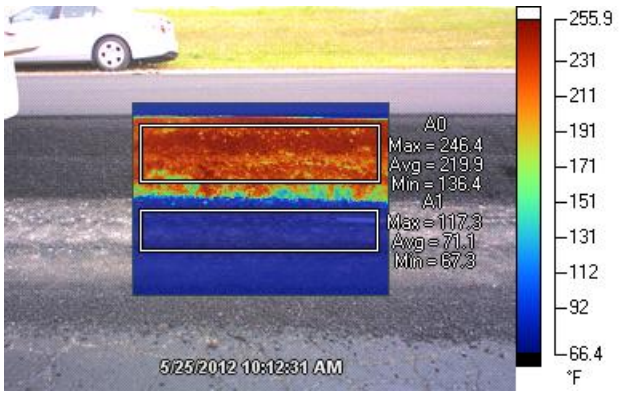
After Intermediate Roller

Before Finish Roller

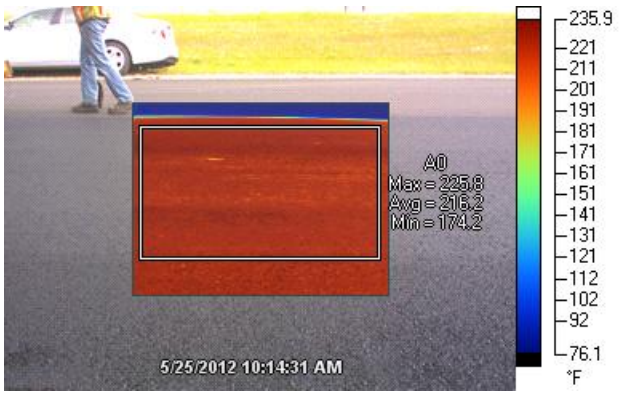


After Finish Roller

ND 15 WMA (Evotherm) East bound lane E02 at STA 660+00 = RP 73



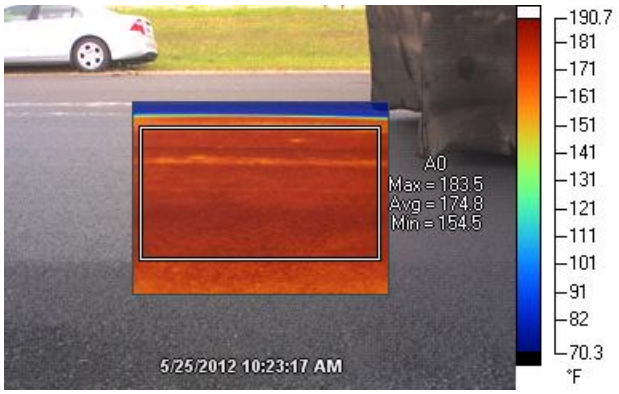
Unloading



Behind Paver

Before Breakdown Roller

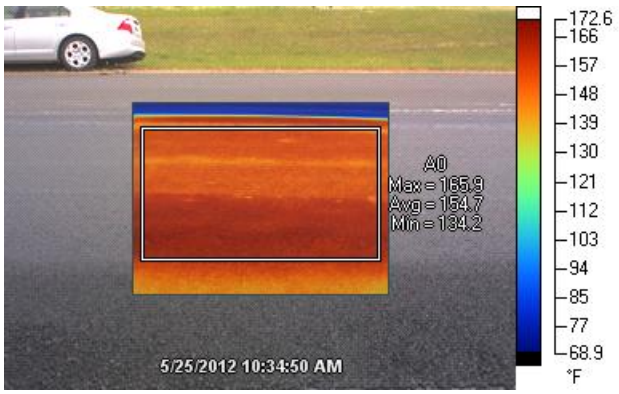
After Breakdown Roller



Before Intermediate Roller

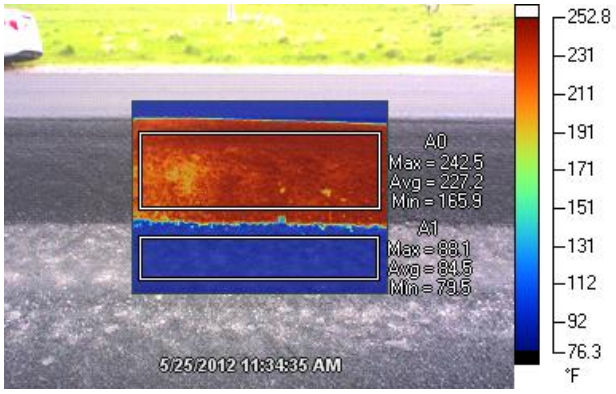
After Intermediate Roller

Before Finish Roller

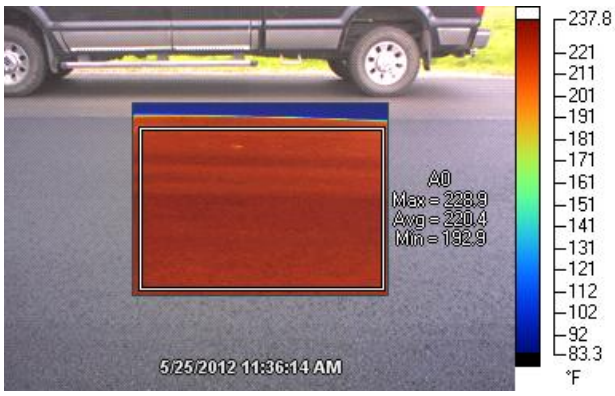


After Finish Roller

ND 15 WMA (Evotherm) East bound lane E03 at STA 630+00

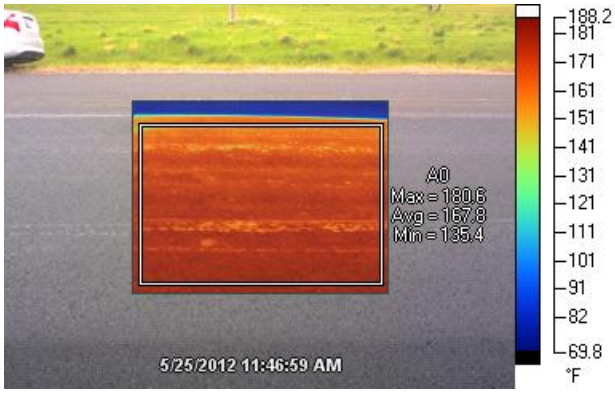


Unloading



Behind Paver

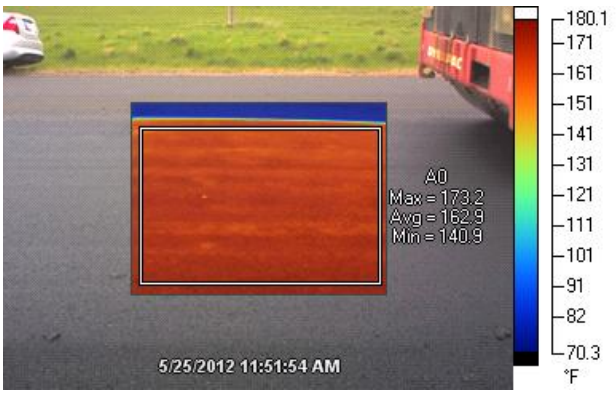
Before Breakdown Roller



After Breakdown Roller

Before Intermediate Roller

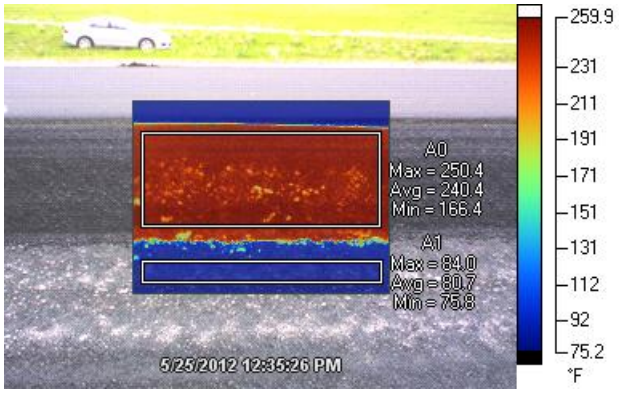
After Intermediate Roller



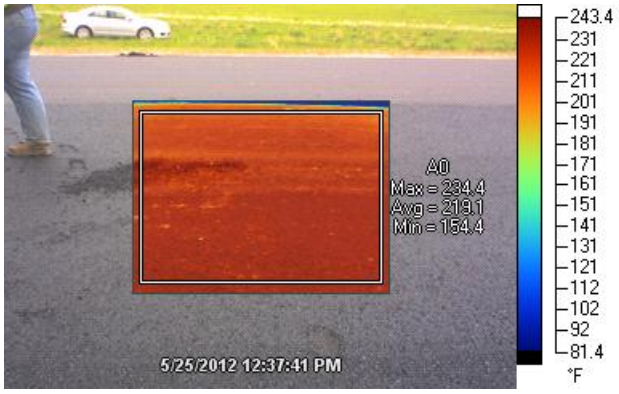
Before Finish Roller

After Finish Roller

ND 15 WMA (Evotherm) East bound lane E04 at STA 610+00

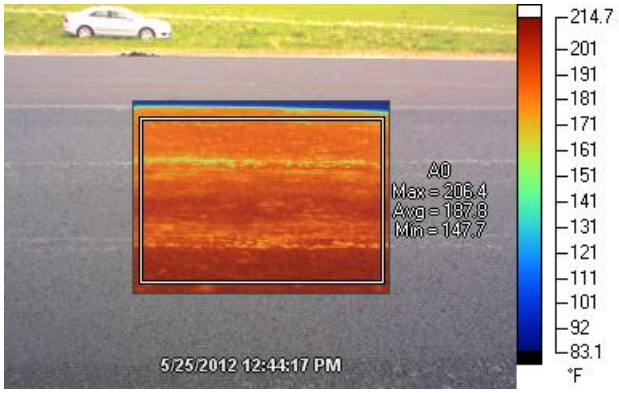


Unloading



Behind Paver

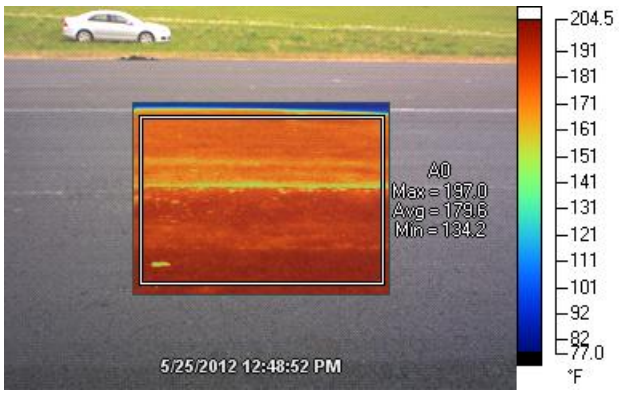
Before Breakdown Roller



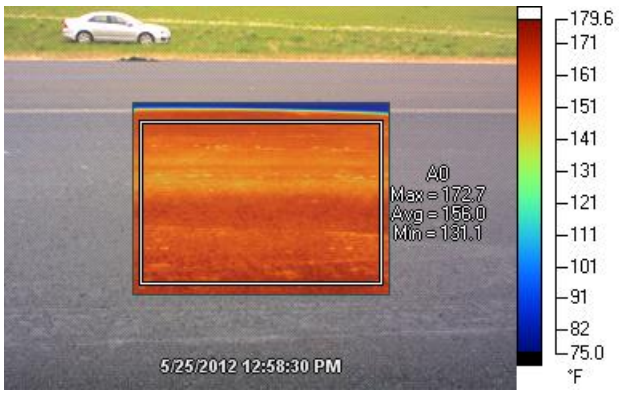
After Breakdown Roller

Before Intermediate Roller

After Intermediate Roller

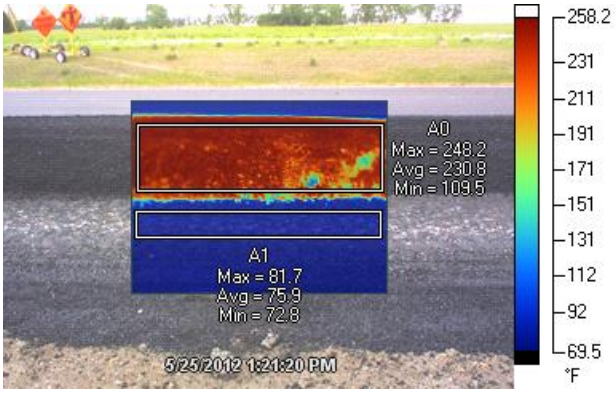


Before Finish Roller

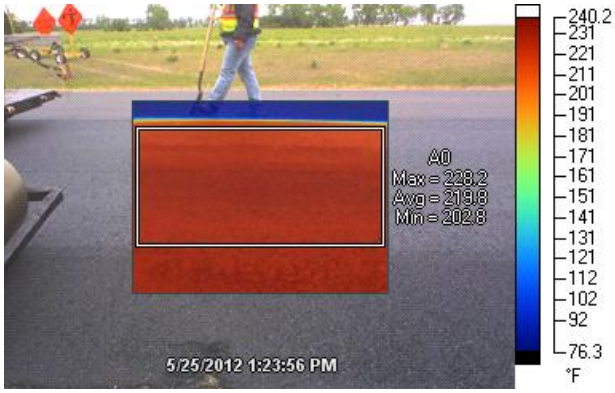


After Finish Roller

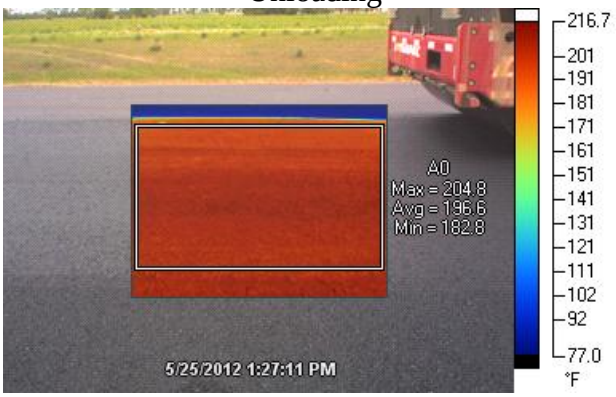
ND 15 WMA (Evotherm) East bound lane E05 at STA 590+00



