A Study of the Effect of Testing Environment Conditions on Physical Properties of High Efficiency Particulate Air Filter Media

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ABSTRACT

The American Society of Mechanical Engineers AG-1 Code on Nuclear Air and Gas Treatment (AG-1) requires that high efficiency particulate air (HEPA) filter media be pretreated and/or tested in accordance with Technical Association of the Pulp and Paper Industry (TAPPI) T 402, *Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products*, when certain physical properties are being evaluated. TAPPI T 402 defines a preconditioning environment as having a relative humidity (RH) of 10 to 35% and a temperature of 22 to 40 °C (72 to 104 °F), a conditioning environment as having an RH of 50.0 ± 2.0% and a temperature of 23.0 ± 1.0 °C (73.4 ± 1.8 °F), and a testing environment to be the same as for conditioning. The Effect of Testing Environment Conditions Study was performed at the Institute for Clean Energy Technology (ICET) to determine whether or not testing environment conditions outside of the RH and temperature ranges allowed by TAPPI T 402 have a significant effect on tensile strength in the machine and cross directions, water repellency, and thickness of HEPA filter media. ICET chose two different types of media with drastic differences in age and operational history to test. Ten samples in each direction from each media type were prepared for tensile strength testing at each testing environment, and five samples from each media type were prepared for water repellency and thickness testing at each testing environment. Samples were preconditioned in accordance with TAPPI T 402 for a minimum of 24 hours before being moved to the ICET fabricated Testing Environment Chamber. Samples were allowed to equilibrate for at least six hours in the chamber before testing began in one of the testing environment conditions. Results of the tensile strength, water repellency, and thickness testing for each media type were analyzed to evaluate the differences in results across testing environment conditions. The analysis indicated that testing environment conditions do have an effect on those physical properties; although, the effect varies for each property.

INTRODUCTION

The American Society of Mechanical Engineers AG-1 Code on Nuclear Air and Gas Treatment (AG-1) requires that tensile strength and thickness testing of high efficiency particulate air (HEPA) filter media be performed in accordance with Technical Association of the Pulp and Paper Industry (TAPPI) T 494 and TAPPI T 411, respectively [1 – 3]. Both of these test methods direct to the use of TAPPI T 402 for preconditioning, conditioning, and testing conditions of the media [4]. Additionally, AG-1 requires that media tested for water repellency be conditioned in accordance with TAPPI T 402. TAPPI T 402 specifies the atmospheric environment including relative humidity (RH) and temperature for preconditioning, conditioning, and testing conditions. For the preconditioning environment, the RH is required to be within the range of 10 to 35%, and the temperature range is 22 to 40 °C (72 to 104 °F). The conditioning and testing environments are required to have an RH of 50.0 ± 2% and a temperature of 23.0 ± 1.0 °C (73.4 ± 1.8 °F).

These conditioning and testing conditions can be difficult to maintain over extended periods of time. The Institute for Clean Energy Technology (ICET) at Mississippi State University (MSU) performed a study to determine if having a conditioning and testing environment outside of the ranges specified by TAPPI T 402 would have a significant effect on the results of tensile strength, water repellency, and thickness testing for HEPA filter media.

METHODS

Instrumentation

Specifications for instruments used throughout preconditioning, conditioning, and testing are shown in Table I.

Throughout preconditioning, conditioning, and testing, Vaisala HMT 33X humidity and temperature transmitters were used to monitor the conditions of the preconditioning chamber and the Testing Environment Chamber.

A Thwing-Albert Vantage NX Universal Tester model 1902-2001 with a 50 N model SMT1-50N-354 load cell was used for all tensile strength testing.

The water repellency tester was designed using details from the E1R3 test unit as a guideline [5]. The pressure gage used was a Dwyer DPG-101 pressure gage with a range of 138.30 in. w. c.

A Thwing-Albert ProGage Thickness Tester model 89-2007 was used for all thickness testing. The calibration for the thickness tester was past due for the duration of this testing; however, it was verified with a calibrated gage block before testing began each day.

Table I. Instrument Specifications

Instrument	Property	Specification
HMT33X Humidity and Temperature Transmitter	Relative Humidity Uncertainty	± 2% RH
	Temperature Uncertainty	± 0.5 °C (± 1 °F)
Thwing-Albert Vantage NX Universal Tester	Force Capacity	Variable Using Load Cells (25-2000 N)
	Force Accuracy	± 0.25% of Measuring Value at 10 to 100% Load Capacity ± 0.025% of Measuring Value under 10% of Load Cell Capacity
	Force Resolution	16 Bit A/D to 0.001 N
	Position Accuracy	± 2.5 µm per 25 mm
	Position Resolution	0.6 µm
	Crosshead Speed Range	1 to 1000 mm/min
50 N Load Cell	Accuracy	± 0.25% Full Scale
Water Repellency Tester	Measurement Uncertainty	± 0.0964 kPa (± 0.3875 in. w. c.)
Pressure Gage	Range	34.415 kPa (138.30 in. w. c.)
Thwing-Albert ProGage Thickness Tester	Range	1 mm (0.04 in.)
	Display Resolution	0.00025 mm (0.00001 in.)
	Parallelism	0.0010 mm (0.00004 in.)
30 mils Gage Block	Reading Tolerance	±0.0010 mm (± 0.04 mils)

Environmental Chambers

A Sheldon Manufacturing Incorporated forced air oven, model number FX28-2, was used as the preconditioning chamber.

The Testing Environment Chamber was purpose-built by ICET. The wooden chamber has a front face of plexiglass with an opening for using the Vantage NX Universal Tester and vinyl flaps to allow for the insertion and removal of samples, the ICET-fabricated water repellency tester, and the ProGage Thickness Tester.

A supply of dry air with a dewpoint of approximately -40 °C (-40 °F) is directed through a heating element, which has a control and setpoint for preheated temperature. Airflow through the chamber is controlled via a pressure regulator to maintain a slight positive pressure. Air is then directed through a splitter. One leg is directed to a bypass damper, and the other leg is directed through a damper to a humidifier. Air then passes through a chilled water heat exchanger, where the water temperature is controlled, before passing through a mixing chamber that leads air into the Testing Environment Chamber.

There is positive pressure inside the Testing Environment Chamber, so the conditions inside are not easily influenced by the conditions of the room where it is housed. A schematic of the Testing Environment Chamber is shown in Figure 1 below.

