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16. Abstract

Research has shown that thickness plays a major role in the retroreflective performance of thermoplastic pavement markings, especially on newly sealcoated roadway surfaces. Therefore, accurate thickness measurement by inspectors on striping jobsites is necessary to ensure adequate thickness is being achieved. This report presents the results of a statistical analysis comparing two thickness measurement methods for thermoplastic pavement markings that are commonly used by Texas Department of Transportation (TxDOT) inspectors. These two methods are: 1.) measure thickness of thermoplastic pavement marking sample with a standard laboratory caliper and 2.) measure thickness of thermoplastic pavement marking sample with a needlepoint micrometer. The main difference between the two measurement methods is the accuracy of the instrument. The needlepoint micrometer allows for accurate measurement to the top of the binder material, while it is very difficult to get a measurement to the top of the binder material with a caliper. Therefore, caliper measurements are often made to the top of the drop-on beads. Current TxDOT policy states that thermoplastic thickness be specified and measured to the top of the binder material. However, many TxDOT field inspectors still use calipers to make thickness measurements. Therefore, it was deemed important to quantify the differences in the two measurement methods. Forty-seven thermoplastic pavement marking samples of varying thickness were taken from striping jobsites statewide and used in the analysis. The results show that the caliper measured an average of 20.5 mils (0.0205 inch) and 16.7 mils (0.0167 inch) thicker than the needlepoint micrometer for large and small bead samples, respectively. As such, the researchers recommend that needlepoint micrometers be used for all thermoplastic thickness inspection performed by TxDOT. Further findings and recommendations are made in the report.

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ANALYSIS OF TXDOT THICKNESS MEASUREMENT PROCEDURES FOR THERMOPLASTIC PAVEMENT MARKINGS

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ACKNOWLEDGMENTS

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CHAPTER 1: OVERVIEW

BACKGROUND

Ensuring adequate thermoplastic thickness for pavement markings has recently become an important issue for TxDOT. Research has shown that thickness plays a major role in the retroreflective performance of thermoplastic pavement markings, especially on newly sealcoated roadway surfaces[1]. Therefore, accurate thickness measurement by inspectors on striping jobsites is necessary to achieve adequate thickness.

One particularly important issue has been the correct procedure for measurement of thermoplastic thickness in the field. Two measurement procedures have existed for many years, both of which are described in TxDOT Test Method Tex-854-B "Evaluation of Thermoplastic Striping for Uniformity and Thickness" (*1*). The first method is the Usage Rate Method, which allows inspectors to determine stripe thickness based on gauge readings taken from the striping truck. The second method is the Tape Measurement Method, which allows for direct measurement of a thermoplastic marking sample using a measuring instrument. Until recently, both methods were used frequently to determine thermoplastic thickness, as TxDOT did not formally favor the use of one method over the other. However, both methods were the subject of major discussion during the 2000 striping season. Questions were raised as to the accuracy of the Usage Rate Method and the correct and consistent use of the Tape Measurement Method and corresponding measurement instrument.

In January 2001, after much discussion, TxDOT revised the Tape Measurement Method of Tex-854-B to include two major items that were previously absent from the language. The first item was that measurements were to now be made to the *top of the binder material*, excluding drop-on beads. The second item was that measurements were to be made using a *needlepoint (or needlenose) micrometer instrument* (Figure 1), instead of the commonly used laboratory caliper (Figure 2), to ensure accurate measurement of binder thickness.

[1] Unpublished memorandum from Tim Gates and Gene Hawkins to Greg Brinkmeyer. "Effect of Thermoplastic Pavement Marking Thickness on Retroreflective Performance on New Sealcoat (US 79 Evaluation)." Project Number 0-4150. February 19, 2002.