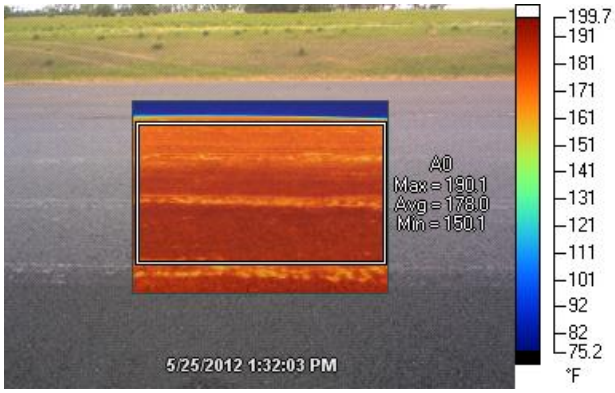
Unloading



Behind Paver

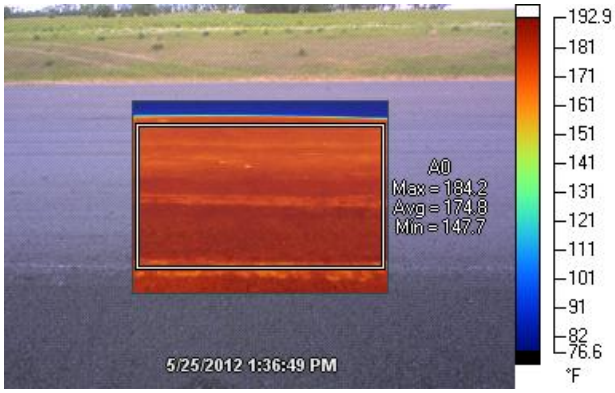


Before Breakdown Roller



After Breakdown Roller

Before Intermediate Roller

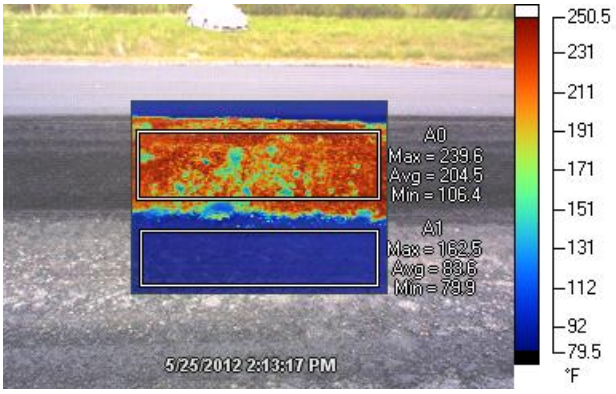


After Intermediate Roller

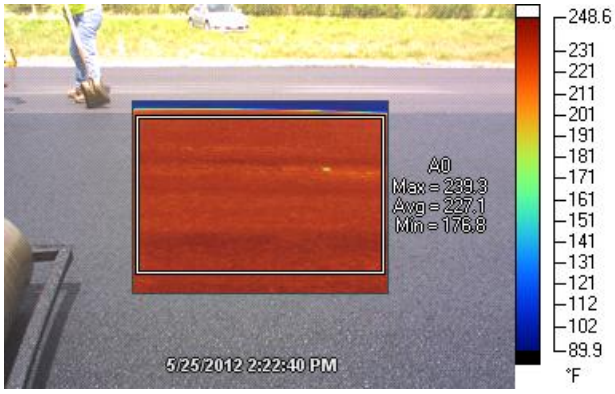
Before Finish Roller

After Finish Roller

ND 15 WMA (Evotherm) East bound lane E06 at STA 570+00

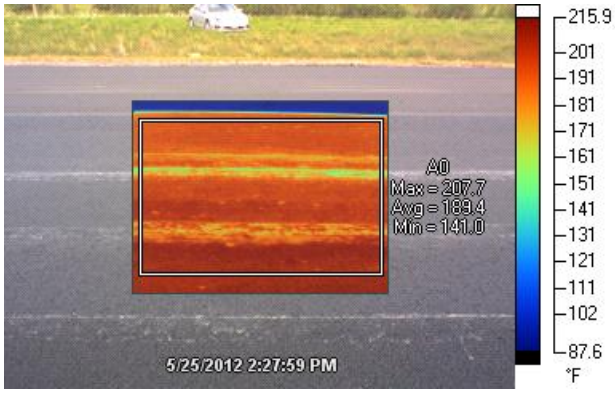


Unloading

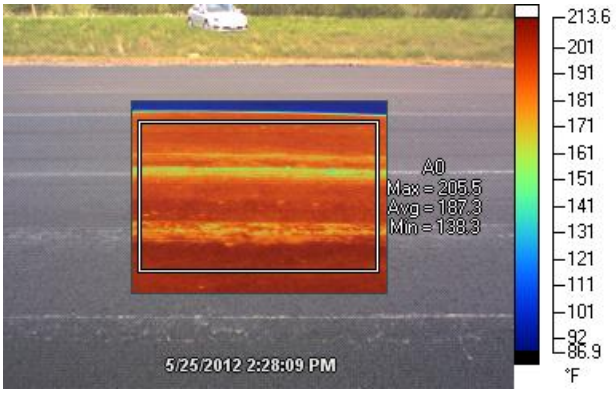


Behind Pave r

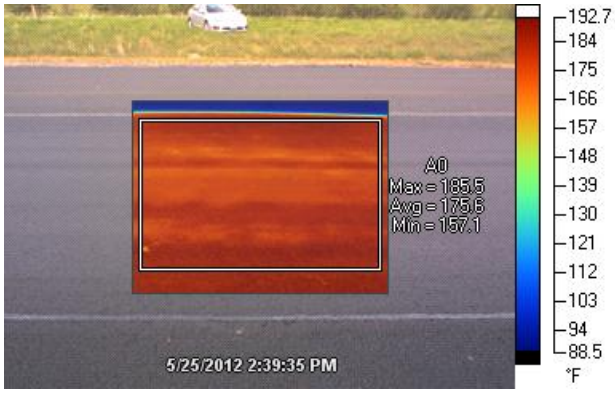
Before Breakdown Roller



After Breakdown Roller



Before Intermediate Roller

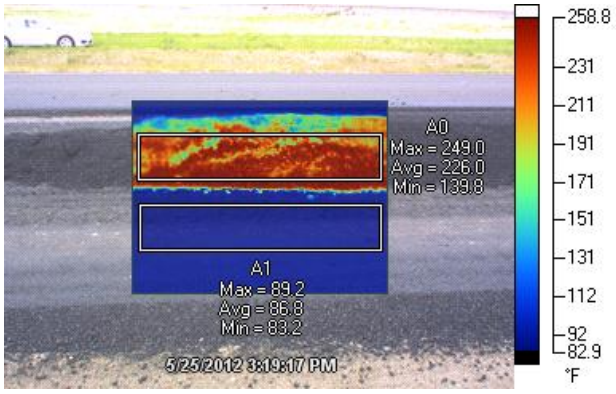


After Intermediate Roller

Before Finish Roller

After Finish Roller

ND 15 WMA (Evotherm) East bound lane E07 at STA 550+00



Unloading

Behind Paver

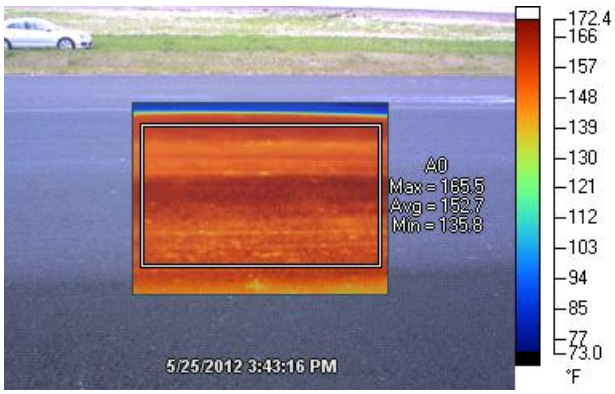
Before Breakdown Roller

After Breakdown Roller

Before Intermediate Roller

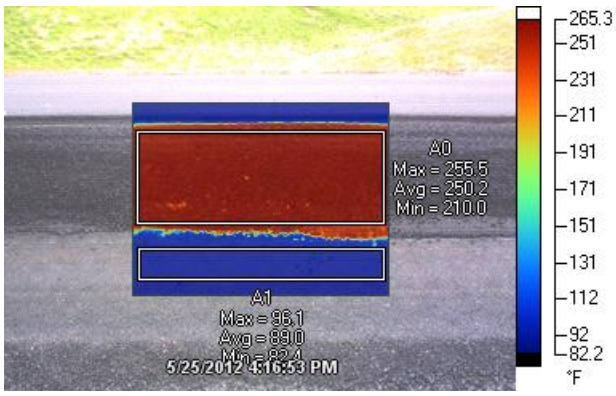
After Intermediate Roller

Before Finish Roller



