Pennsylvania Turnpike: Dry and Wet Retroreflectivity Test Results of Different Combinations of Retroreflective Optics Installed in an Epoxy Binder

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TABLE OF CONTENTS

Page

CHAPTER 1:
BACKGROUND INFORMATION

The goals and objectives of this research were to, 1) review epoxy triple drop pavement marking specification and related material, 2) determine the performance of various bead loading rates, and 3) recommend changes to the PTC's triple drop pavement marking specification. These goals and objectives were to be met by, 1) reviewing materials provided by the sponsor, 2) creating and evaluating pavement marking test samples, and 3) making recommendations to the PTC's current triple drop pavement marking specification.

EPOXY TRIPLE DROP SPECIFICATION

The research team was provided the latest version of the highly reflectorized triple drop epoxy pavement marking specification as well as other supporting documents to review prior to an initial kickoff meeting (data from striping contractors and product bulletins from the manufacturers).

During a kickoff conference call, Tom Macchione indicated that the goal of the triple drop specification was to produce a functional pavement marking for two to four years. In addition, there is also interest in providing a pavement marking product with enough wet performance that the use of SRPMs may be eliminated.

The PTC has been through several versions of the triple drop specification. The specification was originally adopted from the New York State Thruway Authority. Eventually the specification may become a standard provision.

Price and performance are a concern. Earlier experiments with inlaid (rolled) tape proved unsuccessful. While the cost was high (approximately $4.30/lf for inlaid (rolled)), the performance of the rolled tape was marginal as some of the rolled tape started coming up during year two. Earlier experiments with recessed (grooved) tape performed well, but were more expensive at approximately $6.50/lf . The current triple drop markings (as of fall 2013) are approximately $2.00/lf and are expected to provide at least two years of service (possibly more).

The PTC's experience with the retroreflective performance of the triple drop epoxy markings has been mixed. Some contractors are having difficulties meeting the minimum retroreflectivity levels using the specified optics and loading rates. Contractors have reported that the bead loading rates are too high, causing shadowing of optics and lower than intended performance.

The version of the PTC specification that was provided at the beginning of this research called for the following bead types and drop rates to be applied to a 25 mil epoxy marking.

- First Drop: 3M all-weather microcrystalline ceramic beads at 7 lbs/gallon.
- Second Drop: Visibead Plus II beads at 7 lbs/gallon.
- Third Drop: Standard glass beads at 10 lbs/gallon.

According to the specification, markings are required to have initial performance levels that meet or exceed the values in Table 1.

Table 1. Retroreflectivity Requirements.

WHITE	DRY	WET & RAINY
Entrance Angle	88.76°	88.76°
Observation Angle	1.05°	1.05°
Retroreflected Luminance R_L ($mcd/m^2/lx$)	500	250
YELLOW	DRY	WET & RAINY
Entrance Angle	88.76°	88.76°
Observation Angle	1.05°	1.05°
Retroreflected Luminance R_L ($mcd/m^2/lx$)	300	200

In an effort to better understand how various combinations of the specified optics and their loading rates impact retroreflectivity, the research team worked with the PTC to develop 30 different pavement marking test samples for retroreflectivity testing. The research team used tools in the TTI Visibility Research Lab to make and test the 30 pavement marking test samples. This work is described in the next chapter.

CHAPTER 2:
PAVEMENT MARKING SAMPLE TESTING

Using the data provided by the sponsor, the material manufacturers, and previous testing results, the research team and the PTC devised a plan to test 30 combinations of bead types, rates, and binder thickness. The matrix of combinations tested, the sample creation process, and the retroreflectivity measurements are described in this chapter.

MATRIX OF SAMPLES TESTED

In conjunction with the PTC, the research team developed a matrix of the 30 bead/bead rate/binder combinations for testing. The research team tested bead types and rates that were included in the current triple drop specification as well as lower bead rates and some additional types of beads. All samples created were white epoxy; no other binders or yellow epoxy was used.

The pavement marking combinations tested is provided in

Table 2. The types of beads tested were 3M 100% wet elements, 3M 70/30 wet/dry elements, Potters Visimax+, Potters Ultra 1.9 High Index, Potters Visibead Plus II, and Potters Standard bead (the 3M 50/50 element was not provided). The samples were applied at 25 mil or 20 mil. The bead rates varied for the different bead type from 3.5 lbs/gal to 12.5 lbs/gallon. In addition to triple drop tests, the study also included some double drop tests.