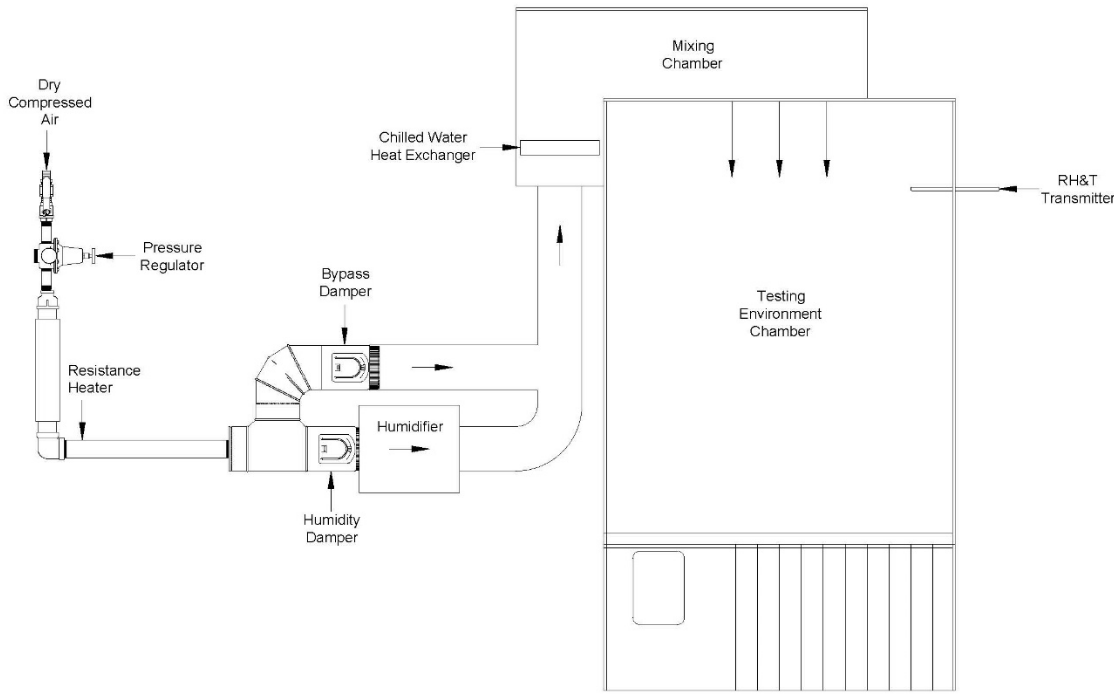

Figure 1. Schematic of Testing Environment Chamber.

Testing Environment Conditions Study Process

ICET chose two different types of media to test. The first type of media, M008, came from a roll of media that was manufactured in 2018. The second type of media, A114, was taken from an in-service HEPA filter that was manufactured in 1980. These two media types with drastic differences in age and operational history were chosen in order to capture the full spectrum of variation due to the effect of testing environment.

Samples were placed in a preconditioning chamber, where RH and temperature were monitored to ensure that conditions stayed within the specifications of TAPPI T 402. Samples were preconditioned for a minimum of 24 hours before being moved to the ICET-fabricated Testing Environment Chamber. It was determined through previous studies at ICET that preconditioned samples reached equilibrium in the testing chamber in less than six hours, where equilibrium is defined here as being obtained when the change in mass of the samples at time intervals of not less than two hours does not exceed 0.2%. Therefore, samples were allowed to equilibrate for at least six hours in the Testing Environment Chamber before testing began. Additionally, if test equipment was removed from the Testing Environment Chamber between sets, the test equipment was allowed to equilibrate for at least three hours before testing began. If the water repellency tester was removed between sets, the three-hour equilibration time began after the reservoir of the tester was filled.

The target ranges and actual conditions reached for each of the conditioning and testing environment sets that were tested as part of this study are shown in Table II. A visual representation of the conditions is shown in Appendix A. Once conditions and equilibrium were reached, samples were tested for tensile strength in the machine and cross directions, water repellency, and thickness in accordance with AG-1 specifications.

Table II. Conditioning and Testing Environment Target Ranges and Actual Conditions

Environment Set	Target Relative Humidity (%)	Actual Relative Humidity (%)	Target Temperature [°C (°F)]	Actual Temperature [°C (°F)]
1	48-52	49.5-50.7	22.0-24.0 (71.6-75.2)	22.0-23.0 (71.6-73.5)
2	30-35	32.1-32.9	24.0-26.8 (75.2-80.2)	25.4-26.0 (77.8-78.8)
3	60-65	61.9-63.6	24.0-26.8 (75.2-80.2)	25.7-26.1 (78.2-79.1)
4	60-65	61.8-63.3	15.6-18.3 (60.0-65.0)	15.8-17.1 (60.4-62.8)
5	30-35	30.9-33.9	15.6-18.3 (60.0-65.0)	16.4-17.7 (61.6-63.9)
6	42-45	43.0-44.0	22.0-24.0 (71.6-75.2)	22.2-22.8 (72.0-73.0)
7	55-58	56.0-57.0	22.0-24.0 (71.6-75.2)	22.1-22.6 (71.7-72.6)
8	48-52	49.5-50.7	15.6-18.3 (60.0-65.0)	16.4-17.9 (61.5-64.3)
9	48-52	49.5-50.5	24.0-26.8 (75.2-80.2)	24.8-25.3 (76.6-77.6)
10	45-48	46.1-47.0	22.0-24.0 (71.6-75.2)	22.4-23.5 (72.3-74.4)
11	52-55	53.1-54.0	22.0-24.0 (71.6-75.2)	22.3-23.3 (72.1-74.0)

TESTING ENVIRONMENT CONDITIONS RESULTS AND DISCUSSION

Data reported here were collected and reduced in accordance with ICET's Quality Assurance Program (QAP). However, the distribution and interaction plots presented were produced using software that has not been qualified under ICET's QAP. The original data are available upon request. The RH and temperature interaction plots presented in this section refer to different "levels" of RH and temperature. Those levels are indicated in Table III.

Table III. Interaction Plot Levels

Level	Target Relative Humidity (%)	Target Temperature [°C (°F)]
1	30-35	15.6-18.3 (60.0-65.0)
2	42-45	22.0-24.0 (71.6-75.2)
3	45-48	24.0-26.8 (75.2-80.2)
4	48-52	N/A
5	52-55	N/A
6	55-58	N/A
7	60-65	N/A

Preliminary Results

A preliminary study was performed at ICET before the final design of the Testing Environment Chamber was completed. The overall testing process was the same as the Testing Environment Conditions Study; however, the conditions of the chamber in which conditioning and testing was performed were not maintained as closely as possible. The actual conditions experienced during the preliminary study are shown in Table IV. A visual representation of the conditions is shown in Appendix A.