After Finish Roller

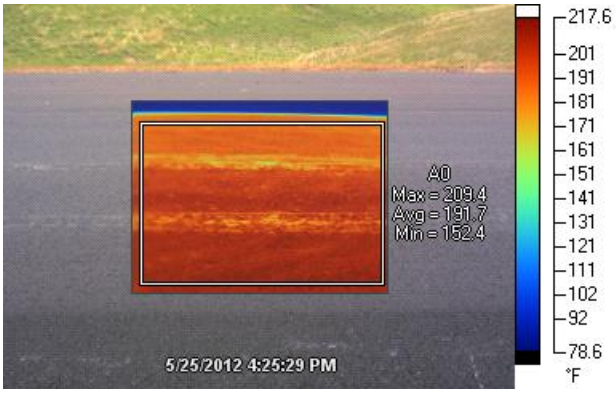
ND 15 WMA (Evotherm) East bound lane E08 at STA 530+00



Unloading

Behind Paver

Before Breakdown Roller



After Breakdown Roller

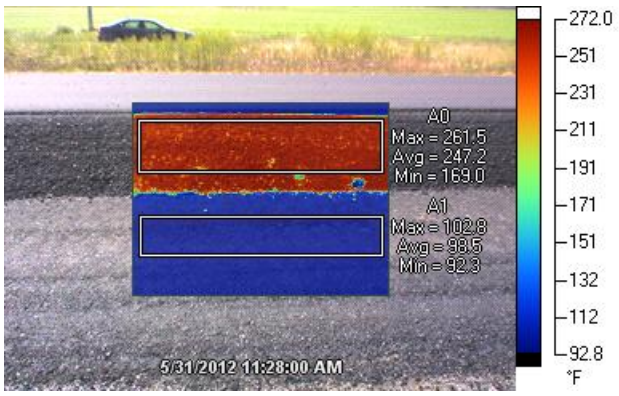
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

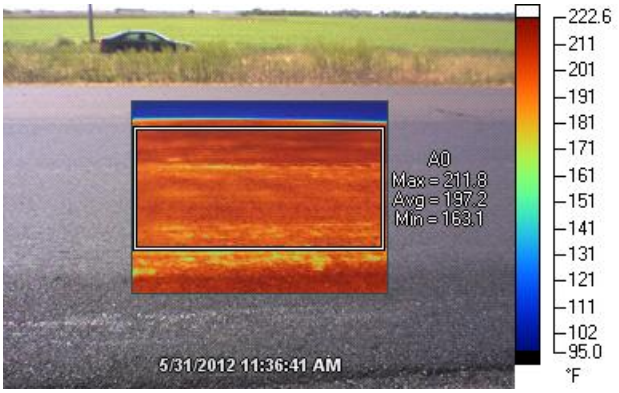
ND 15 WMA (Foamed) West bound lane W01 at STA 370+00



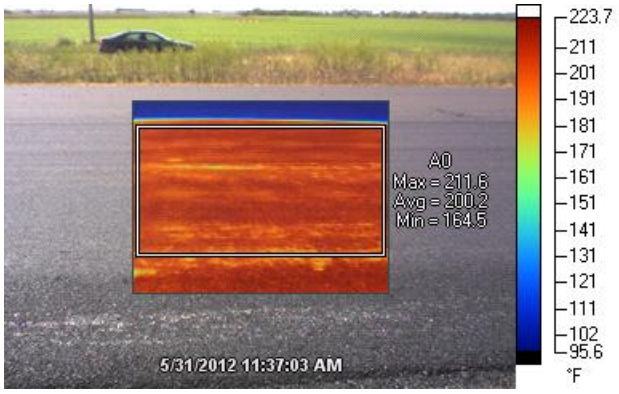
Unloading

Behind Paver

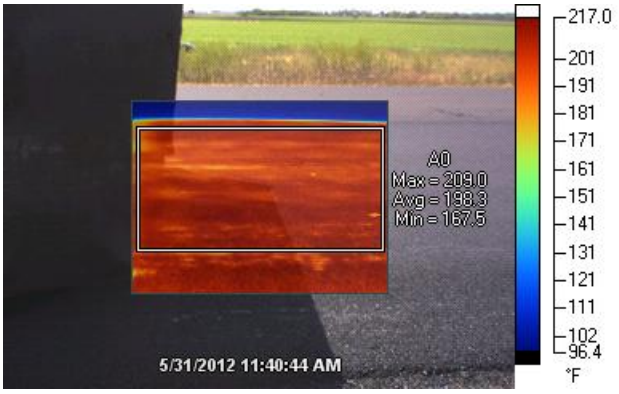
Before Breakdown Roller



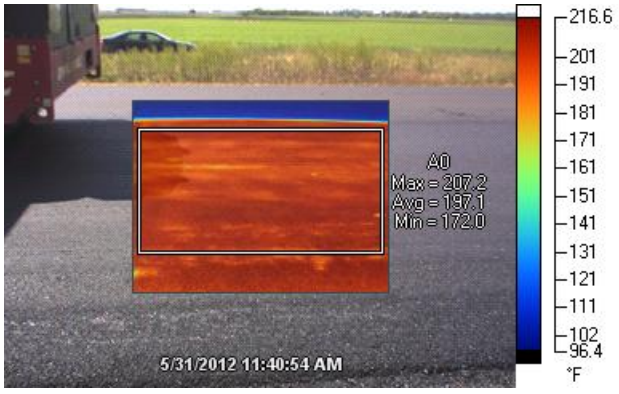
After Breakdown Roller



Before Intermediate Roller



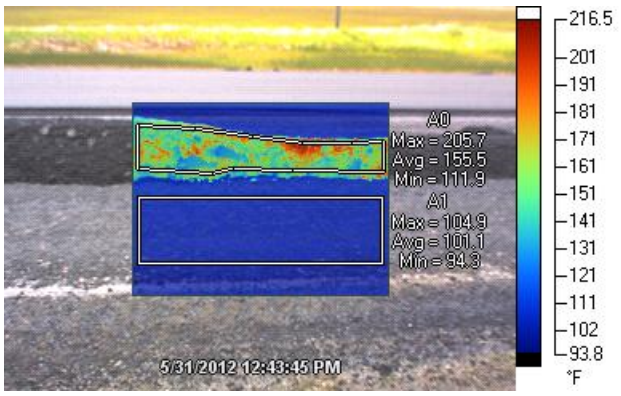
After Intermediate Roller



Before Finish Roller

After Finish Roller

ND 15 WMA (Foamed) West bound lane W02 at STA 330+00



Unloading

Behind Paver

Before Breakdown Roller

After Breakdown Roller

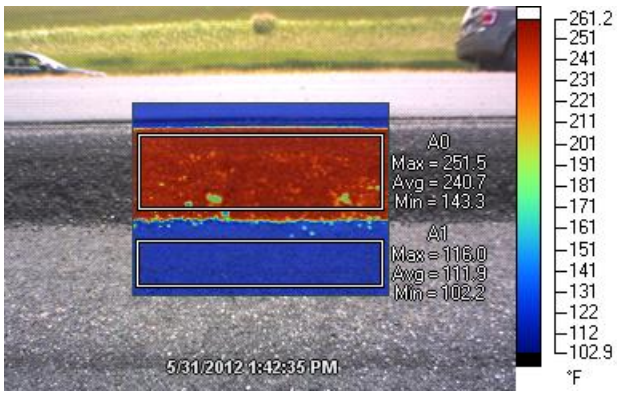
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

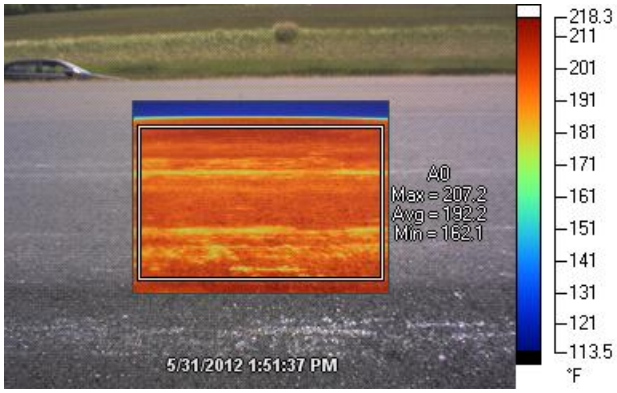
ND 15 WMA (Foamed) West bound lane W03 at STA 310+00