The specific loading rates tested included those recommended by the manufacturers. The triple drop specification has element drop rates that were higher than the manufacturer recommended rates so this was a key area for exploration. In addition to the specific bead loading rate of an individual bead type, the overall bead loading has to be adequate enough to facilitate application of the marking.

Table 2. Pavement Marking Test Sample Matrix.

		Bead Types and Rates (lbs/gal)							
		All-Weather Elements			Visibead Plus II	Visimax+	Ultra 1.9 High Index	AASHTO M247 Type I
Sample	Epoxy mil	Total	100/0	70/30				
1*	25	7	X		7	0	0	10
2**	25	7		X	7	0	0	10
3	25	7		X	5	0	0	5
4	25	4.5	X		7	0	0	10
5	25	4.5	X		7	0	0	5
6	25	4.5	X		10	0	0	0
7	25	4.5	X		3.5	0	0	10
8	25	4.5		X	7	0	0	10
9	25	4.5		X	10	0	0	0
10	25	4.5		X	7	0	0	5
11	25	4.5		X	3.5	0	0	10
12	25	5		X	5	0	0	10
13	25	5		X	7	0	0	7
14	25	5		X	5	0	0	5
15	25	3	X		7	0	0	10
16	25	3		X	7	0	0	10
17	25	3		X	10	0	0	5
18	25	4.5	X		12	0	0	0
19	25	4.5		X	12	0	0	0
20	25	4.5		X	0	0	7	10
21	25	0			7	7	0	10
22	25	0			7	4.5	0	10
23	25	0			7	4.5	0	5
24	20***	0			9	5.5	0	12.5
25	20***	0			9	5.5	0	6
26	20***	9	X		9	0	0	12.5
27	20***	5.5	X		9	0	0	12.5
28	20***	5.5		X	9	0	0	6
29	20***	5.5		X	12.5	0	0	0
30	20***	6		X	6	0	0	6

*Identical to initial specification

**Identical to initial specification but with a different blend of all-weather elements

***Bead rate converted by volume of material applied to give same coverage as 25 mil samples

CREATING THE SAMPLES

The research team created the 30 pavement marking samples on 24 inch long glass substrate panels. The substrate panels were marked to identify each sample. The two part epoxy binder was received in 5 gallon pails. Each part was poured into smaller containers to make it easier to mix for each marking sample. All of the beads were acquired and measured out according to Table 2. The specific quantity of beads used for each sample was related to the bead drop rate in lbs/gallon, the thickness of the marking being applied, and the area covered by the beads. Each bead type for each sample was measured prior to making any of the samples.

To create the marking samples the beads were loaded into the bead drop system as pictured in Figure 1. The bead drop system evenly disperses the beads over the marking area. The system is setup for a double drop, so a third bead trough was filled to the side and added after the first two were dumped. The labeled glass substrate panel was placed in the drawdown jig as pictured in Figure 1. The epoxy was mixed in individual batches at a 2 to 1 ratio for each sample. After adequate mixing the epoxy was poured into the drawdown applicator and the marking was applied to the substrate panel. The beads were then immediately dumped onto the wet marking as seen in Figure 2. Figure 3 provides an overhead view of a finished sample. Each sample was created in a similar manner.