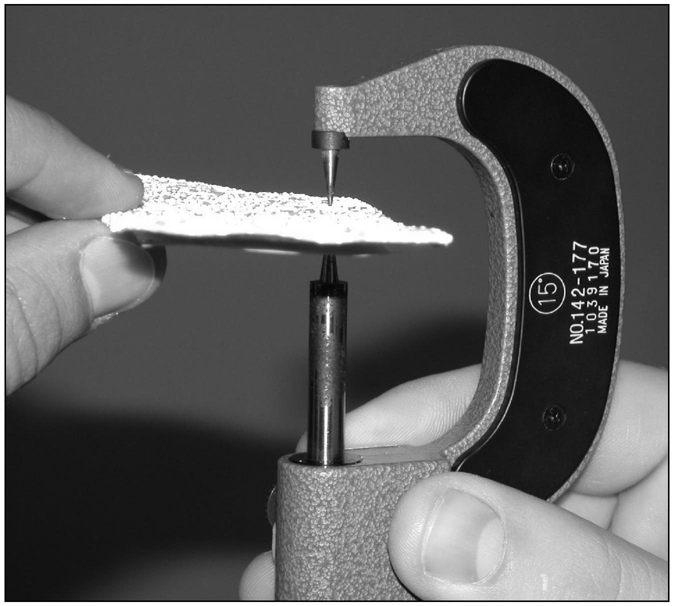


Figure 1. Typical Needlepoint Micrometer.

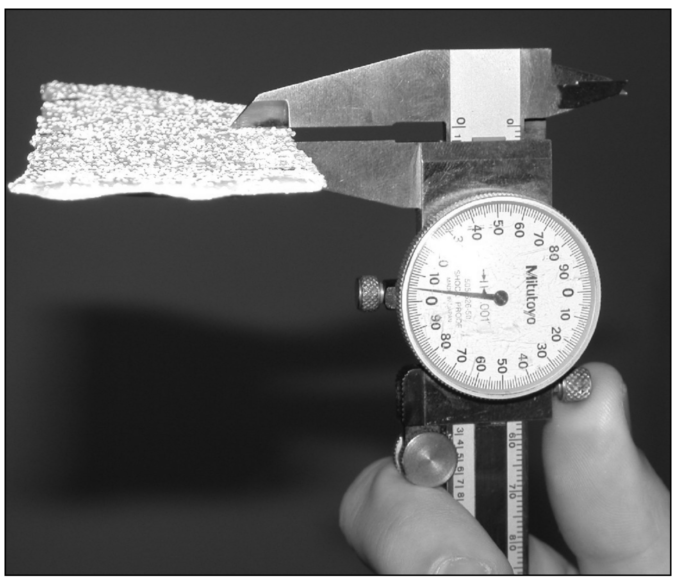


Figure 2. Standard Laboratory Caliper.

In November 2001, after further discussion, Special Provisions 042 and 043 to ITEM 666 were released, which included language stating that thickness shall be measured using the Tape Measurement Method, thereby discouraging the use of the Usage Rate Method (*2*). These Special Provisions also established 100 mil[2] (top-of-binder) as the minimum thickness for all thermoplastic longline pavement markings placed on new sealcoats and surface treatments.

[2] 1 mil = 0.001 inch = 0.0254 mm

PROBLEM STATEMENT

Recent revisions to the TxDOT thermoplastic construction specifications and test methods have placed increased importance on field inspection of pavement markings. However, observations made on striping jobs by TTI researchers and TxDOT staff during 2001 revealed that thermoplastic tape thickness measurements were often not being performed as recommended by the Tape Measurement Method in Tex-854-B. On multiple occasions, researchers observed that inspectors were using a standard caliper to measure thickness, instead of a needlepoint micrometer as recommended by the test method. Further examination revealed that most measurements made with a caliper did not exclude the drop-on beads, and therefore thermoplastic binder thicknesses were less than what was being measured and approved by inspectors.

The main difference between the two measurement instruments is that the needlepoint micrometer allows for accurate measurement to the top of the binder material (Figure 3), while it is very difficult to measure to the top of the binder material with a caliper. Due to the nature of the device, caliper measurements usually can only be made to the top of the drop-on beads (Figure 4). Even when binder-only measurements are attempted with a caliper, the accuracy is often questionable because the measurements are usually taken near the "lip" of the sample, which is often curled, warped, and/or of a different thickness than the rest of the sample (Figure 5). As such, it can be concluded that most calipers provide an inaccurate measurement of binder thickness. Therefore, it was deemed important to quantify the differences between the two measurement instruments for thermoplastic thickness measurements.

Figure 3. Binder-Only Measurement with Needlepoint Micrometer.

Figure 4. Top-of-Bead Measurement with Caliper.