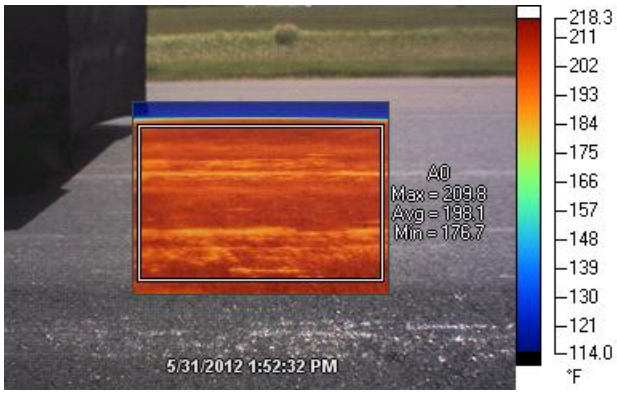
Unloading

Behind Paver

Before Breakdown Roller



After Breakdown Roller



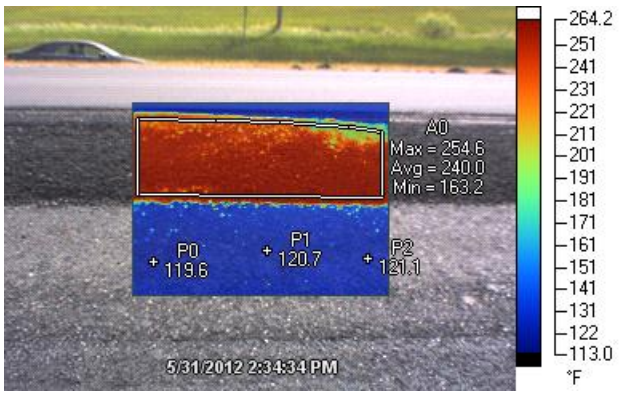
Before Intermediate Roller

After Intermediate Roller

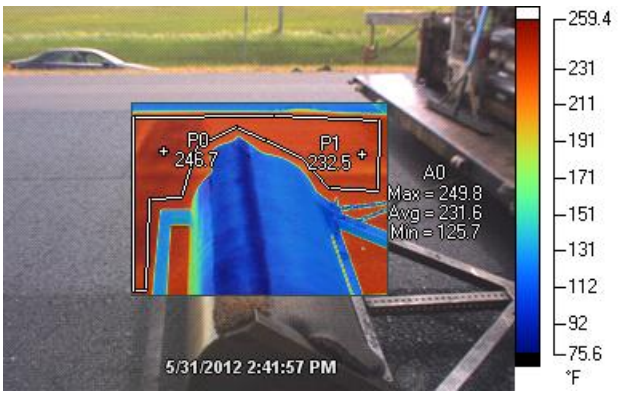
Before Finish Roller

After Finish Roller

ND 15 WMA (Foamed) West bound lane W04 at RP 66



Unloading



Behind Paver

Before Breakdown Roller

After Breakdown Roller

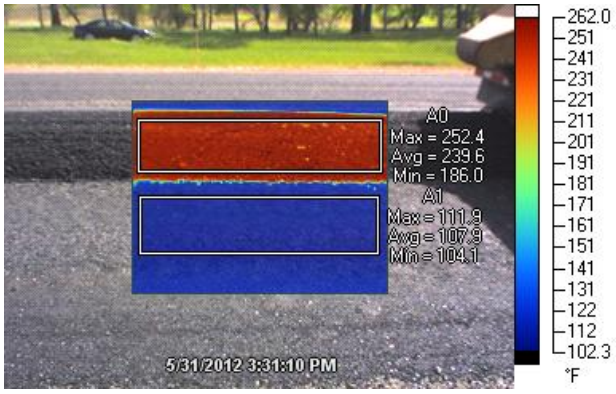
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

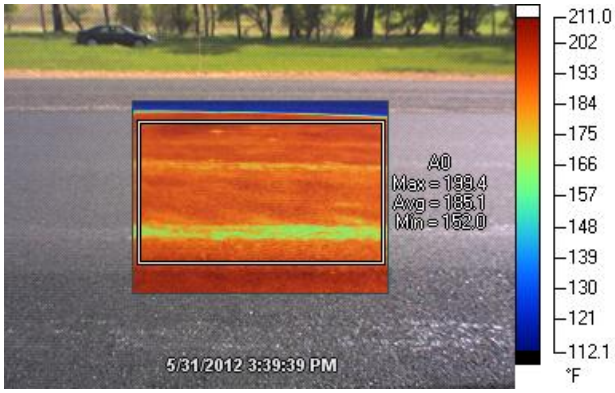
ND 15 WMA (Foamed) West bound lane W05 at STA 270+00



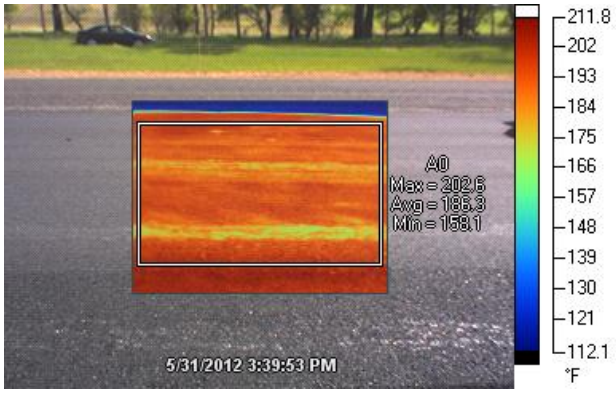
Unloading

Behind Paver

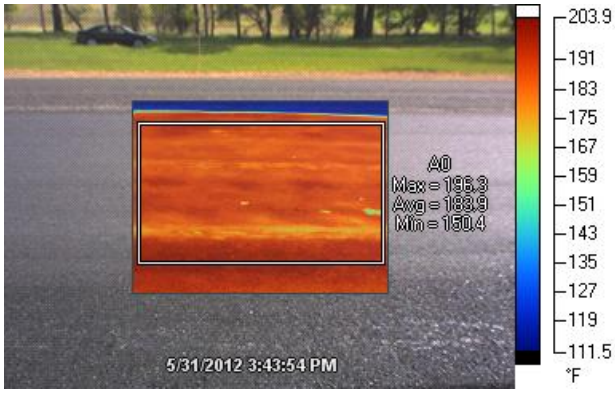
Before Breakdown Roller



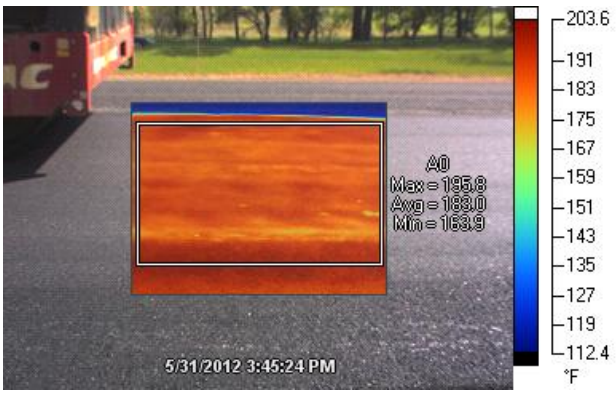
After Breakdown Roller



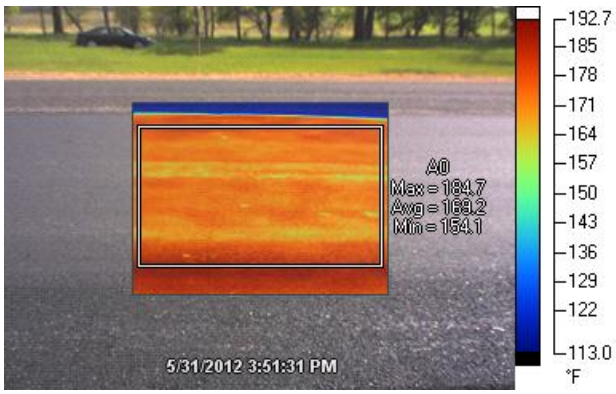
Before Intermediate Roller



After Intermediate Roller

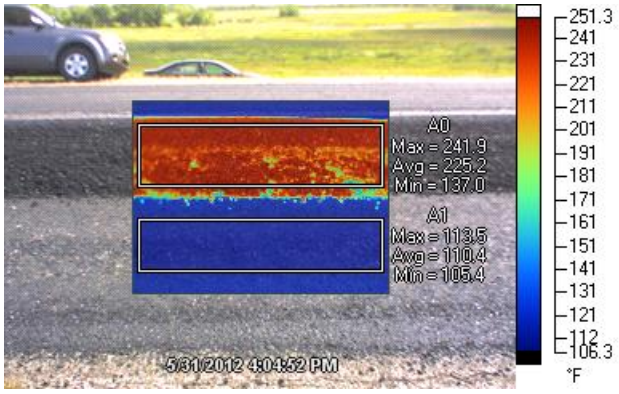


Before Finish Roller



After Finish Roller

ND 15 WMA (Foamed) West bound lane W06 at STA 250+00

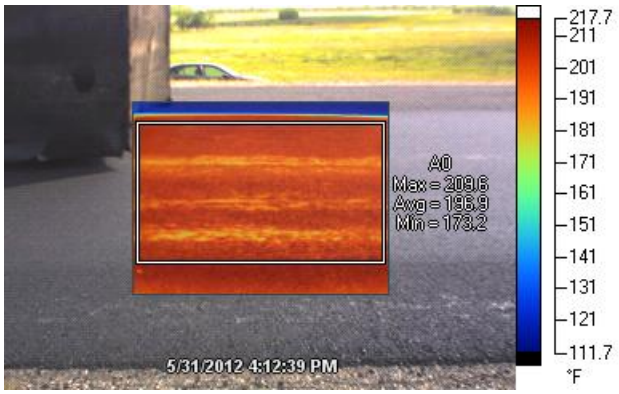


Unloading

Behind Paver

Before Breakdown Roller

After Breakdown Roller



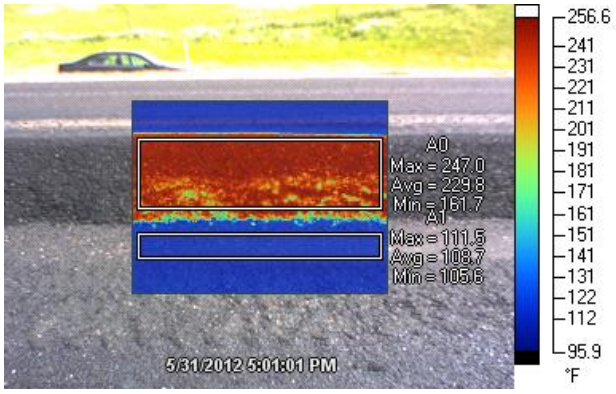
Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller

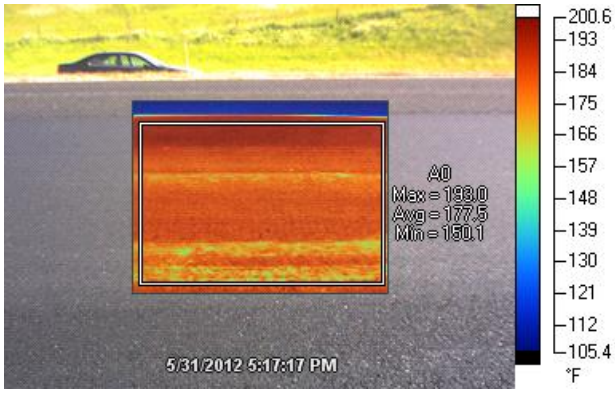
ND 15 WMA (Foamed) West bound lane W07 at STA 230+00



Unloading

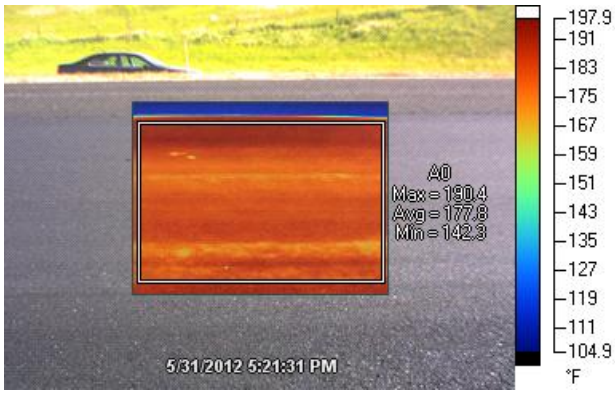
Behind Paver

Before Breakdown Roller

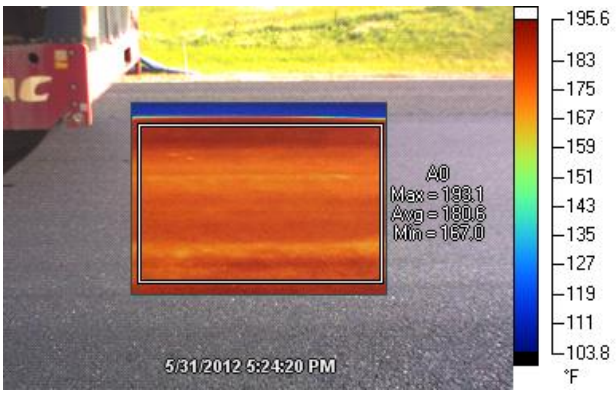


After Breakdown Roller

Before Intermediate Roller



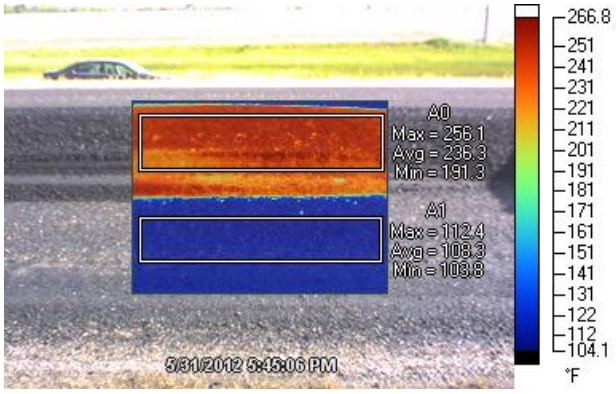
After Intermediate Roller



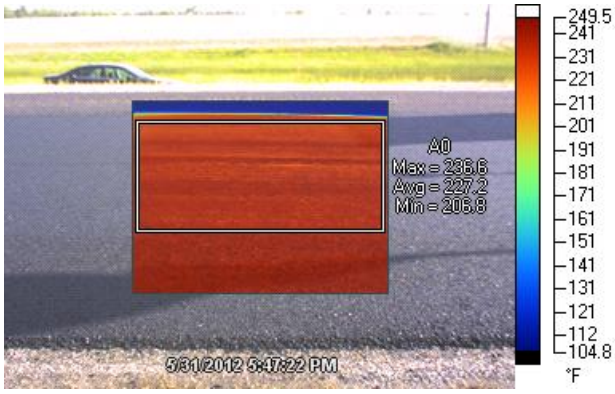
Before Finish Roller

After Finish Roller

ND 15 WMA (Foamed) West bound lane W08 at STA 210+00

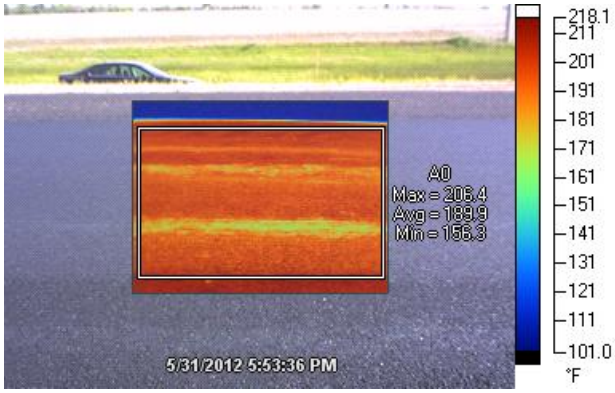


Unloading



Behind Paver

Before Breakdown Roller



After Breakdown Roller

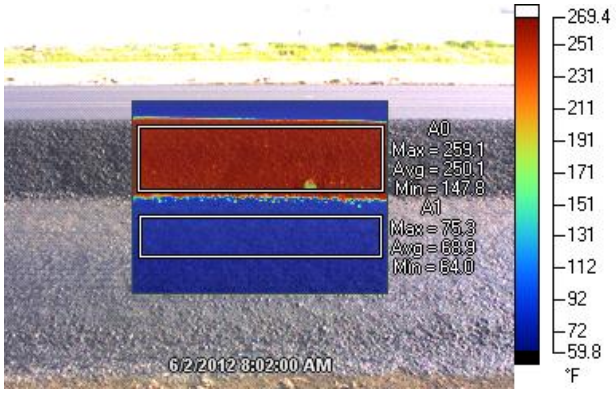
Before Intermediate Roller

After Intermediate Roller

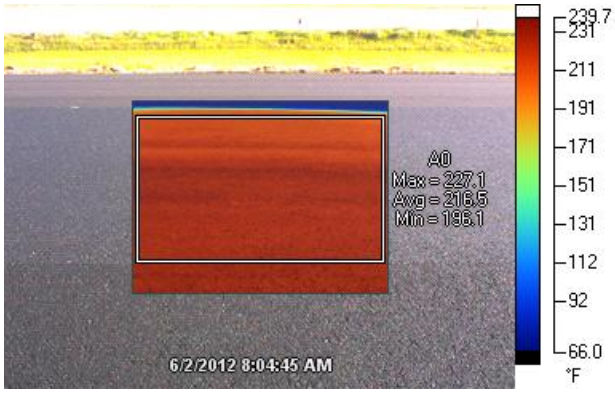
Before Finish Roller

After Finish Roller

ND 15 WMA (Foamed) East bound lane E01 at STA 262+59



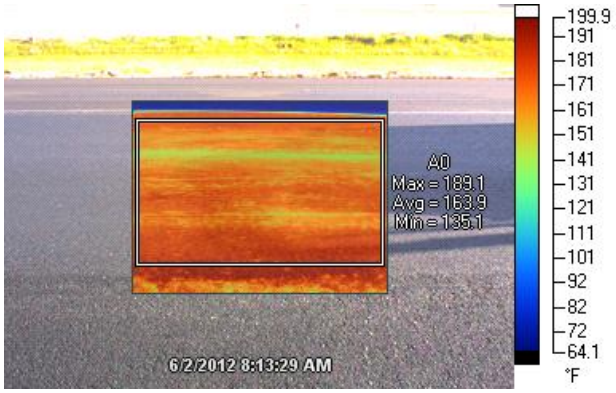
Unloading



Behind Paver

Before Breakdown Roller

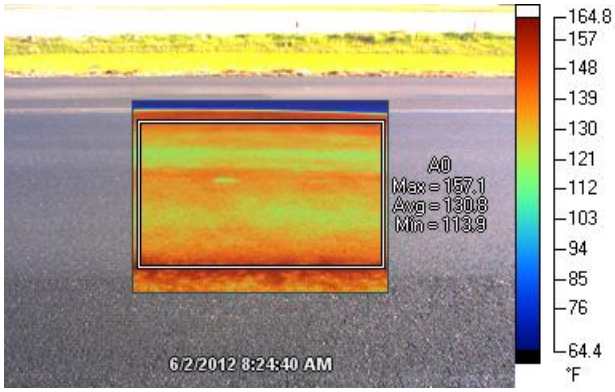
After Breakdown Roller



