Test Report

Selected Measurements According to ASTM C547 on Power-teK PS 450 Mineral Fiber Pipe Insulation Supplied by Knauf

Prepared For:

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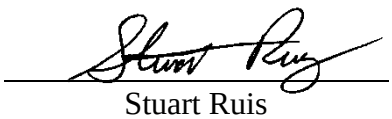
Report: RD17874-R1



Stuart Ruis
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January 8, 2018

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January 8, 2018

R&D Services, Inc. has completed tests on Power-teK PS 450 Mineral Fiber Pipe Insulation provided by Knauf Insulation (Slovenia). R&D Services, Inc. received eight pieces of material on September 19, 2017. Additional material was received on December 20, 2017. Tests have been completed to verify that the product complies with ASTM C547 requirements for Type I, Grade A insulation. The test results are summarized in Table 1 and 2.

Table 1

MATERIAL PROPERTY	TEST STANDARD	RESULT	ASTM C547 REQUIREMENT PASS/FAIL
Density (kg/m^3)	ASTM C302	89.8	NA
Dimensions (% of label)	ASTM C302	Length – 100.0 % Thickness – 100.6 %	PASS PASS
Sag Resistance (% thickness)	ASTM C411	2.7	PASS
Maximum Use Temperature (454 °C)	ASTM C447/C411	PASS	PASS
Exothermic Temperature Rise (°C)	ASTM C447/C411	66	PASS
Linear Shrinkage (% change)	ASTM C356	0.5	PASS
Water Vapor Sorption (Mass %)	ASTM C1104	0.73	PASS
Non Fibrous Shot Content (% content)	ASTM C1335	15.4	PASS
Thermal Conductivity	ASTM C335	See Table 2	See Table 2
Surface Burning Characteristics	ASTM E84	FSI – 0 SDI – 0	PASS

The apparent thermal conductivity was measured according to ASTM C335 at mean temperatures specified in ASTM C547. One piece of Power-teK PS 450 with inner diameter of 89 mm and wall thickness of 50 mm was measured. Thermal conductivity data are summarized in Table 2.

Table 2

MEAN TEMPERATURE (°C)	THERMAL CONDUCTIVITY (W/m·K)	ASTM C547 REQUIREMENT (W/m·K)	PASS/FAIL
24	0.033	n/a	n/a
38	0.035	0036	PASS
93	0.042	0.045	PASS
149	0.051	0.058	PASS
204	0.061	0.074	PASS
260	0.078	0.092	PASS
316	0.094	n/a	n/a

Test results on the Knauf Insulation Power-teK PS 450 Mineral Fiber Pipe Insulation show that the product meets the requirements of ASTM C547 for Type I, Grade A classification.

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Dimensions and Density of Preformed Block and Board Insulation

Test Number: RD172687DB Date of Test: September 28, 2017

Specimen Number: 1211170919-3,4 Date of Manufacture: August 23, 2017

Description of Test Specimen: Power-teK PS 450 Mineral Fiber Pipe Insulation

Test Method: ASTM C547-17, "Standard Specification for Mineral Fiber Pipe Insulation" Section 11.1.1; ASTM C 302-13 "Standard Test Method for Density and Dimensions of Preformed Pipe-Covering-Type Thermal Insulation", Procedure A.

Report Prepared For: Knauf Insulation (Slovenia) / Delfina-Bi Baranda Robles

Background

ASTM C302, Procedure A is a procedure for determining the density of preformed pipe insulation from a measurement of mass and volume. The volume is the product of the length, circumference, and wall thickness of the specimen. The mass is measured using a digital scale. The density is calculated as the mass divided by the volume. Conversions factors 1.0 kg = 2.205 lb_m and 1.0 m^3 = 35.314 ft^3 are used in this report.

Two one-piece sections of pipe insulation approximately 1200 mm long, with inner diameter of 89 mm and wall thickness of 100 mm (47 by 3.5 by 4 inches) were used for this determination. Specimens were conditioned for a minimum of 48 hours at 70 ± 3° F and 50 ± 2 % RH. Two specimens were prepared and measured.