Table IV. Preliminary Study Conditions

Equivalent Environment Set	Actual Relative Humidity (%)	Actual Temperature [°C (°F)]
1	45.3-52.3	22.6-24.3 (72.7-75.7)
2	23.0-35.3	23.7-25.2 (74.6-77.3)
3	59.7-66.0	23.6-25.1 (74.5-77.2)
4	59.5-76.1	14.5-18.6 (58.1-65.5)
5	25.8-35.0	16.4-20.1 (61.6-68.1)

When compared to the results for testing under the conditions specified by TAPPI T 402 (Equivalent Environment Set 1), statistically significant differences were shown under at least one set of conditions for tensile strength results in both directions, water repellency results, and thickness results for both M008 and A114. Upon seeing the differences in results under the various environmental conditions, the Testing Environment Chamber was fine-tuned to be able to maintain more stable conditions before more testing was performed.

Variability Considerations

To limit any variation in results due to operator, one personnel performed all of the testing for each type of physical property testing.

For each set of conditions, the force of a check mass was measured in the Vantage NX Universal Tester. The difference in the maximum load and minimum load measured for all conditions was 0.02 N. For a standard sample, that difference would be the equivalent of less than 0.0008 kN/m. Similarly, a gage block was used to verify the ProGage Thickness Tester before testing in each condition. The difference in the maximum average thickness and minimum average thickness was 0.0010 mm (0.04 mils).

An additional study was performed to see if there was any variation due to the position of the samples within the media roll or filter pack. For the media roll (M008), sheets were taken from the beginning of the available roll, midway through the sheets needed for this study, and from the last sheets cut for this study. Note that this study only sampled from a limited section of the entire media roll due to the low number of sheets needed to complete testing. For the filter pack (A114), pleats were taken from each end of the filter, as well as from the middle of the filter pack. Samples taken from each of these sections were preconditioned, conditioned, and tested for each specified physical property in the conditions specified by TAPPI T 402. The distribution plots for those results are shown in Figure 2 through Figure 5.

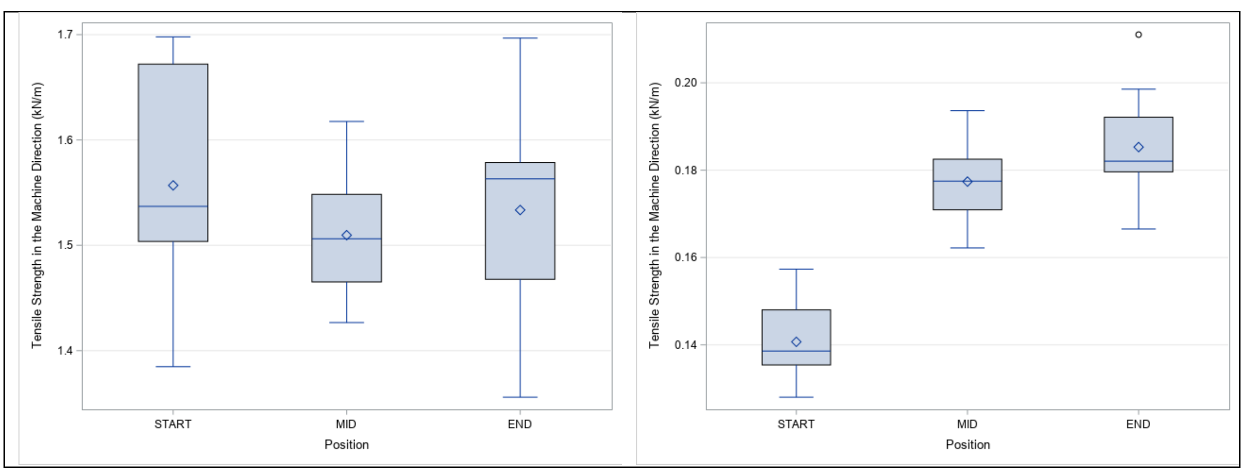

Figure 2. Distribution plots for tensile strength in the machine direction with respect to position for M008 (left) and A114 (right).

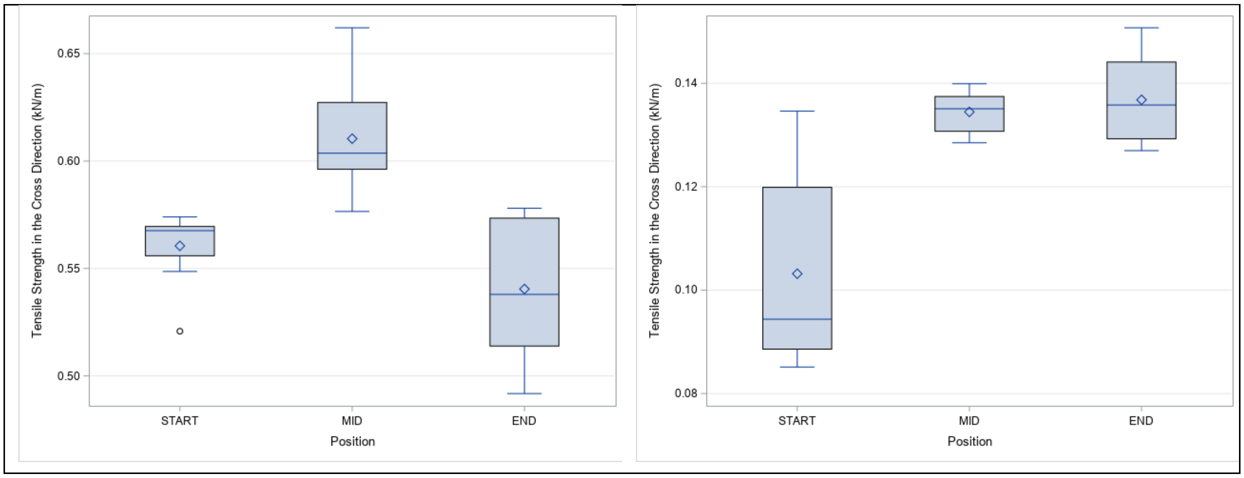

Figure 3. Distribution plots for tensile strength in the cross direction with respect to position for M008 (left) and A114 (right).