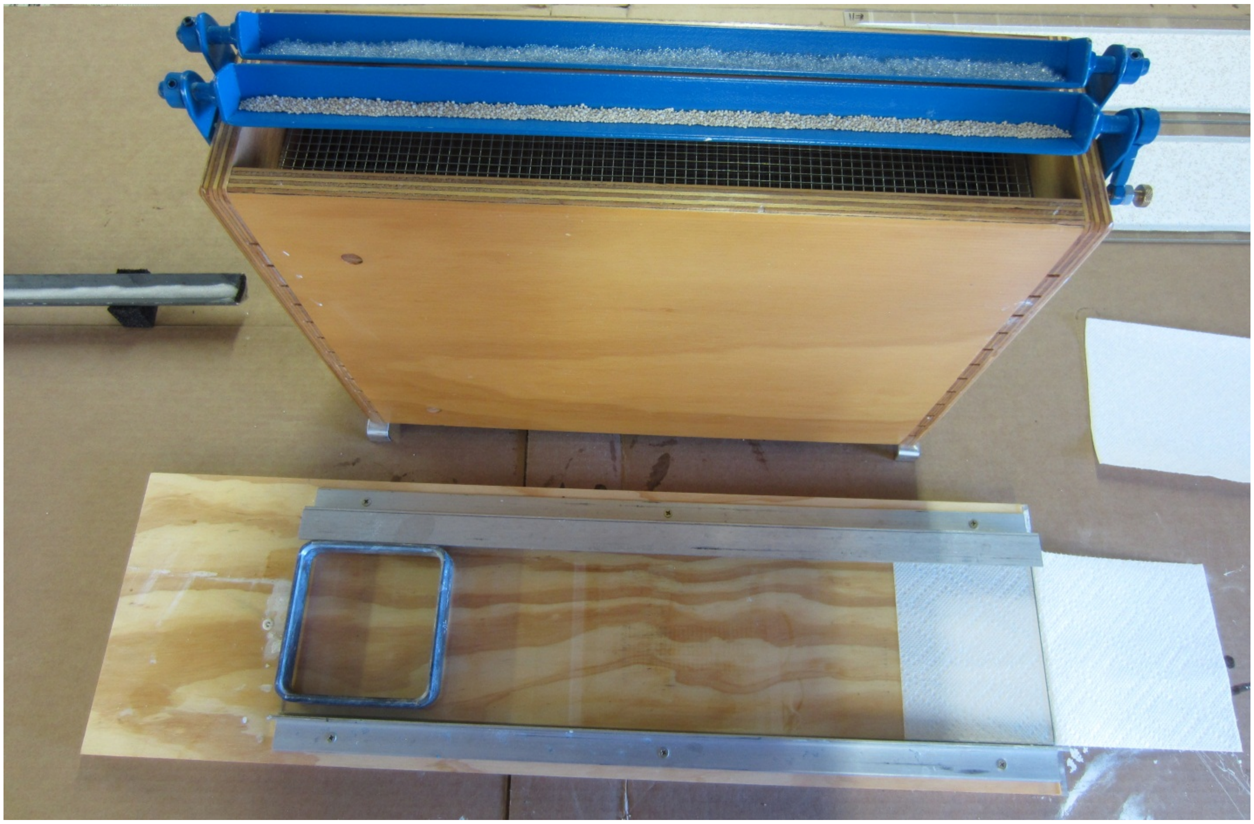

Figure 1. Bead Box and Drawdown Jig.