Test Results

Specimen Number	Measured Length (mm)	Measured Circumference (mm)	Measured Wall Thickness (mm)
A	1199.8	921.0	100.5
B	1200.3	919.6	100.7

Specimen Number	Volume		Mass		Density	
	m^3	ft^3	kg	lb_m	kg/m^3	lb_m/ft^3
A	0.07300	2.5778	6.690	14.75	91.7	5.72
B	0.07292	2.5753	6.418	14.15	88.0	5.50
Average					89.8	5.61
Standard Deviation					2.6	0.16

Conclusion

The average density for the insulation that was tested is 89.8 kg/m^3 (5.61 lb_m/ft^3).

Reviewed by: 12/1/17 Date:

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Hot Surface Performance of High-Temperature Thermal Insulation

Test Number:	RD173027HS	Date of Manufacture:	November 30, 2017
Specimen Number:	1211171220-14	Date of Test:	December 15-19, 2017

Description of Test Specimen: Power-teK PS 450 89/150 Mineral Fiber Pipe Insulation

Report Prepared For: Knauf Insulation (Slovenia)

Contact Person: Delfina-Bi Baranda Robles

Test Method: ASTM C547-17, "Standard Specification for Mineral Fiber Pipe Insulation".

ASTM C411-17, "Standard Test Method for Hot-Surface Performance of High-Temperature Thermal Insulation".

Description of Test

ASTM C411 tests the performance of a thermal insulation intended for high temperature applications when the insulation is in continuous contact with a hot surface at a controlled temperature for a period of 96 hours.

The specimen is 1.2 meter long, single specimen layer, on a nominal 89 mm (nominal 3 inch) stainless steel pipe. Six thickness measurements are performed while the apparatus is at room temperature. These measurements are the initial sag measurements. The measurements are performed at 2, 5 and 10 inches on both sides of the midpoint of the specimen.

The pipe is heated to the test temperature using a ramp schedule stated in ASTM C411. Once the pipe is heated to the test temperature, the pipe is held at a constant temperature for 96 hours. Visible signs of flaming, glowing, smoldering, or smoking results in termination of the test. The electrical power to the heater is turned off at the end of 96 hours and the test specimen is allowed to cool to room temperature. After cooling the sag measurements are repeated. The material is then removed from the pipe for evaluation.

Conclusion

The Power-teK PS 450 89/150 Mineral Fiber Pipe Insulation manufactured by Knauf Insulation (Slovenia) meets the requirements of ASTM C547, Section 11.1.7 when tested according to ASTM C411, for use up to 454°C.

Note: The specimen was installed on the apparatus at room temperature and ramped to the test temperature per the heat up schedule in ASTM C411.

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Conditions and Observations

Product Identification	Power-teK PS 450 89/150 Mineral Fiber Pipe Insulation
Nominal Thickness	150 mm
Layers of Material Tested	1
Target test temperature	454.0 ± 5.0 °C
Average measured test temperature	455.6 °C
Measured sag after test	2.7 %
Change in flexibility after test	YES
Cracking or delamination of specimen	NO
Evidence of flaming	NO
Evidence of glowing	NO
Evidence of smoldering	NO
Evidence of melting	NO
Discoloration of specimen	YES

Below is a description of the tables included in the report:

Table 3 Sag measurements before and after testing
Table 4 Physical dimensions before testing.
Table 5 Physical Dimensions After Testing
Table 6 Percent Change in Physical Properties

Below is a description of the figures included in the report:

Figure 1 Photograph of specimen before testing
Figure 2 Photograph of specimen after testing
Figure 3 Temperature profile for the duration of the test

	-10	-5	-2	2	5	10	Average
Initial	151.0	150.0	150.0	149.5	150.5	150.0	150.2
Final	147.0	146.0	146.0	146.0	146.0	146.0	146.2
						Percent Change:	**2.66 %**

Table 3 – Sag Measurements Before and After Testing

	Length (mm)	Diameter (mm)	Thickness (mm)	Mass (g)	Density (kg/m^3)
Specimen (exposed to pipe)	1200.0	391.0	150.6	12490.0	45.8