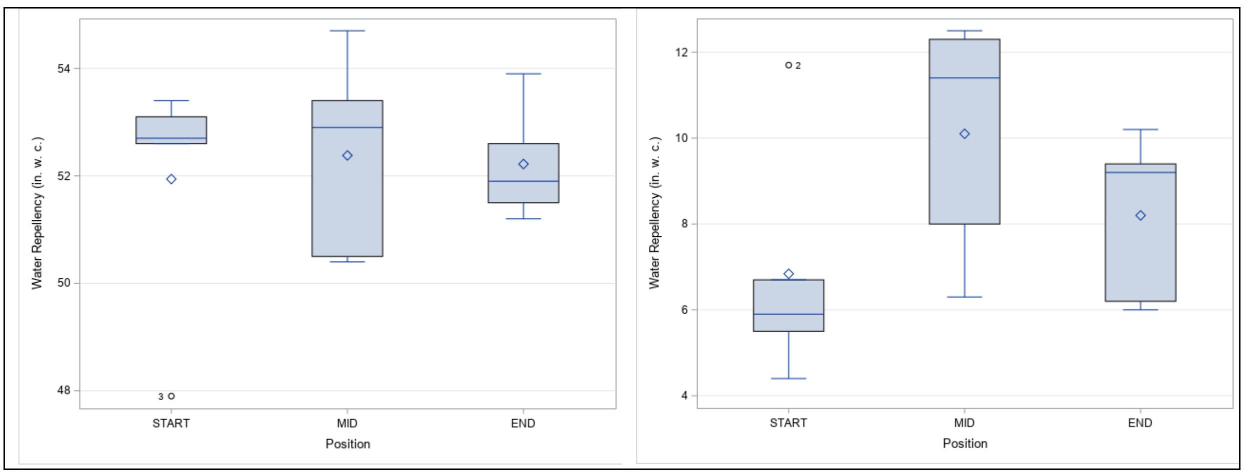

Figure 4. Distribution plots for water repellency with respect to position for M008 (left) and A114 (right).

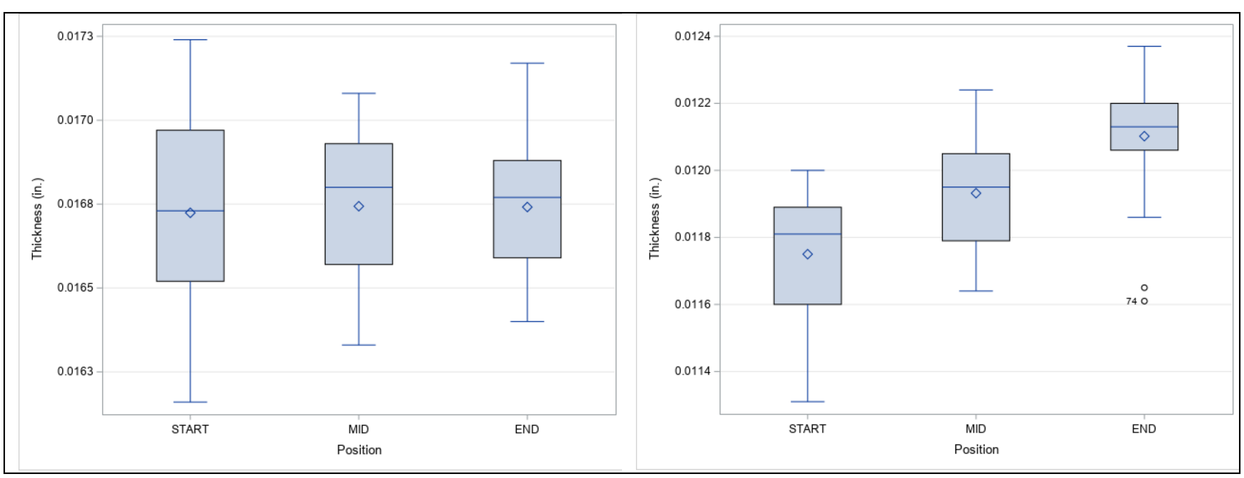

Figure 5. Distribution plots for thickness with respect to position for M008 (left) and A114 (right).

The results of this positioning study were used as the baseline (Environment Set 1) for the remainder of testing. Due to the consistently lower values seen for the "Start" of the A114 results, those values were excluded from the baseline. The pleats sampled for the remainder of testing were not within the outer 20% of the filter pack.

Tensile Strength Results

Ten samples in the machine and cross directions were tested for tensile strength. Upon completion of testing, samples were examined to ensure that breaks were not due to slipping in the jaws or breaking in the clamping area. If it was found that the break location was due to slippage, improper clamping, or misalignment, then that sample was rejected, as required by TAPPI T 494 [2].

The average results for tensile strength in the machine direction for each environment set are shown in Table V, and the RH and temperature interaction plots are show in Figure 6. Generally, an increase in RH and/or temperature tends to decrease the tensile strength in the machine direction, with significant differences seen in the results of samples tested under TAPPI T 402 conditions and samples tested in most other conditions.

Table V. Tensile Strength in the Machine Direction Results

Environment Set	**M008 Average Tensile Strength – Machine (kN/m)**	**A114 Average Tensile Strength – Machine (kN/m)**
1	1.53	0.181
2	1.67	0.203
3	1.15	0.121
4	1.58	0.157
5	1.76	0.278
6	1.59	0.183
7	1.53	0.156
8	1.70	0.221
9	1.53	0.165
10	1.60	0.182
11	1.45	0.171