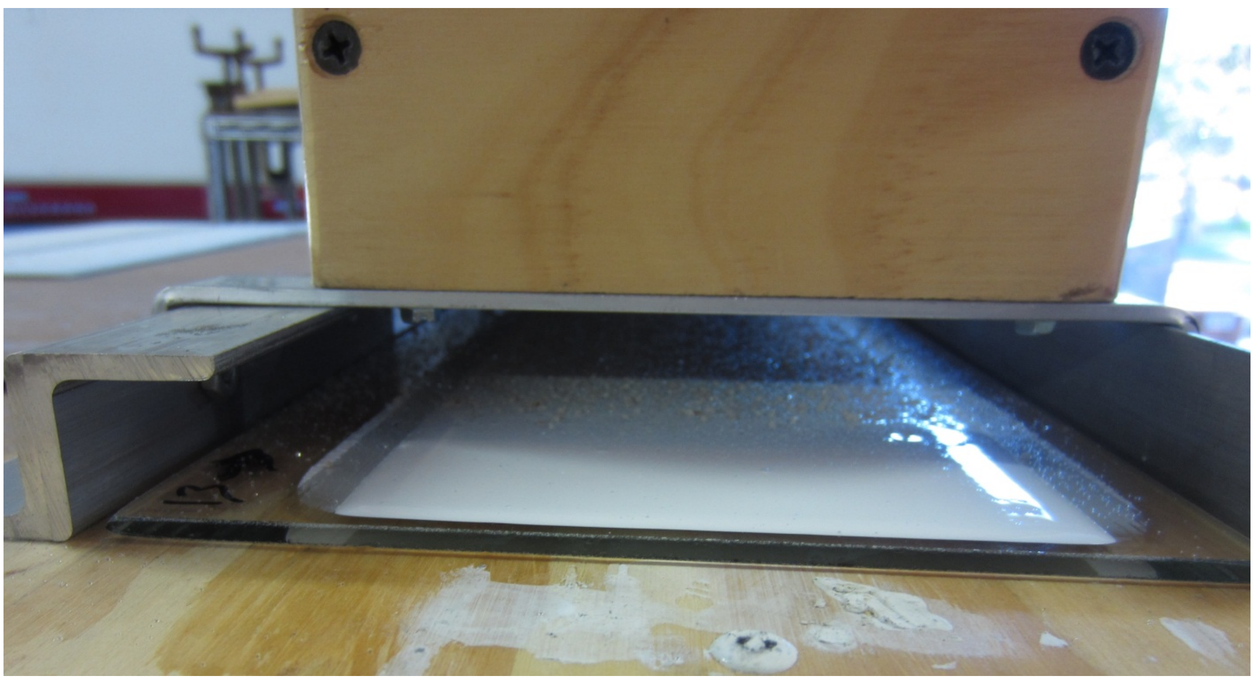

Figure 2. Sample Immediately After Beads Applied.

Figure 3. Overhead View of Sample.

RETROREFLECTIVITY TESTING

Approximately 24 hours after the 30 pavement marking test samples were created, the research team conducted the retroreflectivity testing. The first step was brushing off excess and loose optics.

The retroreflectivity measurements were conducted in accordance with ASTM E1710 (dry), ASTM E2177 (recovery), and ASTM E2832 (continuous wet). The retroreflectivity testing began with dry measurements of each sample. In total, five measurements were taken in various locations around each sample. The average and standard deviation of these initial dry retroreflectivity readings can be found in

Table 3 under the Dry #1 column.

The continuous wetting measurements were then conducted as seen in Figure 4. The samples and spray box were placed on a 2 percent cross slope, with approximately a 1 percent vertical grade. Due to the length of the samples, two samples were placed end to end. The sample of interest was inside the spray box, with the second sample resting under the retroreflectometer to create a level surface for the retroreflectometer to maintain the correct geometry for the measurements. The continuous wetting system was allowed to operate until the marking was saturated. After saturation retroreflectivity readings were periodically taken until they stabilized. Once the readings stabilized, four readings were recorded. The average and standard deviation of these readings can found in

Table 3 under the Continuous Wet column.

The recovery measurements were conducted at the same location as the continuous wetting measurements. After the continuous wetting measurements were completed, the spray box was removed and the marking was left in place. A pail was used to saturate the marking with approximately 3 liters of water as specified in ASTM E2177. The marking was allowed to recover for 45 seconds. After the 45 seconds three retroreflectivity readings were taken in rapid succession. The average and standard deviation of these readings can found in

Table 3 under the Recovery column.

After the continuous wetting and recovery testing the pavement marking samples were allowed to dry for approximately 24 hours. The research team then recorded a second set of dry retroreflectivity readings. These readings were conducted in the same manner as the first set of readings. The average and standard deviation of the second set of dry retroreflectivity readings can be found in

Table 3 under the Dry #2 column.