Table 4 – Physical Dimensions Before Testing

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	Length (mm)	Diameter (mm)	Mass (g)
Specimen (exposed to pipe)	1196.7	390.7	12210.0

Table 5 – Physical Dimensions After Testing

	Length Change (%)	Outer Diameter Change (%)	Mass Loss (%)
Specimen (exposed to pipe)	0.3	0.1	2.2

Table 6 – Percent Change in Physical Properties

Figure 1. Specimen Before Testing

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Figure 2. Specimen After Testing

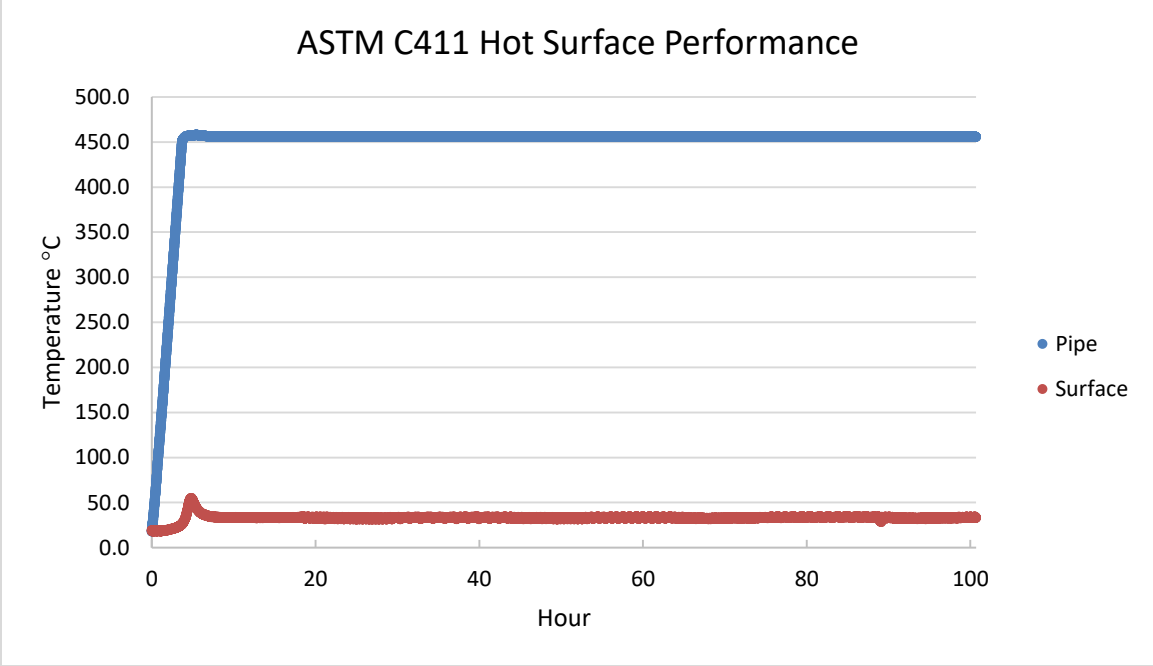

Figure 3. Temperature Profile for Duration of Testing

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Hot Surface Performance of High-Temperature Thermal Insulation

Test Number:	RD173026HS	Date of Manufacture:	November 30, 2017
Specimen Number:	1211171220-13	Date of Test:	December 21-25, 2017

Description of Test Specimen: Power-teK PS 450 89/150 Mineral Fiber Pipe Insulation

Report Prepared For: Knauf Insulation (Slovenia)

Contact Person: Delfina-Bi Baranda Robles

Test Method: ASTM C547-17, "Standard Specification for Mineral Fiber Pipe Insulation".

ASTM C411-17, "Standard Test Method for Hot-Surface Performance of High-Temperature Thermal Insulation".

ASTM C447-15, "Standard Practice for Estimating the Maximum Use Temperature of Thermal Insulations".

Description of Test

ASTM C411 tests the performance of a thermal insulation intended for high temperature applications when the insulation is in continuous contact with a hot surface at a controlled temperature for a period of 96 hours.