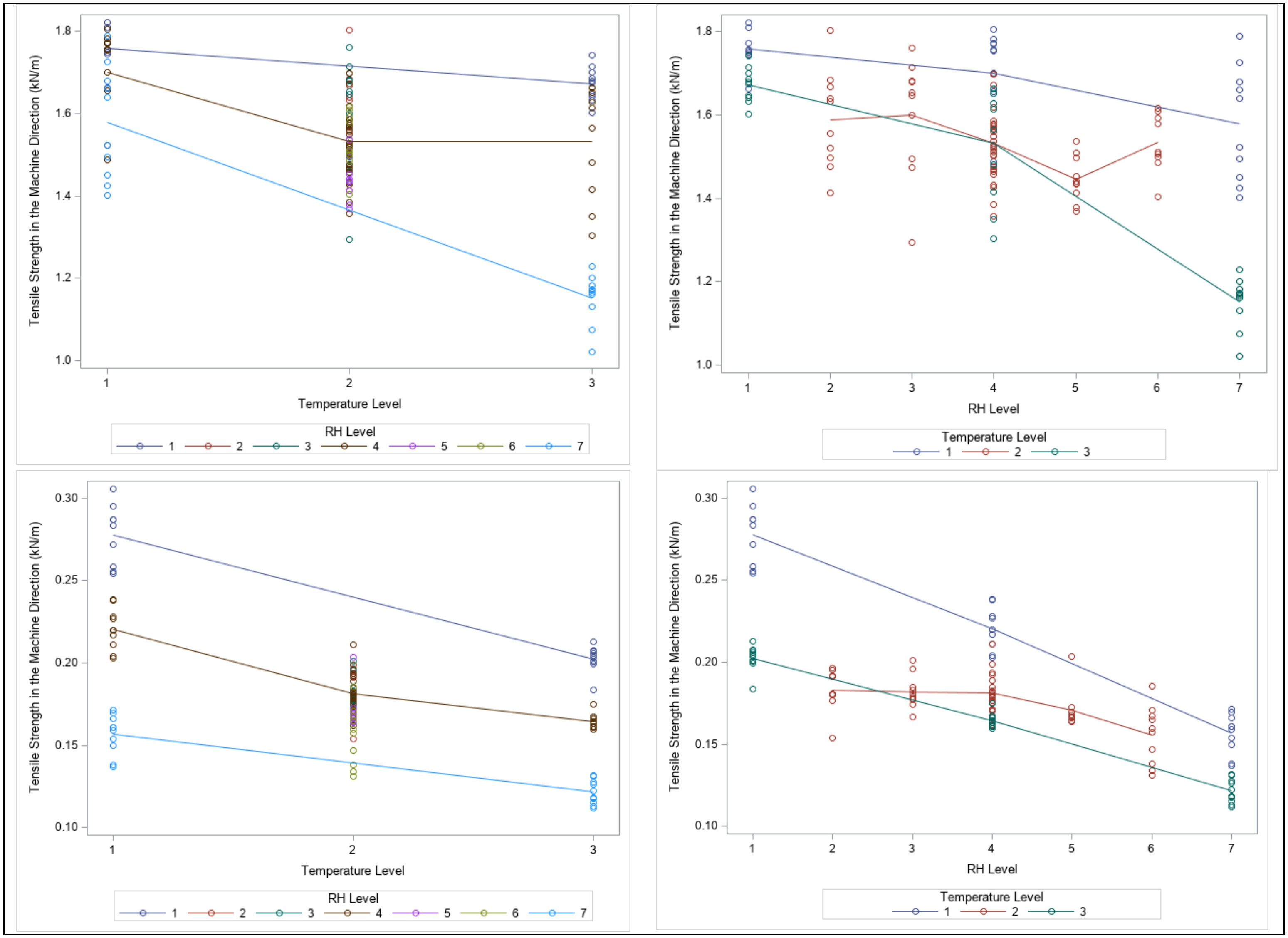

Figure 6. RH and temperature interaction plots for tensile strength in the machine direction for M008 (top) and A114 (bottom).

The average results for tensile strength in the cross direction for each environment set are shown in Table VI, and the RH and temperature interaction plots are show in Figure 7. Generally, an increase in RH and/or temperature tends to decrease the tensile strength in the cross direction, with significant differences seen in the results of samples tested under TAPPI T 402 conditions and samples tested in most other conditions.

Table VI. Tensile Strength in the Cross Direction Results

Environment Set	**M008 Average Tensile Strength – Cross (kN/m)**	**A114 Average Tensile Strength – Cross (kN/m)**
1	0.570	0.136
2	0.552	0.153
3	0.407	0.101
4	0.567	0.123
5	0.603	0.197
6	0.596	0.148
7	0.495	0.125
8	0.619	0.159
9	0.533	0.124
10	0.573	0.144
11	0.477	0.137