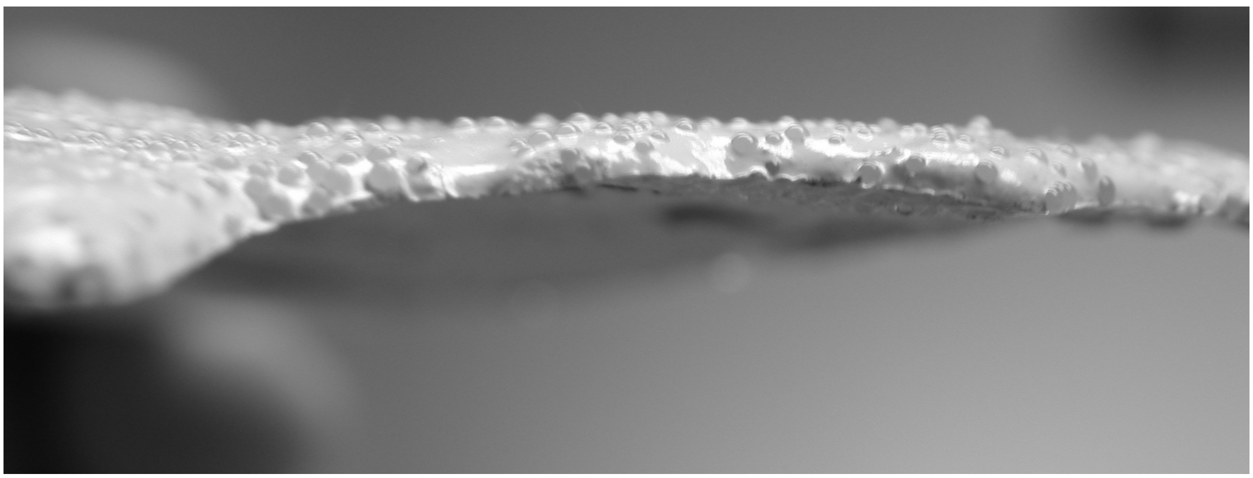


Figure 5. Typical Edge of Thermoplastic Sample.

PURPOSE AND OBJECTIVES

The overall purpose of the research discussed herein was to provide TxDOT with a recommended measurement procedure for thermoplastic pavement marking thickness. The following objectives were undertaken:

- Determine the measurement differences between thermoplastic samples measured with a needlepoint micrometer vs. a laboratory caliper.
- Determine the measurement differences between Type II bead and Type III bead thermoplastic samples when measured with a needlepoint micrometer vs. a laboratory caliper.

- Determine if binder thickness varies with location on a sample when measured with needlepoint micrometer.
- Determine the minimum number of measurements per sample necessary to achieve accurate representation of binder thickness when measured with a needlepoint micrometer.
- Determine the locations on a thermoplastic sample where measurements should be taken with a needlepoint micrometer to provide the most accurate representation of binder thickness.

CHAPTER 2:
METHODOLOGY AND FINDINGS

METHODOLOGY

To accurately represent thermoplastic striping statewide, sprayed alkyd thermoplastic samples were randomly taken from multiple striping sites during summer 2001. The thermoplastic samples were removed from the roadway surface using the duct tape method described in Tex-854-B (*1*). The specified thermoplastic thickness varied from site to site and ranged from 60 mil to 100 mil. Most of the thermoplastic samples were taken from new sealcoat surfaces, although samples from asphalt, concrete, and restripe jobs were included, as well. Samples were taken at random from the centerline, edge line, and lane line.

Normal dimensions for a sample were 2 inches (width of the duct tape) by 4 inches (specified width of a standard stripe). Occasionally, samples would break apart either when removed from the duct tape or while in transit back to the office. Because of this, samples were only included in this analysis if they were at least 3 inches in length and 1.5 inches in width. The final set of 47 samples used in the analysis included both large and small beaded samples of both white and yellow color.

Data Collection

Each sample was measured at six different locations along the edges with a caliper (Figure 6). Because it is very difficult to get an accurate "between bead" measurement with a caliper, the caliper measurements were made to the top of the bead, which has been observed to be the standard practice of many TxDOT field inspectors. Nine different measurements were made on each sample with the needlepoint micrometer (Figure 7). Six of the micrometer measurements were in approximately the same locations on the sample as the caliper measurements, while the other three measurements were taken from the center of the sample. Measurements with the needlepoint micrometer were made between the beads, which allowed for accurate measurement of the binder material thickness.

Mitutoyo manufactured the caliper used for all caliper measurements (Figure 2). The needlepoint micrometer used for all needlepoint micrometer measurements was manufactured by Mitutoyo, Product No. 142-177 (Figure 1).