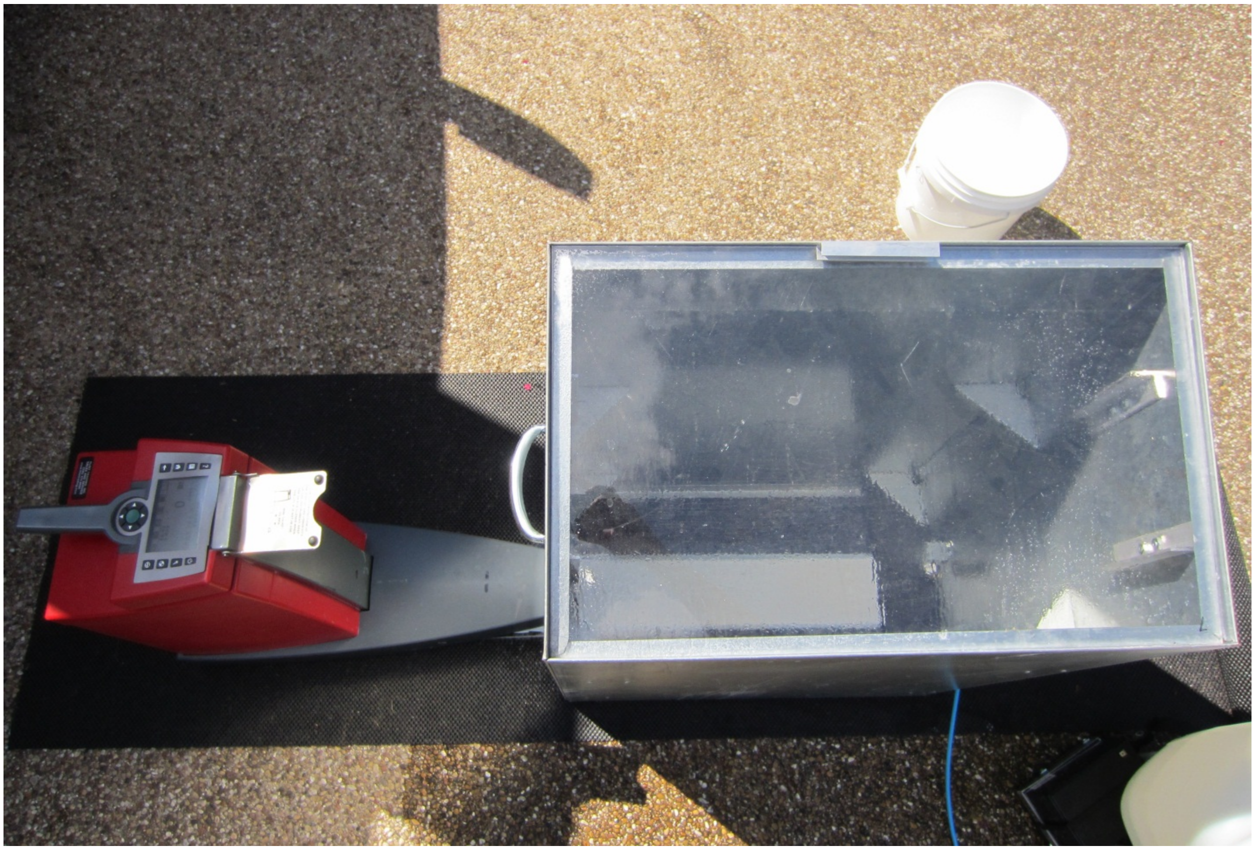

Figure 4. Continuous Wetting Retroreflectivity Testing.

RETROREFLECTIVITY RESULTS

A summary of the retroreflectivity results is presented in

Table 3. Cells highlighted in yellow with bold numbers passed the requirements for the triple drop specification that were presented in Table 1. As expected, the Dry #2 readings are noticeable higher than the Dry #1 readings (due to the epoxy having more time to fully cure). All 30 samples showed an increase in retroreflectivity, resulting in approximately a 10 percent average increase. Still only 6 Dry #2 samples passed the requirements.

The recovery retroreflectivity requirements were satisfied by 16 of the 30 test samples. The continuous wet requirements were satisfied by only 3 of the 30 test samples. It should be noted that the recovery and continuous wet requirements are the same even though continuous wet measurements are typically lower than recovery measurements.

In discussions with the PTC, the dry and continuous wet retroreflectivity performance were identified as being the most important. Therefore, the results from the Dry #2 and continuous wetting measurements are rank ordered in Table 4. The test sample ranked 1 had the highest average retroreflectivity (using Dry #2 and continuous wet data). The test sample ranked 30 had the lowest for each of the two measurements. The average rank order for the two measurements is also provided. The average rank order considers each measurement equally, i.e. it is not weighted toward one measurement or the other.

Table 3. Retroreflectivity Results Summary.