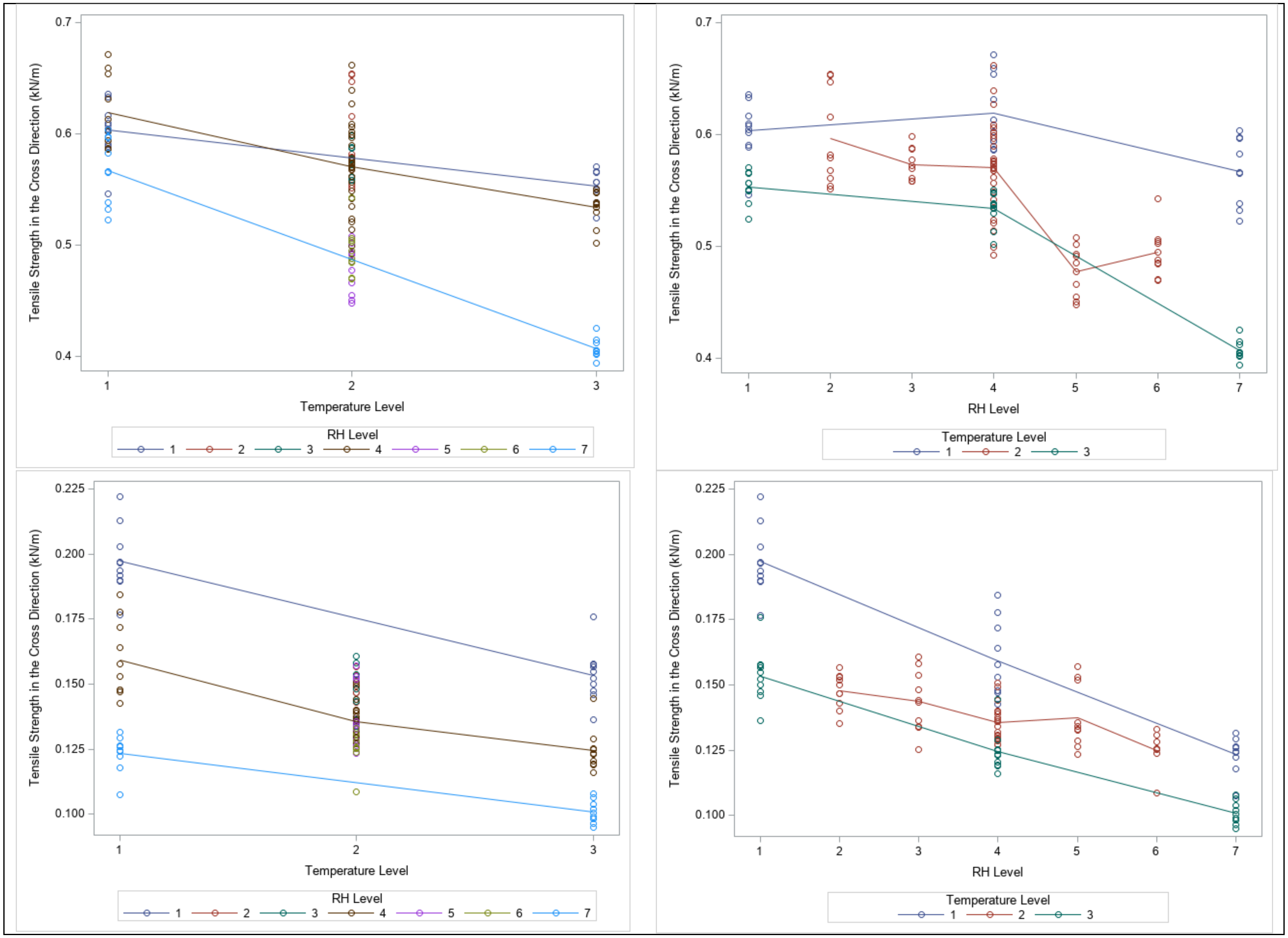

Figure 7. RH and temperature interaction plots for tensile strength in the cross direction for M008 (top) and A114 (bottom).

Water Repellency Results

Five samples were prepared for water repellency testing at each condition, and samples were cut in half such that the felt and wire side of each sample could be tested. The lesser of the two measured values is considered the water repellency of the sample [1]. The average results for water repellency for each environment set are shown in Table VII, and the RH and temperature interaction plots are show in Figure 8. Generally, an increase in temperature tends to decrease the water repellency, with significant differences seen in the results of samples tested under TAPPI T 402 conditions and samples tested in most other temperatures.

Table VII. Water Repellency Results

Environment Set	M008 Average Water Repellency [kPa (in. w. c.)]	A114 Average Water Repellency [kPa (in. w. c.)]
1	13.0 (52.2)	2.28 (9.15)
2	12.9 (52.0)	2.72 (10.9)
3	12.8 (51.4)	2.65 (10.7)
4	13.7 (55.2)	3.31 (13.3)
5	13.9 (55.9)	3.49 (14.0)
6	12.8 (51.4)	3.56 (14.3)
7	13.2 (52.9)	3.04 (12.2)
8	13.8 (55.4)	3.08 (12.4)
9	12.6 (50.5)	2.76 (11.1)
10	12.7 (51.2)	3.02 (12.1)
11	13.2 (53.1)	2.57 (10.3)

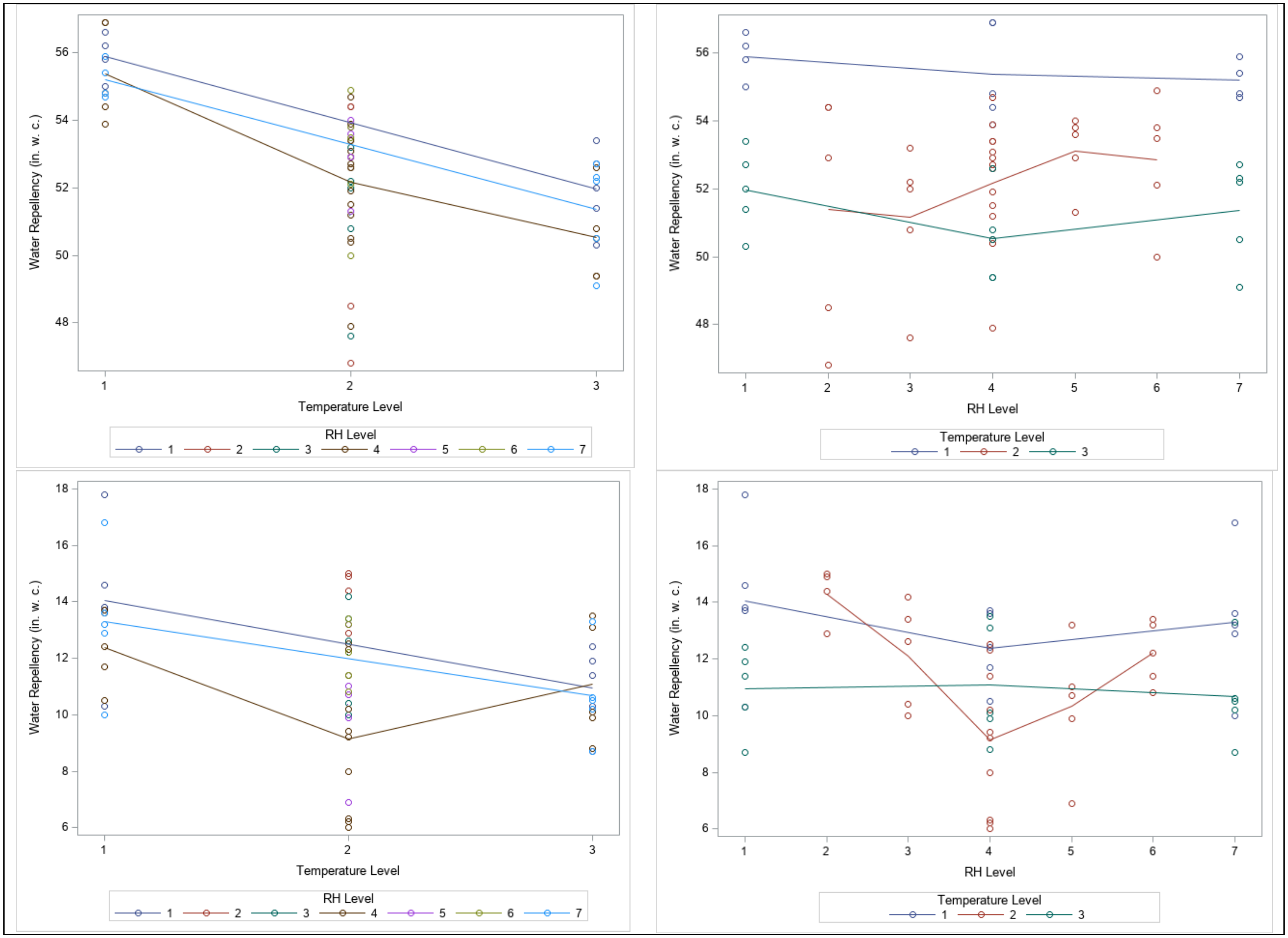

Figure 8. RH and temperature interaction plots for water repellency for M008 (top) and A114 (bottom).