Before Intermediate Roller

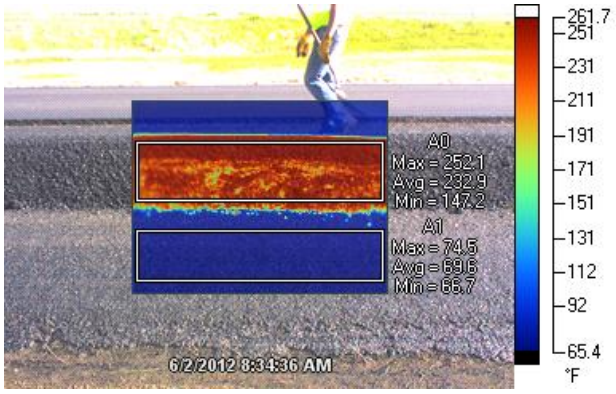
After Intermediate Roller

Before Finish Roller



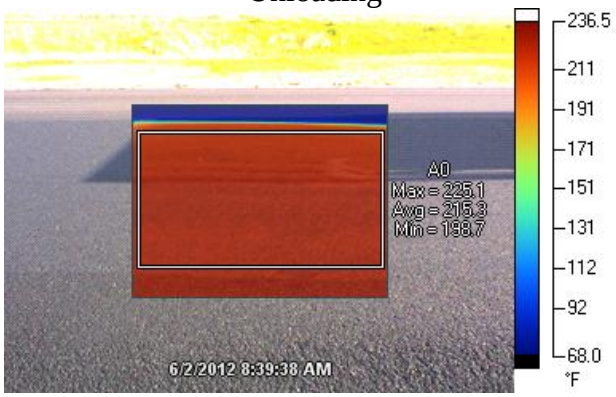
After Finish Roller

ND 15 WMA (Foamed) East bound lane E02 at STA 247+42

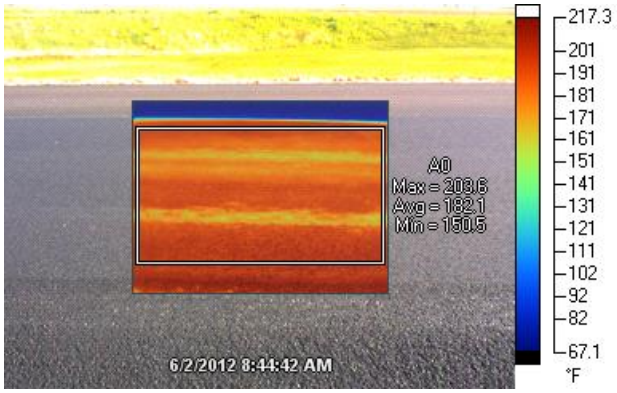


Unloading

Behind Paver



Before Breakdown Roller

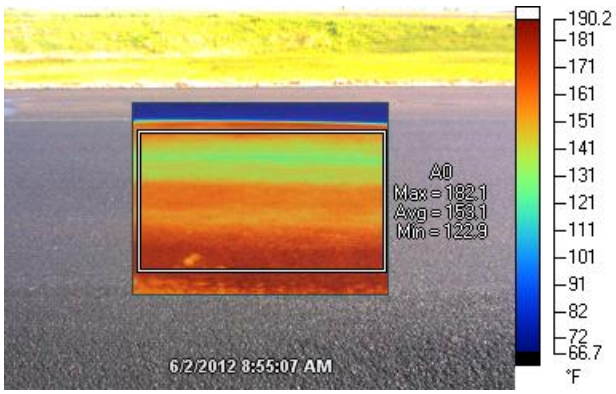


After Breakdown Roller

Before Intermediate Roller

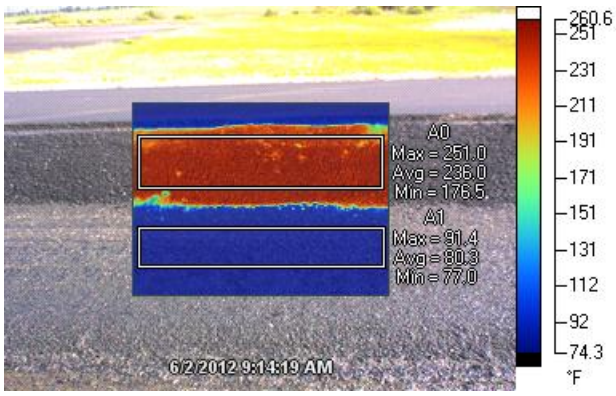
After Intermediate Roller

Before Finish Roller

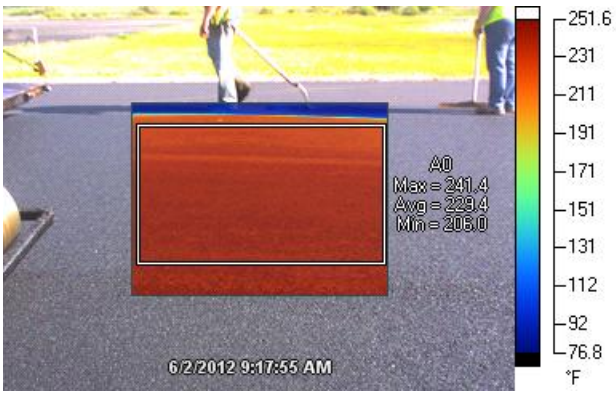


After Finish Roller

ND 15 WMA (Foamed) East bound lane E03 at STA 229+13

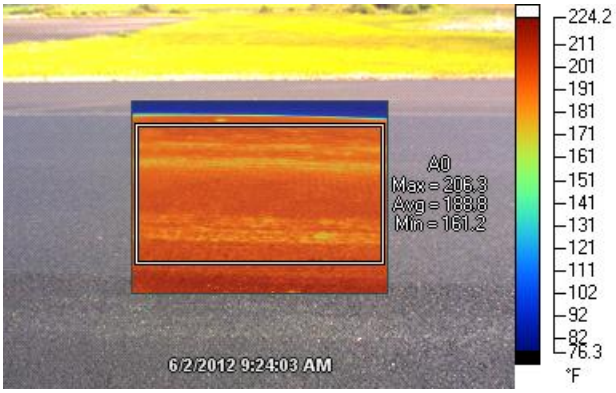


Unloading

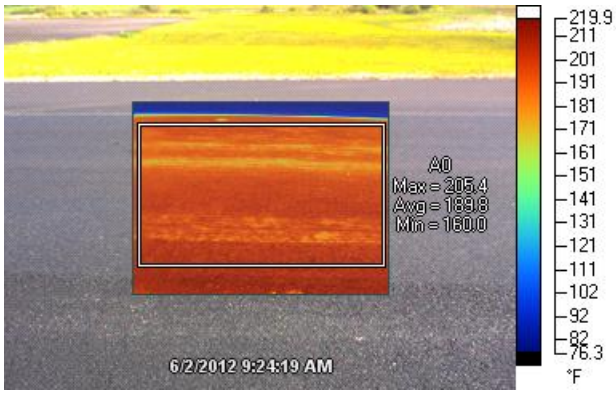


Behind Paver

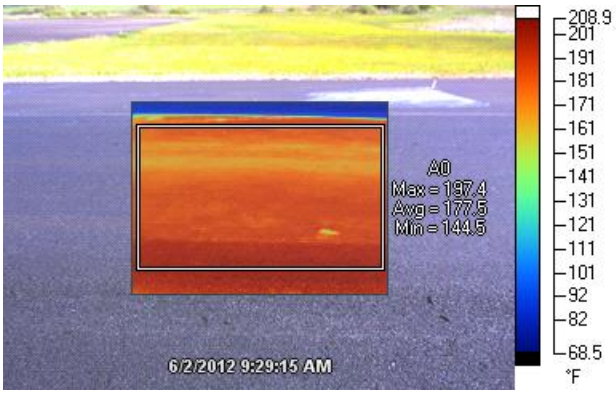
Before Breakdown Roller



After Breakdown Roller

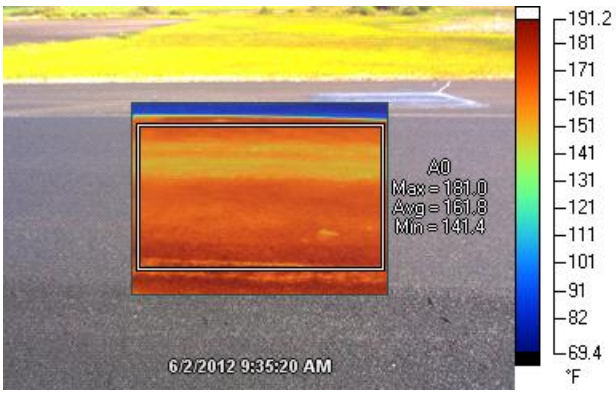


Before Intermediate Roller



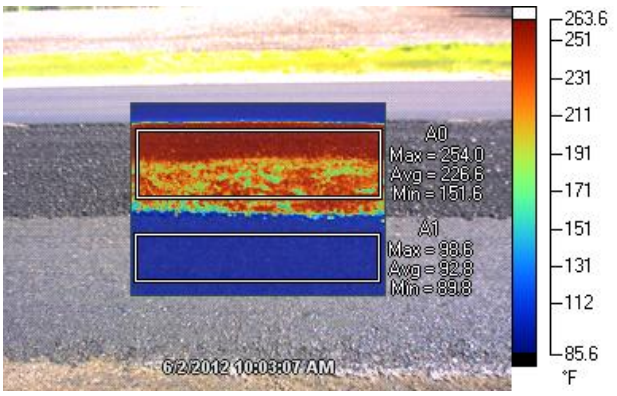
After Intermediate Roller

Before Finish Roller

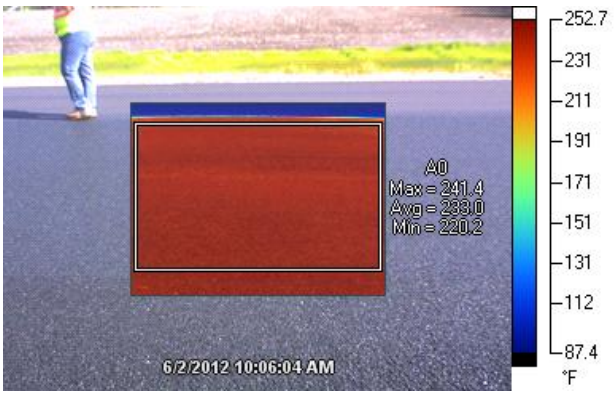