Sample	Dry #1		Dry #2		Recovery		Continuous Wet	
	Avg R_L	Stdev	Avg R_L	Stdev	Avg R_L	Stdev	Avg R_L	Stdev
1	210	12	228	8	74	6	4	1
2	426	33	433	42	212	3	168	7
3	467	30	483	28	**439**	4	**348**	26
4	210	9	229	11	178	1	92	6
5	276	10	293	8	**268**	2	104	6
6	352	13	383	22	**299**	2	78	4
7	198	13	223	9	174	1	109	6
8	355	52	369	65	247	2	68	7
9	467	29	**514**	36	**396**	4	234	16
10	460	30	**502**	23	**329**	2	206	23
11	382	57	406	48	202	2	153	7
12	432	33	459	30	**300**	1	81	5
13	394	10	418	9	**293**	2	220	16
14	426	17	438	11	**356**	3	248	22
15	191	14	212	14	133	1	70	6
16	259	20	294	36	197	1	131	3
17	373	7	402	5	**291**	2	174	19
18	317	10	356	12	**346**	2	112	13
19	468	13	**528**	30	**386**	3	238	16
20	316	23	335	18	217	2	65	4
21	247	4	296	7	101	2	23	1
22	213	10	247	11	69	2	21	1
23	287	4	343	8	97	2	19	1
24	251	20	295	15	80	2	30	1
25	348	9	434	12	189	3	45	3
26	240	6	256	3	**341**	3	222	14
27	236	8	258	7	**270**	2	152	11
28	**517**	45	**574**	45	**387**	5	209	7
29	**577**	39	**715**	45	**490**	5	**351**	22
30	**544**	24	**620**	13	**455**	2	**326**	22

Table 4. Rank Order Results.

Sample	Condition Rank Order		
	Dry #2	Continuous Wet	Average
1	28	30	29
2	11	12	11.5
3	7	2	4.5
4	27	19	23
5	23	18	20.5
6	15	21	18
7	29	17	23
8	16	23	19.5
9	5	6	5.5
10	6	10	8
11	13	13	13
12	8	20	14
13	12	8	10
14	9	4	6.5
15	30	22	26
16	22	15	18.5
17	14	11	12.5
18	17	16	16.5
19	4	5	4.5
20	19	24	21.5
21	20	27	23.5
22	26	28	27
23	18	29	23.5
24	21	26	23.5
25	10	25	17.5
26	25	7	16
27	24	14	19
28	3	9	6
29	1	1	1
30	2	3	2.5

CHAPTER 3:
FINDINGS AND RECOMMENDATIONS

This chapter describes the findings and recommendations from the testing. These findings and recommendations will be incorporated into the triple drop specification using track changes (a clean version will also be provided). In addition to areas of the specification directly addressed by this research, the TTI research team will also incorporate other comments into the specification based on past experience and requests by the sponsor.

The test samples confirmed data submitted by PTC striping contractors currently using the triple drop specification that triple drop combinations with 100% wet all-weather elements do not meet the dry requirements. It was surprising that the 100% wet all-weather elements did not perform better in wet testing conditions. In fact, test samples with the 70/30 mix all-weather element typically outperformed samples with 100% wet all-weather elements (in wet testing conditions). The test samples tested with the VISIMAX+ optic did not perform as well as the samples with the all-weather elements.

One of the more interesting findings is that the highest overall optic application rates did not always perform the best. In fact, the best performing test sample from Table 4 only included two different optics, not three. In addition, the 20 mil samples outperformed the 25 mil samples. There is likely an interaction between the higher drop rates and the thicker binder resulting different embedment rates.

The research team attempted to quantify the quantity of beads lost during the creation of the samples and when brushing off the samples. It was not feasible due to the relatively small amount of beads and the inability to capture them from the bead drop box and the losses occurred when moving the samples prior to brushing. It was observed that the majority of the excess beads were the standard beads that were unable to bind to the marking due to being flooded with other beads.

While the testing performed as part of this project was ideal in that the conditions were perfect, in the field conditions are not perfect. For instance, the substrate is not perfectly smooth, there are inconsistent winds and temperatures, and, depending on the speed of application and equipment used, there can be substantial bead roll. Furthermore, this testing did not include considerations for durability or in-service performance. The test results provide a way to set specifications for initial performance, which provides some comfort to ensure that contractors have installed a quality marking. It should be noted, however, that the initial retroreflectivity results reported herein may not be indicative of long-term performance. Field installed pavement marking test decks are the best way to evaluate long-term performance.