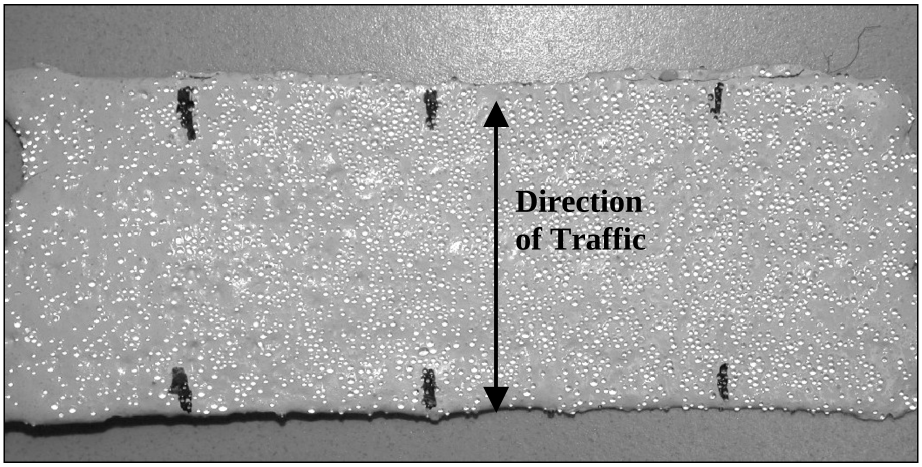


Figure 6. Typical Caliper Measurement Locations.

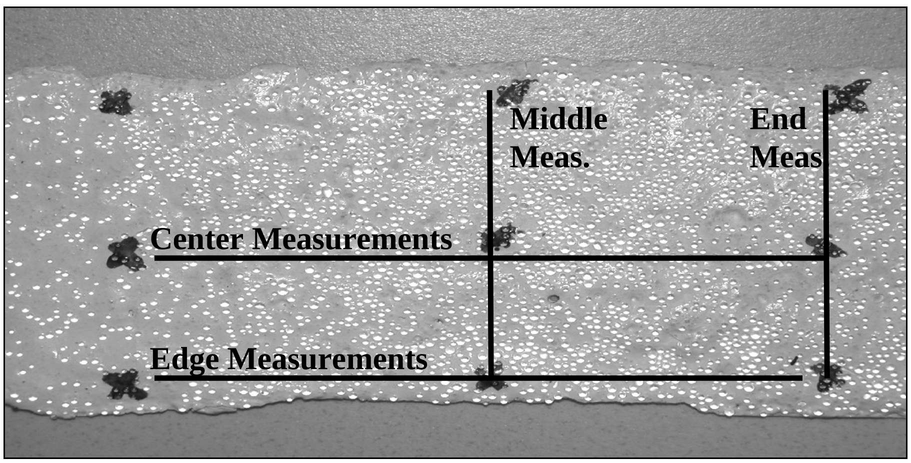


Figure 7. Typical Needlepoint Micrometer Measurement Locations.