After Finish Roller

ND 15 WMA (Foamed) East bound lane E04 at STA 205+18

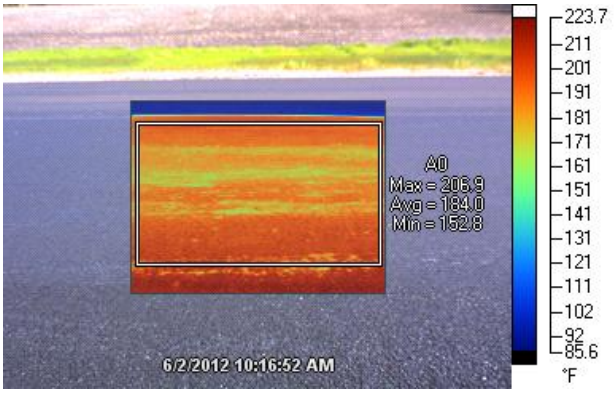


Unloading

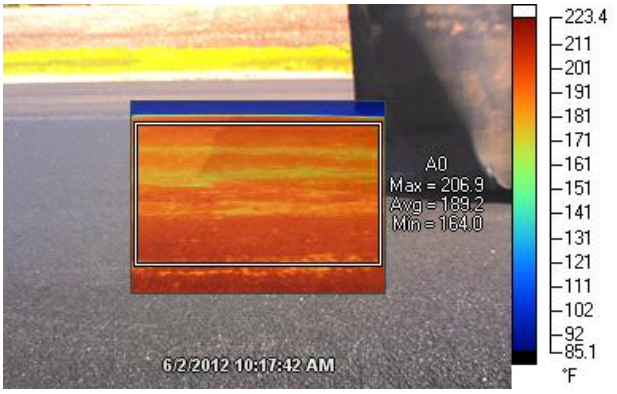


Behind Paver

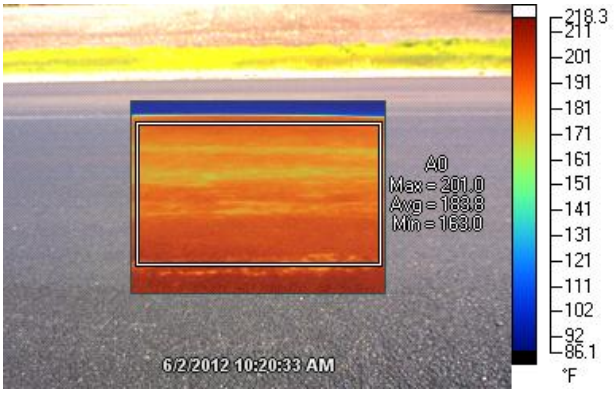
Before Breakdown Roller



After Breakdown Roller



Before Intermediate Roller

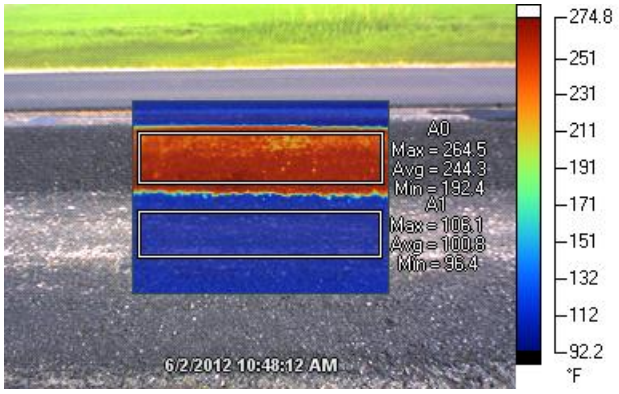


After Intermediate Roller

Before Finish Roller

After Finish Roller

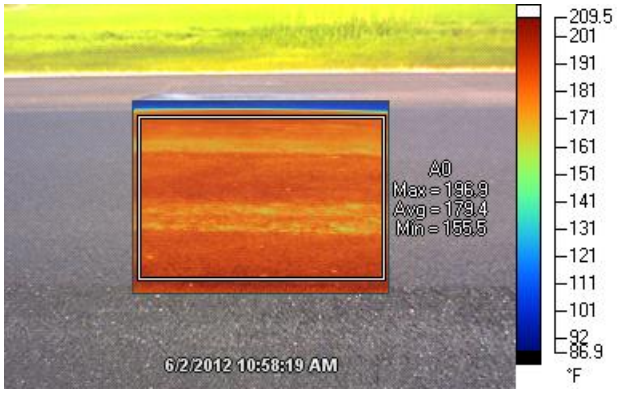
ND 15 WMA (Foamed) East bound lane E05 at STA 189+61



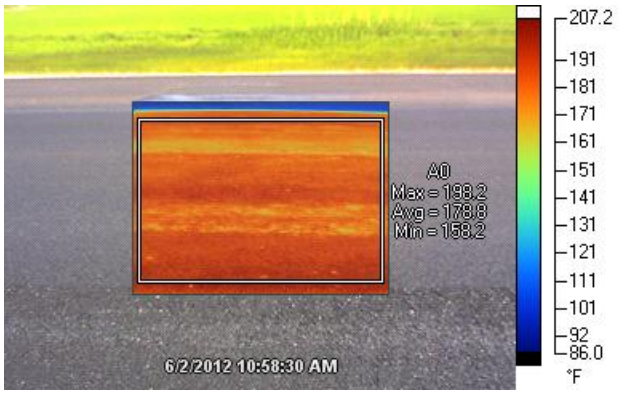
Unloading

Behind Paver

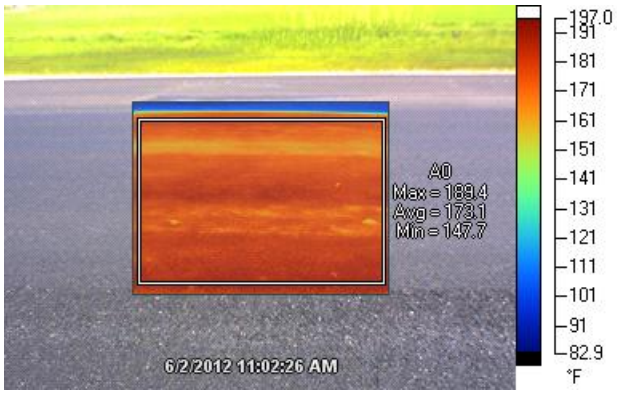
Before Breakdown Roller



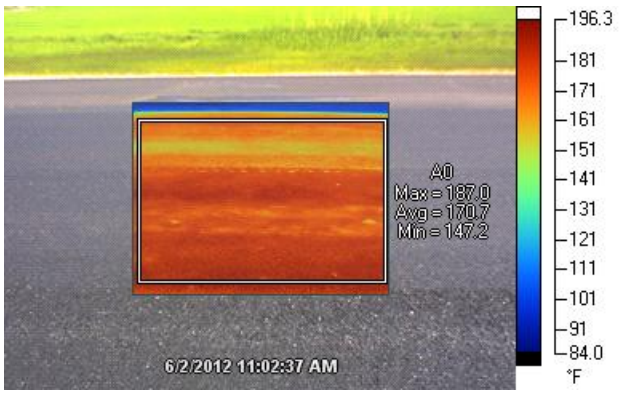
After Breakdown Roller



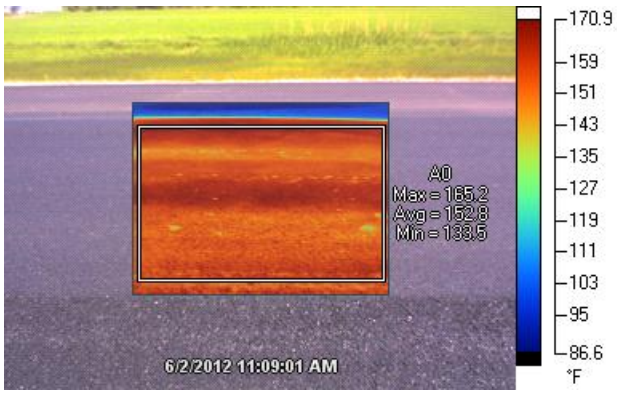
Before Intermediate Roller



After Intermediate Roller

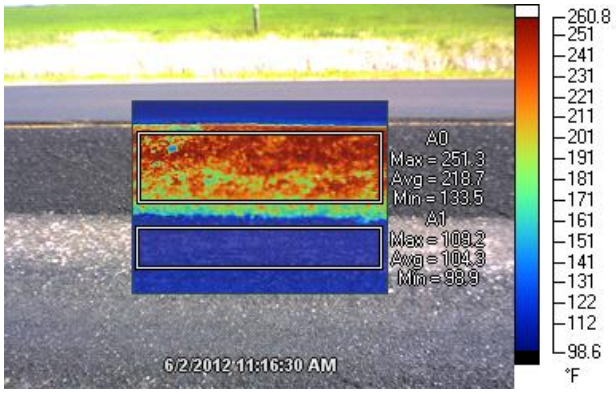


Before Finish Roller



After Finish Roller

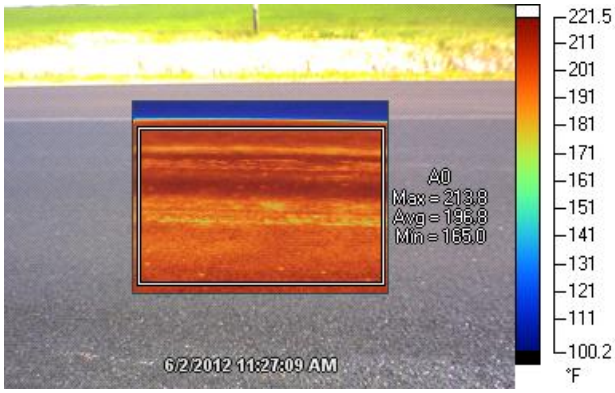
ND 15 WMA (Foamed) East bound lane E06 at STA 174+28