The specimen is 1.2 meter long, single specimen layer, on a nominal 89 mm (nominal 3 inch) stainless steel pipe. The specimen was installed on the pipe after the pipe was heated to the test temperature in accordance with ASTM C447.

Visible signs of flaming, glowing, smoldering, or smoking results in termination of the test. The electrical power to the heater is turned off at the end of 96 hours and the test specimen was allowed to cool to room temperature. After cooling the test specimen was removed from the pipe for evaluation.

Conclusion

The Power-teK PS 450 89/150 Mineral Fiber Pipe Insulation manufactured by Knauf Insulation (Slovenia) meets the requirements of ASTM C547, for use up to 454°C when tested according to ASTM C411 and ASTM C447.

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Conditions and Observations

Product Identification	Power-teK PS 450 89/150 Mineral Fiber Pipe Insulation
Nominal Thickness	150 mm
Layers of Material Tested	1
Target test temperature	454.0 ± 5.3 °C
Average measured test temperature	455.9 °C
Change in flexibility after test	YES
Cracking or delamination of specimen	NO
Evidence of flaming	NO
Evidence of glowing	NO
Evidence of smoldering	NO
Evidence of melting	NO
Discoloration of specimen	YES

Below is a description of the tables included in the report:

Table 7 Physical characteristics before testing
Table 8 Dimensions and Mass After Testing
Table 9 Percent Change in Physical Properties
Table 10 Temperature and exothermic reaction data of the test specimen during testing

Below is a description of the figures included in the report:

Figure 4 Photograph of specimen before testing
Figure 5 Photograph of specimen after testing
Figure 6 Temperature Profile for the First 5 Hours of Testing
Figure 7 Temperature profile for the duration of the test

	Length (mm)	Diameter (mm)	Thickness (mm)	Mass (g)	Density (kg/m^3)
Specimen (exposed to pipe)	1198.0	390.6	149.2	11620.0	42.9

Table 7 – Dimensions and Mass Before Testing

	Length (mm)	Diameter (mm)	Mass (g)
Specimen (exposed to pipe)	1200.0	391.2	11330.0

Table 8 – Dimensions and Mass After Testing

	Length Change (%)	Outer Diameter Change (%)	Mass Loss (%)
Specimen (exposed to pipe)	-0.2	-0.2	2.5

Table 9 – Percent Change in Physical Properties

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Location of Temperature Measurement	Maximum Temperature (°C)	Maximum Exotherm Temperature (°C)	Dwell Temperature (°C)
25 mm	521.5	62.5	349.8
50 mm	525.3	66.2	285.2
75 mm	476.0	16.6	210.2
100 mm	432.6	-26.1	166.8
125 mm	367.9	-90.5	96.5
150 mm	143.0	-316.0	45.3
Surface	52.5	-407.1	28.0

Table 10 – Exothermic Temperature Data

Note- Three measurement locations experienced an exothermic reaction, however, these reactions were not in excess of 111°C which meets the requirements of ASTM C547. The exotherm is the maximum temperature difference between the pipe temperature and the measurement location when the measurement location is above the pipe temperature.

Figure 4. Specimen Before Testing

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Figure 5. Specimen After Testing