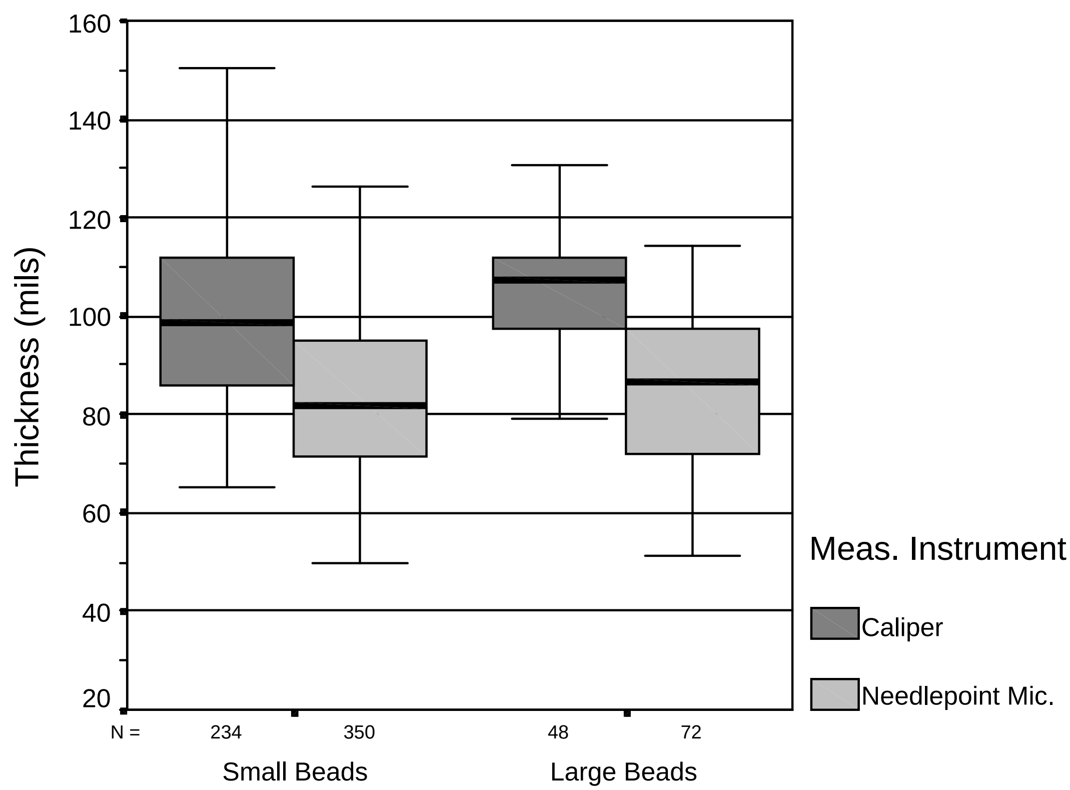
Analysis

Researchers analyzed data using univariate analysis of variance (ANOVA) in SPSS[3], with thickness as the dependent variable and measurement instrument and bead size as the main independent variables. The main effects of bead size and instrument were both found to be significant at 95 percent level of confidence, with no significant interaction between bead size and instrument. From there, researchers grouped thickness data into two categories based on bead size (Type II vs. Type III) for further analysis. A table summarizing the measurement data for each of the 47 samples can be found in the appendix along with statistical summary tables from SPSS.

[3] Statistical Package for the Social Sciences, Version 10.1

FINDINGS

A graphical representation of the thickness data for caliper vs. needlepoint micrometer measurements on both small and large bead samples is shown in common box-and-whisker format in Figure 8. Please note that the specified marking thickness varied from site to site, accounting for much of the variability between samples. For each population, the interquartile range (25th – 75th percentile range) is represented by the edges of the "box," with the median value represented by the heavy solid line within the box. The upper and lower "whiskers" represent the largest and smallest values, respectively, that are not classified as outliers. Summaries of the thickness data and statistical analyses exist in tabular format in the appendix.



Note: Specified marking thickness ranged from 60 mil to 100 mil

Figure 8. Summary of Caliper vs. Needlepoint Measurement Data.

The statistical analysis yielded some interesting findings concerning the measurement of thermoplastic pavement marking samples. Researchers expected many of these findings, which serve to validate the qualitative assumptions that existed concerning the differences between measurement instruments. The significant findings from the analysis were as follows:

- Thickness measurements made with a caliper were found to be significantly greater than those made with the needlepoint micrometer for both large and small bead thermoplastic samples. The caliper measured an average of 20.5 mils and 16.7 mils thicker than the needlepoint micrometer for large and small bead samples, respectively. Researchers assumed that the needlepoint measurements represent the "true" binder thickness, while caliper measurements represent thicknesses that include drop-on beads.
- No significant differences in the measurement standard deviations were found between the caliper and the needlepoint micrometer measurements for both large and small bead samples. Therefore, while needlepoint measurements provide superior accuracy vs. the caliper measurements (i.e., closer to the "true" thickness), they do not necessarily improve the precision of the measurements.
- Analysis of the measurements made at the middle of a sample vs. the end of a sample with the needlepoint micrometer showed significant differences between the two locations for small bead samples. The measurements made at the middle were, on average, 4.1 mils greater than those made at the ends for small bead samples. The greater thickness in the middle of the sample is likely due to a heavier thermoplastic application associated with being closer to the center of the spray nozzle. (Note: See Figure 7 for description of "center" and "edge" vs. "middle" and "end" measurements.)
- Analysis of the measurements made at the center of a sample vs. the edge of a sample with the needlepoint micrometer showed no significant differences. (Note: See Figure 7 for description of "center" and "edge" vs. "middle" and "end" measurements.)
- For statistical quality control purposes, a minimum of three measurements across the sample is necessary.
- Researchers analyzed measurements from numerous combinations of locations on the samples. Measurements made diagonally from end to end across the sample provide the greatest accuracy.