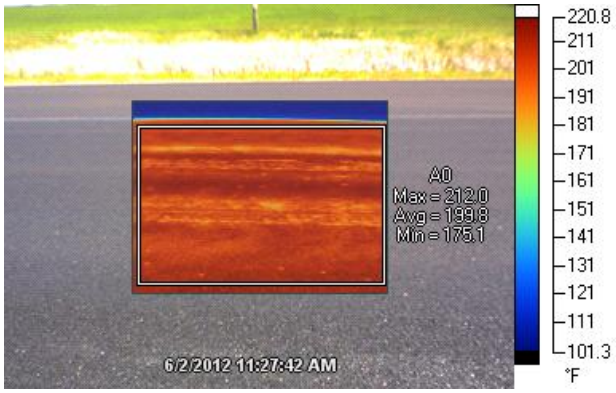
Unloading

Behind Paver

Before Breakdown Roller



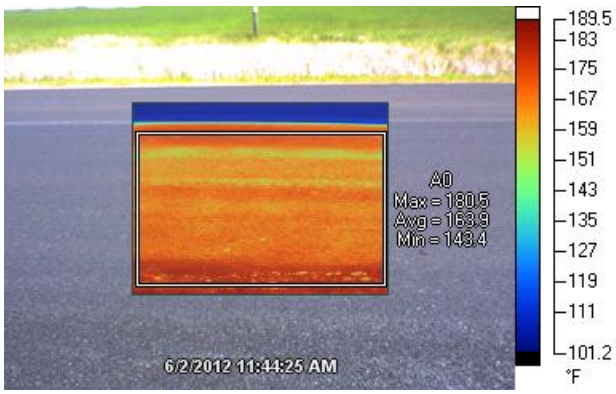
After Breakdown Roller



Before Intermediate Roller

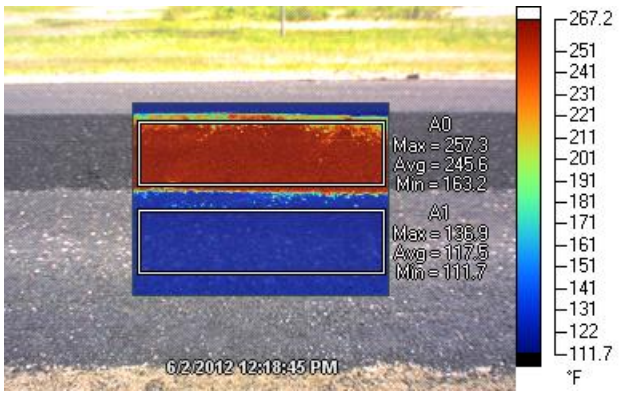
After Intermediate Roller

Before Finish Roller

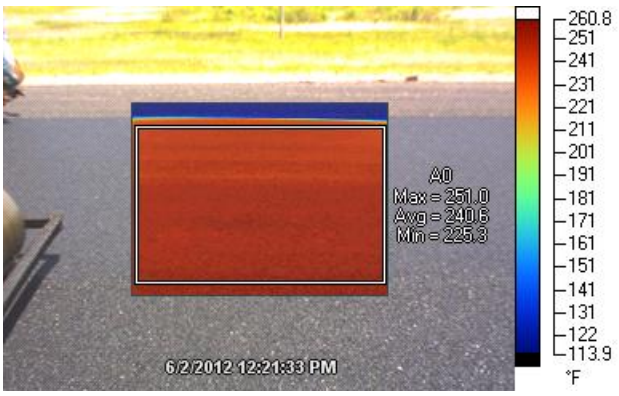


After Finish Roller

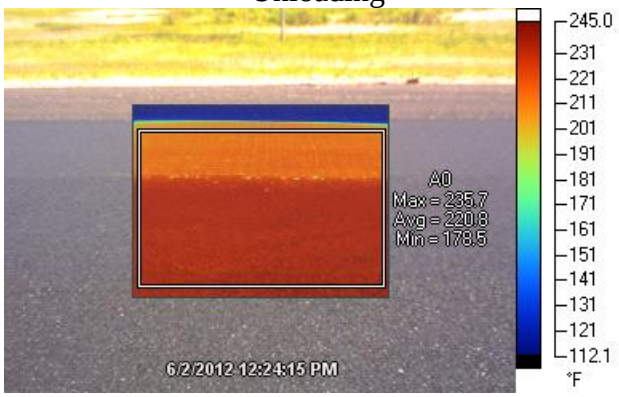
ND 15 WMA (Foamed) East bound lane E07 at STA 147+80



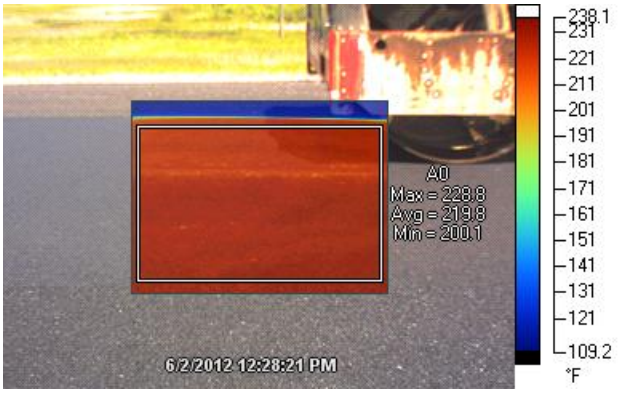
Unloading



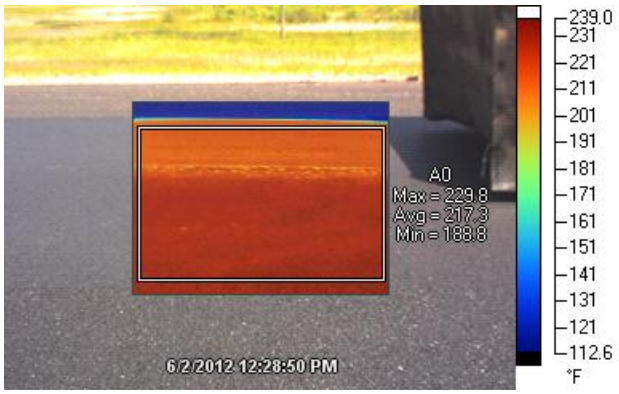
Behind Paver



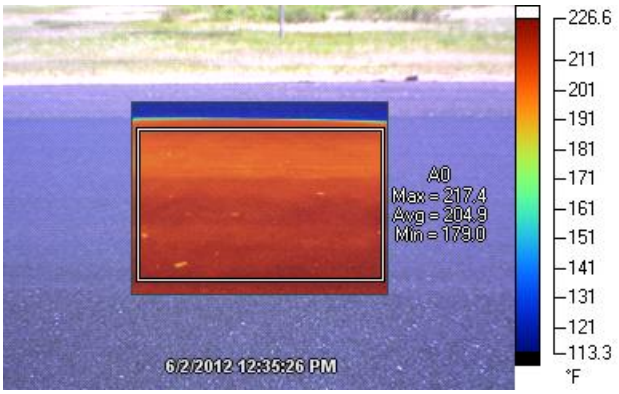
Before Breakdown Roller



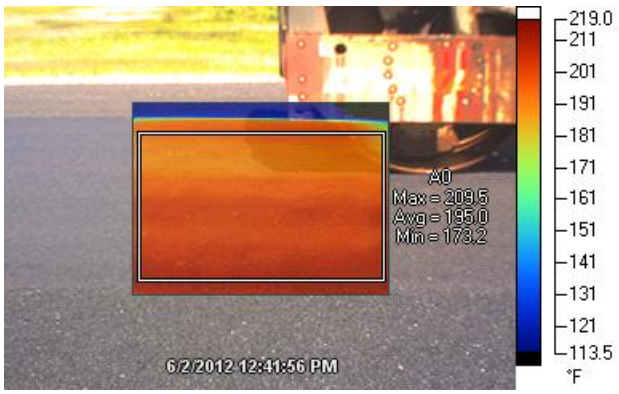
After Breakdown Roller



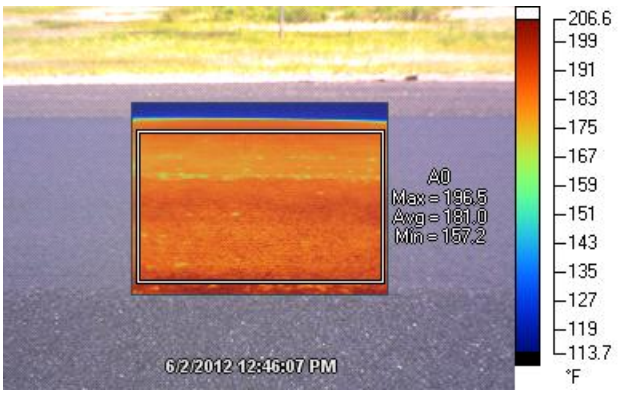
Before Intermediate Roller



After Intermediate Roller

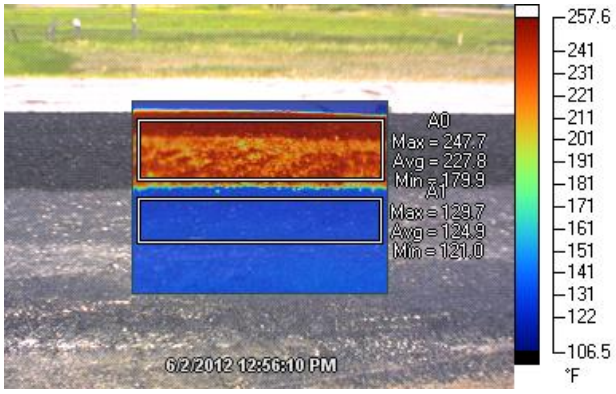


Before Finish Roller



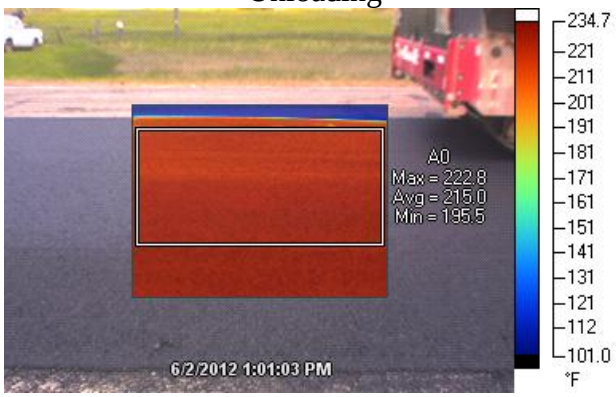
After Finish Roller

ND 15 WMA (Foamed) East bound lane E08 at STA 131+88

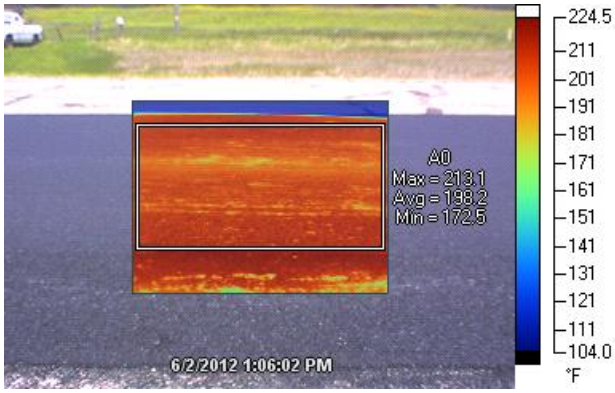


Unloading

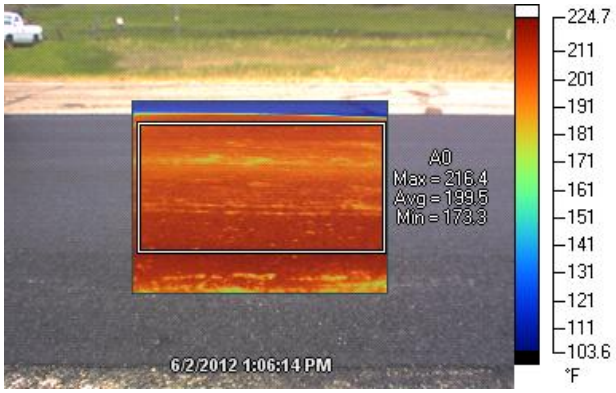
Behind Paver



Before Breakdown Roller



After Breakdown Roller



Before Intermediate Roller

After Intermediate Roller

Before Finish Roller

After Finish Roller