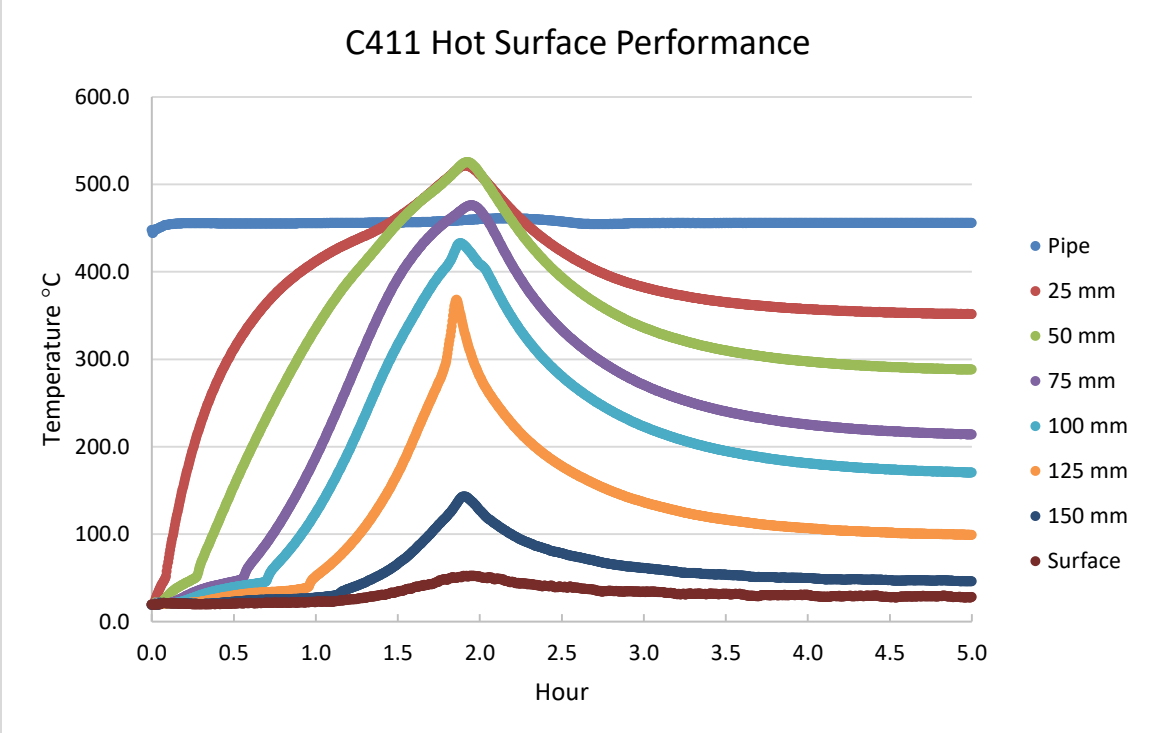

Figure 6. Initial 5 Hours of Testing

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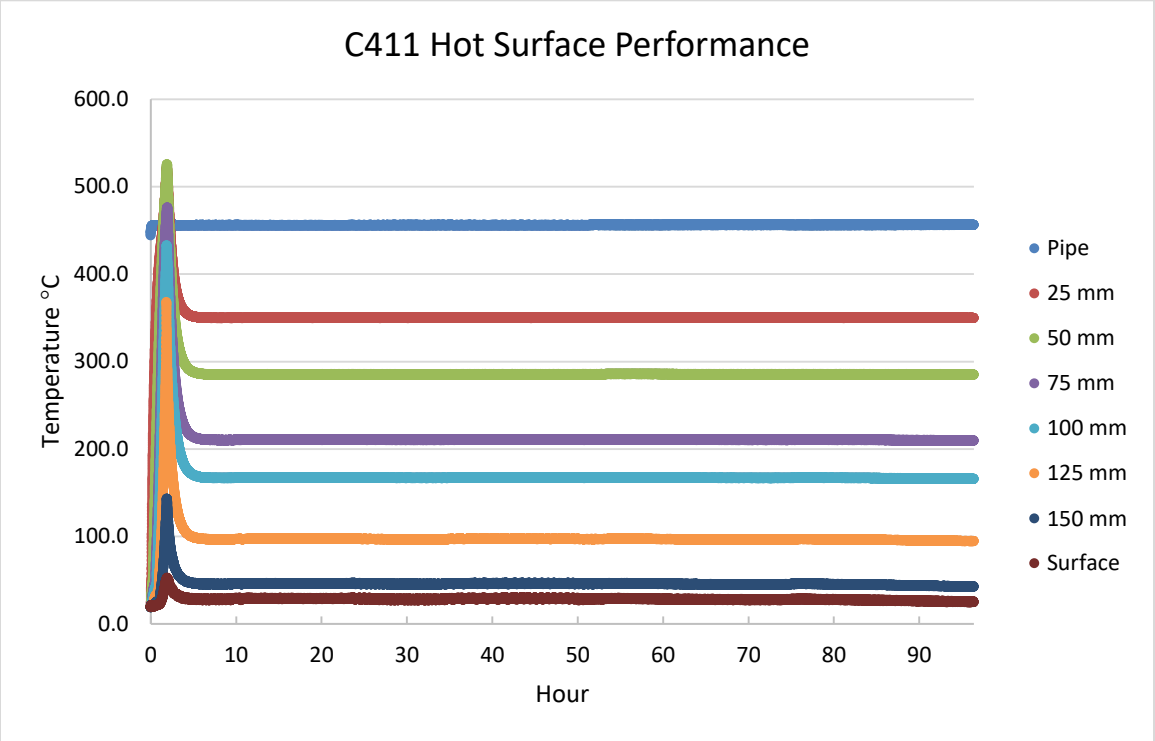