CHAPTER 3:
RECOMMENDATIONS

The end result of this analysis was to provide reasonable suggestions to aid TxDOT inspectors in field measurement of thermoplastic pavement marking thickness. A list of recommendations has been developed based on the analysis of thickness data from 47 thermoplastic samples. Please note that TTI researchers recommend needlepoint micrometers for accurate measurement of thermoplastic binder thickness. The use of standard laboratory calipers is not recommended, although thickness reduction factors are provided here to approximate binder measurements. Researchers suggest the following thickness measurement practices for use in the field by TxDOT inspectors:

- Thermoplastic thickness measurements should be made with a needlepoint micrometer similar to that shown in Figure 1.
- A minimum of three measurements should be taken.
- The most accurate measurement method is to measure diagonally across the sample, as shown in Figure 9 (at least 3 measurements per sample).

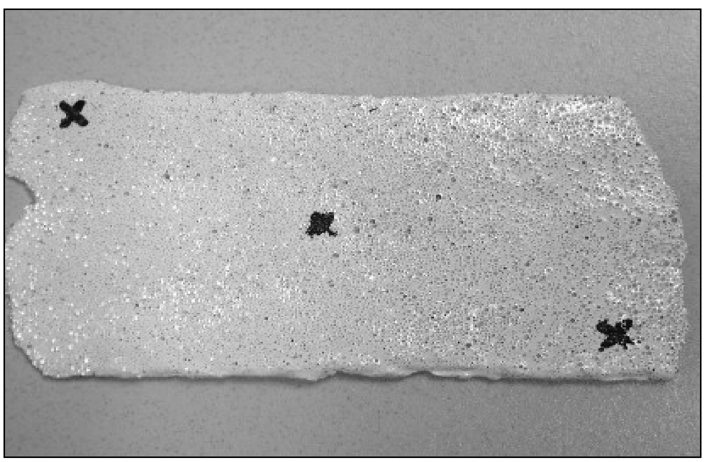


Figure 9. Recommended Measurement Locations.

- For thermoplastic measurements made with a caliper to the top of the bead, conversion to top-of-binder measurements can be approximated by subtracting:
    - 20 mils for large bead samples, and
    - 15 mils for small bead samples.

- Measurements made at the “lip” of the sample with a caliper to determine the thickness of the binder are discouraged due to deformations often encountered around the edges of a sample.

REFERENCES

1. Tex-854-B, Evaluation of Thermoplastic Striping for Uniformity and Thickness. Manual of Testing Procedures. Materials and Test Division, Texas Department of Transportation, Austin, Texas, January 2001.
2. Special Provision 666-042 and 666-043, Reflectorized Pavement Markings. Standard Construction Specifications. Texas Department of Transportation, Austin, Texas, November 2001.

APPENDIX:
MEASUREMENT DATA AND STATISTICAL TABLES

Table A1. Summarized Thermoplastic Measurement Data Set.