Thickness Results

Five samples were prepared for thickness testing at each condition. The thickness of each sample was measured at five points across the media. The average results for thickness for each environment set are shown in Table VIII, and the RH and temperature interaction plots are show in Figure 9. Generally, an increase in RH tends to decrease the thickness, with significant differences seen in the results of samples tested under TAPPI T 402 conditions and samples tested in most other RHs.

Table VIII. Thickness Results

Environment Set	M008 Average Thickness [mm (in.)]	A114 Average Thickness [mm (in.)]
1	0.425 (0.01672)	0.305 (0.01200)
2	0.433 (0.01704)	0.308 (0.01212)
3	0.423 (0.01664)	0.295 (0.01160)
4	0.428 (0.01684)	0.297 (0.01172)
5	0.441 (0.01736)	0.319 (0.01256)
6	0.439 (0.01728)	0.308 (0.01212)
7	0.431 (0.01696)	0.303 (0.01196)
8	0.435 (0.01712)	0.310 (0.01220)
9	0.421 (0.01656)	0.301 (0.01184)
10	0.432 (0.01700)	0.305 (0.01200)
11	0.432 (0.01700)	0.300 (0.01180)

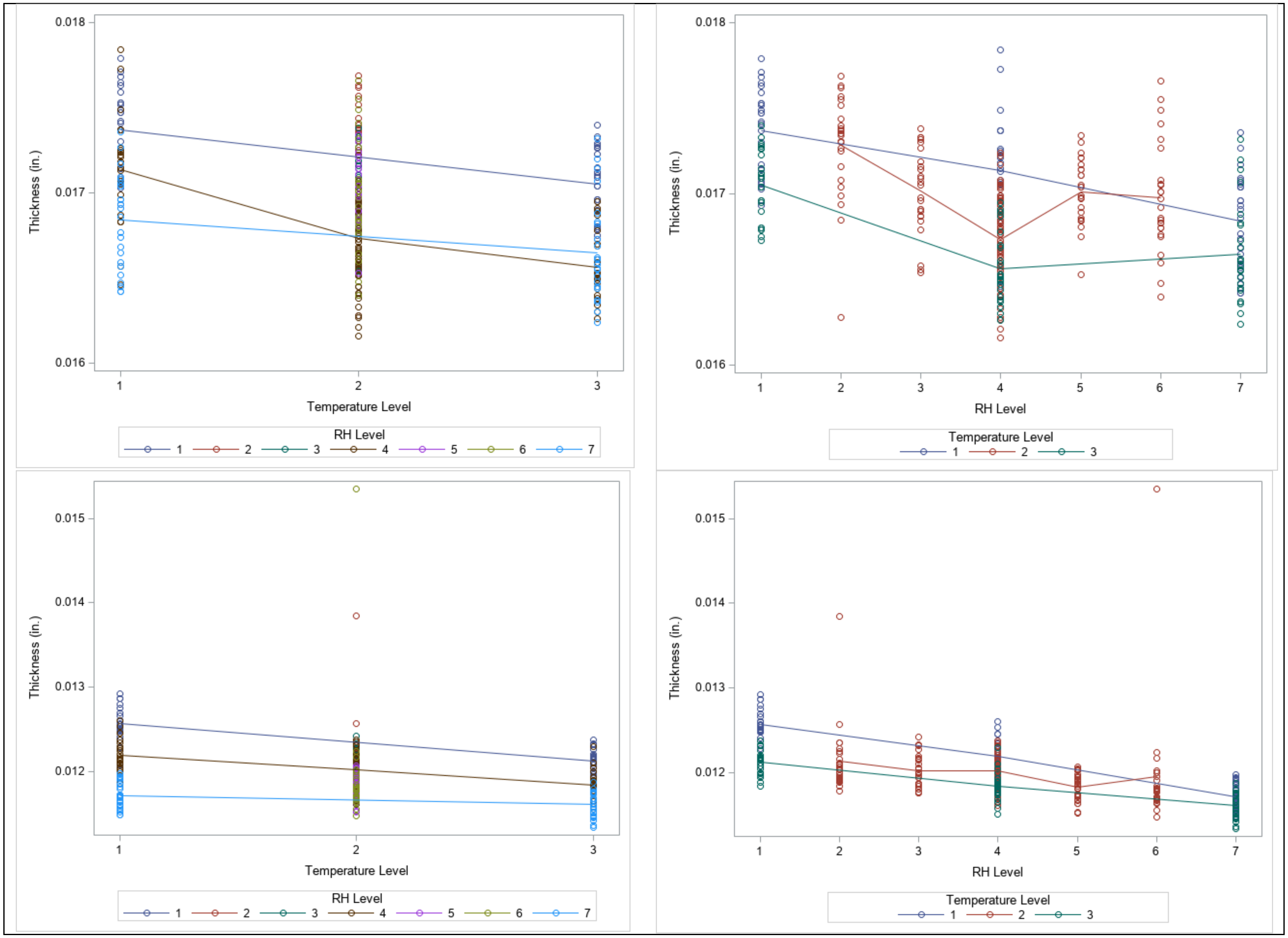

Figure 9. RH and temperature interaction plots for thickness for M008 (top) and A114 (bottom).

CONCLUSIONS

Tensile strength in the machine and cross directions, water repellency, and thickness results of media are affected by the RH and/or temperature in which the media is conditioned and tested. In some cases, a relatively small change in RH or temperature outside of the ranges specified by TAPPI T 402 may have a significant effect on these physical properties. Further testing should be performed in order to pinpoint the ranges in which physical properties of media are unaffected and should be tested in.

REFERENCES

1. *AG-1 Code on Nuclear Air and Gas Treatment*, ASME AG-1, 2017.

2. *Tensile properties of paper and paperboard (using constant rate of elongation apparatus)*, TAPPI T 494 om-13, 2013.

3. *Thickness (caliper) of paper, paperboard, and combined board*, TAPPI T 411 om-10, 2010.

4. *Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products*, TAPPI T 402 sp-13, 2013.

5. Test Method Standard, "*Filter Units, Protective Clothing, Gas-Mask Components and Related Products: Performance Test Methods*," MIL-STD-282, 1956.