Figure 7. Temperature Profile for Duration of Testing

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Linear Shrinkage of Thermal Insulation Report

Test Number: RD172688LS Date of Test: October 4 – 6, 2017

Specimen Number: 1211170919-3,4 Date of Manufacture: August 23, 2017

Description of Test Specimen: Power-teK PS 450 Mineral Fiber Pipe Insulation

Test Method: ASTM C547-17, "Standard Specification for Mineral Fiber Pipe Insulation" and ASTM C356-17, "Standard Test Method for Linear Shrinkage of Preformed High-Temperature Thermal Insulation Subjected to Soaking Heat"

Report Prepared For: Knauf Insulation (Slovenia) / Delfina-Bi Baranda Robles

Background

The linear shrinkage of mineral fiber insulation due to exposure to short-term high temperature has been determined The specimens are conditioned and exposed to high temperature conditions for 24 hours. The average linear shrinkage of four specimens is measured and used to calculate the linear shrinkage percent of the samples expressed as a percentage of the length measured before exposure.

Four samples approximately 153 by 77 by 26 mm were used. The test was conducted at 454 °C.

Test Results

	Specimen 1	Specimen 2	Specimen 3	Specimen 4
Initial Length (mm)	153.7	153.9	153.4	153.5
Initial Width (mm)	76.1	76.6	76.5	76.7
Initial Thickness (mm)	25.84	25.73	25.66	25.78
Final Length (mm)	152.8	153.2	152.8	152.6
Final Width (mm)	76.7	76.4	76.4	76.3
Final Thickness (mm)	26.56	26.12	26.38	26.19
Change in Length (mm)	0.9	0.7	0.6	0.9
Linear Shrinkage (%)	0.6	0.5	0.4	0.6

Result:

The average observed linear shrinkage of the test specimens was 0.5 %. This meets the physical requirements of ASTM C547, Table 1, which states a maximum of 2% in the length dimension.

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Water Vapor Sorption Test Report

Test Number: RD172689WV

Date of Test: October 11 – 16, 2017

Specimen Number: 1211170919-3,4

Date of Manufacture: August 23, 2017

Description of Test Specimen: Power-teK PS 450 Mineral Fiber Pipe Insulation

Test Method: ASTM C547-17, "Standard Specification for Mineral Fiber Pipe Insulation" Section 11.1.4; ASTM C 1104/C 1104M-13a, "Standard Test Method for Determining the Water Vapor Sorption of Unfaced Mineral Fiber Insulation".

Report Prepared For: Knauf Insulation (Slovenia) / Delfina-Bi Baranda Robles

The procedure used to test blanket, board, or pipe insulation products is contained in Section 8 of ASTM C 1104/C 1104M-13a. The procedure is carried out for three specimens of the product. The volume of each test specimen is determined from measurements of the length, width, and thickness. The dry weight of the test specimens is determined after drying to steady state in a 102 to 121 °C environment. The test specimens are brought to a uniform temperature of 60°C before being transferred to an environmental chamber maintained at 49 ± 2 °C and 95 ±3 % relative humidity. The test specimens remain in the environmental chamber for 96 ± 4 hours. At the end of the 96-hour exposure the specimens are sealed in a water impermeable bag and allowed to cool before final weighing. The increase in mass due to the exposure is used to calculate mass % and volume % water sorption relative to the moisture-free material.