			All Units are Thousandths of an Inch (Mils)								
Sample Number	Color	Bead Size	Average Caliper	Min Cal	Max Cal	Standard Dev Caliper	Average NN	Min NN	Max NN	Standard Dev NN	Average Cal - Average NN
1	W	Type II	98.42	86.50	116.00	11.69	79.72	65.50	102.50	13.55	18.69
2	W	Type II	81.75	68.00	97.00	10.93	72.94	51.50	85.00	10.71	8.81
3	W	Type II	105.75	76.00	120.00	16.22	93.28	79.00	101.00	8.45	12.47
4	W	Type II	96.67	75.50	110.00	13.03	79.83	53.50	98.50	14.55	16.83
5	W	Type II	90.00	79.00	103.00	9.80	72.78	60.00	86.00	9.79	17.22
6	W	Type II	74.25	66.50	84.00	6.68	59.11	51.00	70.00	5.65	15.14
7	W	Type II	77.75	65.00	87.00	7.81	71.56	58.50	86.50	8.43	6.19
8	W	Type II	77.92	70.00	87.50	5.61	65.67	57.50	76.00	6.23	12.25
9	W	Type II	131.42	117.50	150.50	12.06	109.33	86.00	126.50	12.97	22.08
10	W	Type II	120.58	104.00	138.50	12.70	102.67	77.50	123.50	16.04	17.92
11	W	Type II	120.17	105.00	133.00	10.28	92.28	78.00	106.00	9.63	27.89
12	W	Type II	116.58	99.50	128.00	10.09	98.50	83.50	111.00	8.23	18.08
13	W	Type II	88.08	75.50	96.00	8.13	68.22	51.00	83.50	11.50	19.86
14	W	Type II	120.67	99.00	146.00	18.61	100.06	69.50	133.00	21.36	20.61
15	W	Type II	80.67	71.50	87.00	5.99	69.94	61.50	82.50	7.66	10.72
16	W	Type II	115.67	105.50	133.50	11.37	99.00	86.00	116.00	9.54	16.67
17	W	Type II	72.17	68.00	78.00	3.33	56.83	50.00	62.50	4.49	15.33
18	W	Type II	86.00	68.50	94.50	9.70	69.89	54.00	81.50	10.69	16.11
19	W	Type II	105.58	91.00	121.50	10.90	85.44	72.00	112.00	12.56	20.14
20	W	Type II	123.83	115.00	129.50	5.13	100.44	80.00	114.50	9.85	23.39
21	W	Type II	113.25	105.00	122.00	6.31	86.22	71.00	116.50	14.08	27.03
22	W	Type II	118.50	110.00	133.00	8.76	90.61	83.50	107.50	7.25	27.89
23	Y	Type II	81.08	70.00	89.00	8.39	70.56	56.00	82.50	9.74	10.52
24	Y	Type II	88.33	74.00	101.00	8.85	67.22	30.00	92.00	19.44	21.11
25	Y	Type II	94.42	77.00	105.00	10.76	73.89	54.50	98.50	13.57	20.53
26	Y	Type II	106.25	74.00	121.00	17.98	95.28	74.00	111.00	12.91	10.97
27	Y	Type II	98.00	89.00	112.00	7.69	83.44	66.50	110.50	15.12	14.56
28	Y	Type II	93.50	85.50	99.00	4.77	80.11	75.50	84.50	2.88	13.39
29	Y	Type II	111.92	97.00	122.50	9.26	96.11	88.50	102.50	4.88	15.81
30	Y	Type II	108.83	87.00	121.00	11.74	87.44	78.50	100.50	7.40	21.39
31	Y	Type II	114.42	104.00	124.00	9.02	96.33	85.00	115.00	9.09	18.08
32	Y	Type II	86.83	81.50	98.00	6.03	71.44	56.00	84.00	10.25	15.39
33	Y	Type II	95.83	78.00	108.50	11.39	75.78	62.50	94.50	9.26	20.06
34	Y	Type II	110.58	100.00	116.50	5.98	89.56	76.00	109.50	9.95	21.03
35	Y	Type II	103.33	95.00	113.00	7.71	90.94	74.50	114.50	13.46	12.39
36	Y	Type II	90.25	76.00	101.00	9.15	80.50	68.50	96.00	9.44	9.75
37	Y	Type II	101.67	94.00	110.50	6.45	90.39	64.00	102.00	11.02	11.28
38	Y	Type II	92.17	87.50	96.00	3.43	78.39	70.50	86.00	5.98	13.78
39	Y	Type II	95.42	84.50	107.00	8.93	85.22	71.00	108.50	12.03	10.19
AVERAGES Type II			**99.71**	**86.55**	**111.29**	**9.30**	**83.00**	**67.47**	**99.33**	**10.50**	**16.67**
40	W	Type III	110.92	107.00	113.50	2.25	86.33	71.00	103.50	9.63	24.58
41	W	Type III	113.83	100.00	130.00	10.85	87.44	70.00	104.50	13.14	26.39
42	W	Type III	99.25	90.50	108.00	7.45	82.17	67.50	94.50	9.48	17.08
43	W	Type III	119.42	107.50	127.00	8.87	95.61	80.00	114.50	11.58	23.81
44	W	Type III	82.08	73.50	87.50	5.10	58.89	51.50	70.00	5.89	23.19
45	W	Type III	103.08	95.50	112.00	6.40	93.39	72.50	111.50	12.58	9.69
46	Y	Type III	109.92	100.50	124.00	8.90	94.89	77.50	106.50	12.05	15.03
47	Y	Type III	104.83	83.50	130.50	17.55	80.94	61.50	108.50	16.91	23.89
AVERAGES Type III			**105.42**	**94.75**	**116.56**	**8.42**	**84.96**	**68.94**	**101.69**	**11.41**	**20.46**

Table A2. Univariate Analysis of Variance (ANOVA) - Thickness vs. Bead Size and Instrument Type.