Appendix A

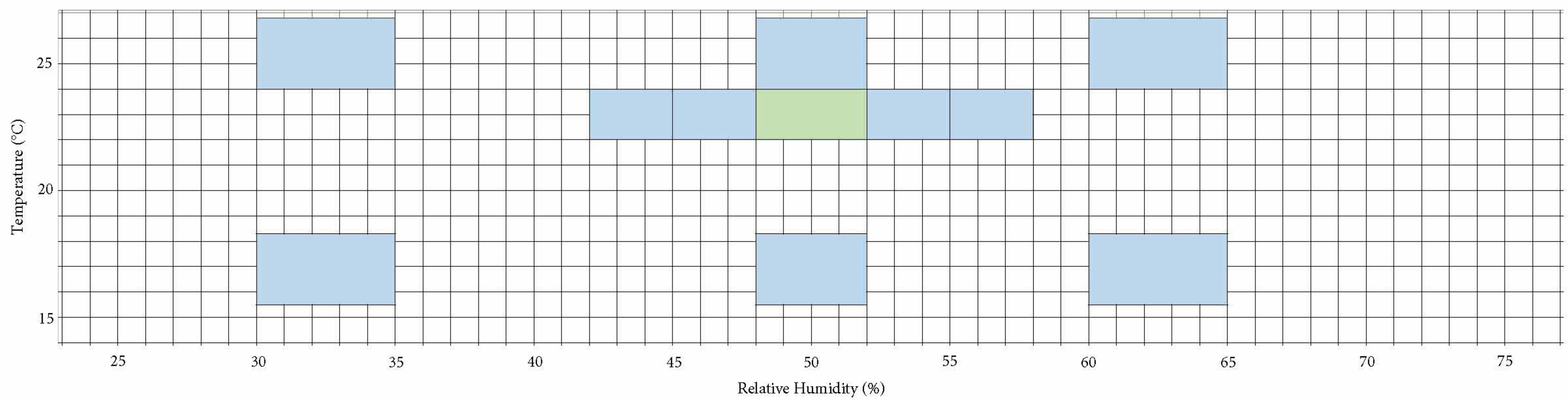

Figure A1. Target ranges for conditioning and testing environments.

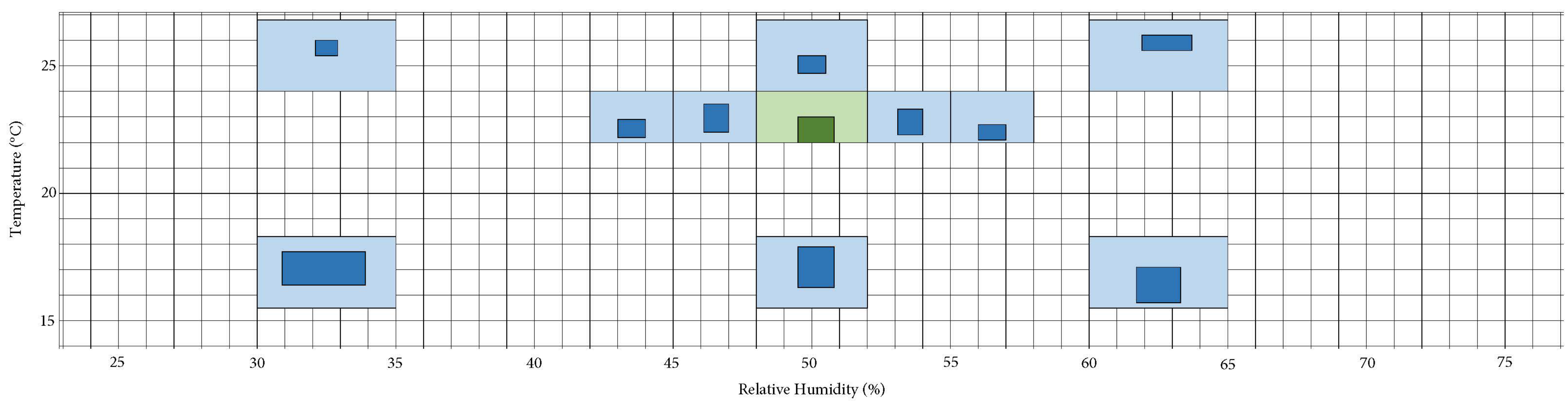

Figure A2. Actual conditions experienced during the Effect of Testing Environment Conditions Study (dark) overlaid on target ranges for conditioning and testing environments (light).

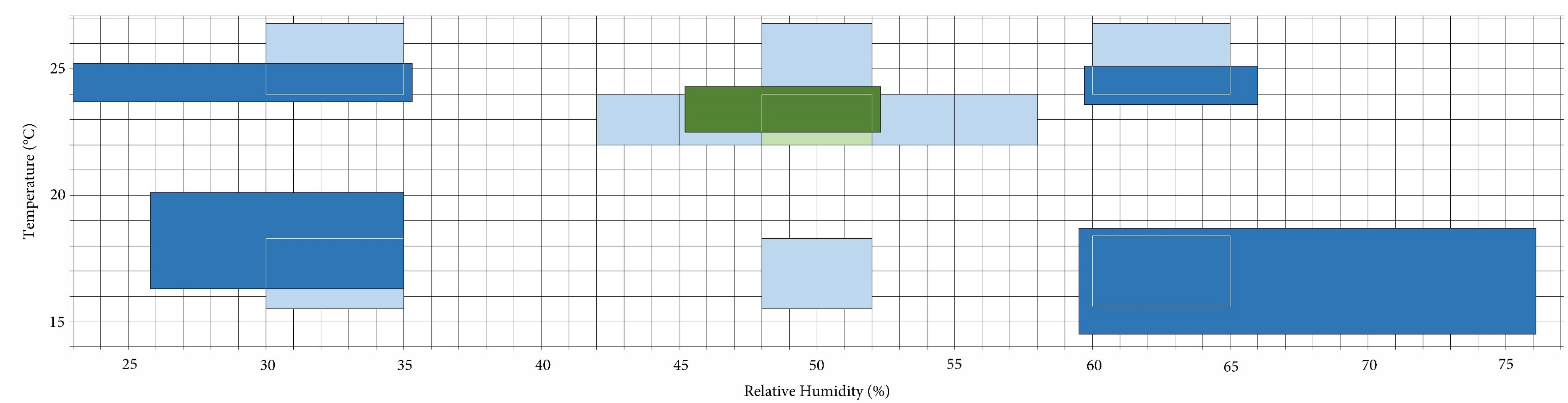

Figure A3. Actual conditions experienced during preliminary study (dark) overlaid on target ranges for conditioning and testing environments (light).