Results:

Specimen:	**1**	**2**	**3**
Volume (cm^3):	1552.37	1566.44	1597.69
Moisture-free Mass (g):	149.59	161.26	155.72
Mass after test (g):	150.77	162.41	156.81
Mass % sorbed:	0.79	0.71	0.70
Volume % sorbed:	0.076	0.073	0.068
Average Mass % sorbed:	**0.73**		
Average Volume % sorbed:	**0.073**		

The precision of C1104/C1104M-13a has been determined to be 0.02 volume % at the 95 % reproducibility limit for light-density mineral fiber.

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Date:

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Non-Fibrous Content Test Report

Test Number: RD172690NF Date of Test: October 4, 2017

Specimen Number: 1211170919-3,4 Date of Manufacture: August 23, 2017

Description of Test Specimen: Power-teK PS 450 Mineral Fiber Pipe Insulation

Test Method: ASTM C547-17, "Standard Specification for Mineral Fiber Pipe Insulation" Section 11.1.8; ASTM C1335-12, "Standard Test Method for Measuring Non-Fibrous Content of Man-Made Rock and Slag Mineral Fiber Insulation", Procedure A

Report Prepared For: Knauf Insulation (Slovenia) / Delfina-Bi Baranda Robles

Background

This test procedure determines the non-fibrous content (shot) of man-made rock and slag mineral fiber insulation. The procedure involves a dry sieve analysis method to distinguish between fiberized and non-fiberized (shot) portions of a specimen of man-made rock and slag mineral fiber insulation.

Three 10 gram specimens are prepared. Test specimens are conditioned at high temperature for 15 minutes and allowed to cool to room temperature. The specimens are placed into a nest of three sieves and shaken for 20 minutes using a Tyler model RX-24 portable sieve shaker. The non-fibrous (shot) content remaining in each sieve is weighed. The percentage of non-fibrous content is calculated using the equation in Section 8 of ASTM C1335.

Test Results

Conditioning Temperature: 593 °C
Type of Sieves Used: Number 20, 50 and 100; brass

	Specimen 1	Specimen 2	Specimen 3
Initial Mass of Specimen (g)	10.0186	10.1692	10.2803
Mass of Specimen After Conditioning (g)	9.7496	9.8652	9.9289
Mass of Non-Fibrous Material in No. 20 Sieve (g)	0.0923	0.0730	0.0222
Mass of Non-Fibrous Material in No. 50 Sieve (g)	2.1991	1.6330	1.5480
Mass of Non-Fibrous Material in No. 100 Sieve (g)	14.7062	13.6622	12.1987
Total Mass of Non-Fibrous Material (g)	1.6572	1.5161	1.3671
Non-Fibrous Content (%)	17.0	15.4	13.8

Result:

The average observed non-fibrous content of the test specimens was 15.4 %.

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Thermal Resistance of Pipe Insulation

Test Number:	RD172742PT	Date of Manufacture:	August 23, 2017
Specimen Number:	1211170919-2	Date of Test:	October 9 - 13, 2017

Description of Test Specimen: Power-teK PS 450 Mineral Fiber Pipe Insulation

Report Prepared For: Knauf Insulation (Slovenia)

Contact Person: Delfina-Bi Baranda Robles

Test Method: ASTM C547-17, "Standard Specification for Mineral Fiber Pipe Insulation".

ASTM C335-17, "Standard Test Method for Steady-State Heat Transfer Properties of Horizontal Pipe Insulation".

ASTM C1045-07 (2013), "Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions".

Description of Test

The steady-state heat transfer properties of pipe insulation are determined using a horizontal guarded end pipe apparatus in accordance with ASTM C335, "Standard Test Method for Steady-State Heat Transfer Properties of Horizontal Pipe Insulation". The pipe apparatus is a DN 80 mm nominal stainless steel pipe with three separately internally heated zones. The primary measurement zone is 914 mm and the guard zones are 305 mm. The pipe temperature is characterized by nine Type K thermocouples located at uniform intervals through the length of the metered area. The insulation surface temperature is characterized by 16 Type K thermocouples located at regular intervals on the surface of the test specimen. Each guard is monitored with thermocouples located 0.5 inches from the guard and test area interface. The power consumed by the primary heater is measured using a Yokogawa WT310E Power Analyzer. Test data is evaluated and thermal conductivity is reported in accordance with ASTM C1045, "Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions". The entire apparatus is in a conditioned space maintained at 23 ± 2 ºC and 50 ± 5% relative humidity.