Descriptive Statistics

Dependent Variable: MILS

BEAD_SIZ	DEVICE	Mean	Std. Deviation	N
small	caliper	99.705	17.7373	234
	nn_mic	83.034	16.5365	350
	Total	89.714	18.8755	584
big	caliper	105.417	13.8293	48
	nn_mic	84.958	15.8620	72
	Total	93.142	18.0817	120
Total	caliper	100.677	17.2476	282
	nn_mic	83.363	16.4209	422
	Total	90.298	18.7744	704

Tests of Between-Subjects Effects

Dependent Variable: MILS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	52198.574[a]	3	17399.525	62.271	.000
Intercept	3326280.086	1	3326280.086	11904.335	.000
BEAD_SIZ	1393.027	1	1393.027	4.985	.026
DEVICE	32938.619	1	32938.619	117.883	.000
BEAD_SIZ * DEVICE	342.750	1	342.750	1.227	.268
Error	195592.284	700	279.418		
Total	5988053.500	704			
Corrected Total	247790.858	703			

a. R Squared = .211 (Adjusted R Squared = .207)

Table A3. T-Test for Comparison of Caliper Measurements (top of bead) vs. Needlepoint Micrometer (top of thermo).

Group Statistics

BEAD_SIZ		DEVICE	N	Mean	Std. Deviation	Std. Error Mean
big	MILS	caliper	48	105.417	13.8293	1.9961
		nn_mic	72	84.958	15.8620	1.8694
small	MILS	caliper	234	99.705	17.7373	1.1595
		nn_mic	350	83.034	16.5365	.8839

Independent Samples Test

			Levene's Test for Equality of Variances		t-test for Equality of Means						
										95% Confidence Interval of the Difference	
BEAD_SIZ			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
big	MILS	Equal variances assumed	2.210	.140	7.278	118	.000	20.458	2.8110	14.8919	26.0248
		Equal variances not assumed			7.481	109.725	.000	20.458	2.7347	15.0386	25.8781
small	MILS	Equal variances assumed	2.733	.099	11.594	582	.000	16.671	1.4378	13.8468	19.4948
		Equal variances not assumed			11.434	475.320	.000	16.671	1.4580	13.8059	19.5358

Table A4. T-Test for Comparison of End vs. Middle Needlepoint Micrometer Thickness Measurements.

Group Statistics

BEAD_SIZ		END_MIDD	N	Mean	Std. Deviation	Std. Error Mean
small	MILS	end	233	81.672	15.9588	1.0455
		middle	117	85.748	17.3838	1.6071
big	MILS	end	48	83.531	15.9842	2.3071
		middle	24	87.813	15.5513	3.1744

Independent Samples Test

			Levene's Test for Equality of Variances		t-test for Equality of Means						
										95% Confidence Interval of the Difference	
BEAD_SIZ			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
small	MILS	Equal variances assumed	1.692	.194	-2.187	348	.029	-4.076	1.8636	-7.7416	-.4108
		Equal variances not assumed			-2.126	215.646	.035	-4.076	1.9173	-7.8552	-.2972
big	MILS	Equal variances assumed	.006	.939	-1.081	70	.283	-4.281	3.9608	-12.1808	3.6183
		Equal variances not assumed			-1.091	47.262	.281	-4.281	3.9242	-12.1746	3.6121

Table A5. T-Test for Comparison of Edge vs. Center Needlepoint Micrometer Thickness Measurements.

Group Statistics

BEAD_SIZ		EDGE_CEN	N	Mean	Std. Deviation	Std. Error Mean
big	MILS	center	24	85.125	18.9331	3.8647
		edge	48	84.875	14.3054	2.0648
small	MILS	center	117	84.077	17.5897	1.6262
		edge	233	82.511	15.9949	1.0479

Independent Samples Test

			Levene's Test for Equality of Variances		t-test for Equality of Means						
										95% Confidence Interval of the Difference	
BEAD_SIZ			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
big	MILS	Equal variances assumed	3.738	.057	.063	70	.950	.250	3.9936	-7.7150	8.2150
		Equal variances not assumed			.057	36.547	.955	.250	4.3817	-8.6319	9.1319
small	MILS	Equal variances assumed	1.815	.179	.836	348	.404	1.566	1.8745	-2.1206	5.2530
		Equal variances not assumed			.810	213.891	.419	1.566	1.9345	-2.2470	5.3794