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Apparent thermal conductivity is determined over the range of operating temperatures for the test specimen. Measured thermal conductivity is calculated once the apparatus has reached steady-state for each set point. The calculations are performed over 15 minute blocks of time. There are three criteria in place to determine steady-state. Criteria one is to verify the block to block thermal conductivity is not monotonic over the previous eight blocks. Criteria two is to verify the block to block change does not exceed 0.4% over the previous six blocks. Criteria three is to verify that any block over the previous six blocks does not exceed the average of the previous six blocks by more than 0.25%. Once the apparatus reaches steady-state, the set point is measured for four hours before moving to the following set point.

Thermal conductivity for the pipe insulation is obtained from Equation (1).

$$k_a = \frac{Q \cdot \ln\left(\frac{r_2}{r_1}\right)}{L \cdot 2\pi \cdot \Delta T} \quad (1)$$

Q = Heat flow through the insulation, W
L = Specimen length, m
r_2 = Outer radius, m
r_1 = Inner radius, m
ΔT = Average temperature difference, K
k_a = Apparent Thermal Conductivity, W/m·K

Description of Test Specimen

Mineral fiber pipe insulation provided by Knauf Insulation (Slovenia) was identified as Power-teK PS 450 Mineral Fiber Pipe Insulation. The product was nominal 50 mm thick. One 1 meter long layer was installed on the apparatus. Table 11 contains the measured physical properties of the specimen.

Table 11. Measured Physical Properties of Tested Specimen

Inside diameter of specimen	89 mm
Thickness of specimen	50.8 mm
Density of specimen	89.4 kg/m^3

Test Results

The thermal conductivity for the pipe material was determined by performing measurements over the temperature range of the product. Six temperature set points were measured. Table 12 contains the measured data.

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Table 12. Measured Apparent Thermal Conductivity

Hot Surface (ºC)	Cold Surface (ºC)	Mean Temperature (°C)	Apparent Thermal Conductivity (W/m· K)
55.6	20.6	38.1	0.03507
134.8	24.6	79.7	0.04071
213.9	29.2	121.5	0.04665
294.6	34.9	164.8	0.05484
375.4	43.6	209.5	0.06500
455.1	50.8	253.0	0.07579

ASTM C1045 Analysis

ASTM C1045, "Standard Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions" is the accepted procedure for calculating thermal transmission properties of materials tested in accordance with ASTM C335. ASTM C1045 allows the user to calculate thermal transmission properties from temperature and heat flux data obtained through the experimental method described in ASTM C335. Since ASTM C335 obtains apparent thermal conductivity measurements for large temperature differences, the Thermal Conductivity Integral Method is used for calculating a three-term polynomial using a least squares fit that allows the user to calculate thermal conductivities over the range of service temperatures for the product.

The equation for $k_a(T)$ is:

$$k_a(T) = 3.005488E\text{-}02 + 1.279942\ E\text{-}04\ (T) + 5.119289\ E\text{-}10\ (T)^3$$

Using the equation for k_a (T) listed above, the smoothed thermal conductivities for the Fiberglass Pipe Insulation are given in Table 13. Figure 8 contains the graphical data.

Table 13. Apparent Thermal Conductivity of Test Specimen

Temperature (°C)	k_a (kcal/hr·m·K)	k_a (W/m·K)	C547 k_a (W/m·K)	Percent Difference
24.0	0.028	0.033	n/a	n/a
38.0	0.030	0.035	0.036	-2.86
93.0	0.036	0.042	0.045	-7.14
149.0	0.044	0.051	0.058	-13.7
204.0	0.052	0.061	0.074	-21.3
260.0	0.062	0.072	0.092	-27.8
316.0	0.075	0.087	n/a	n/a

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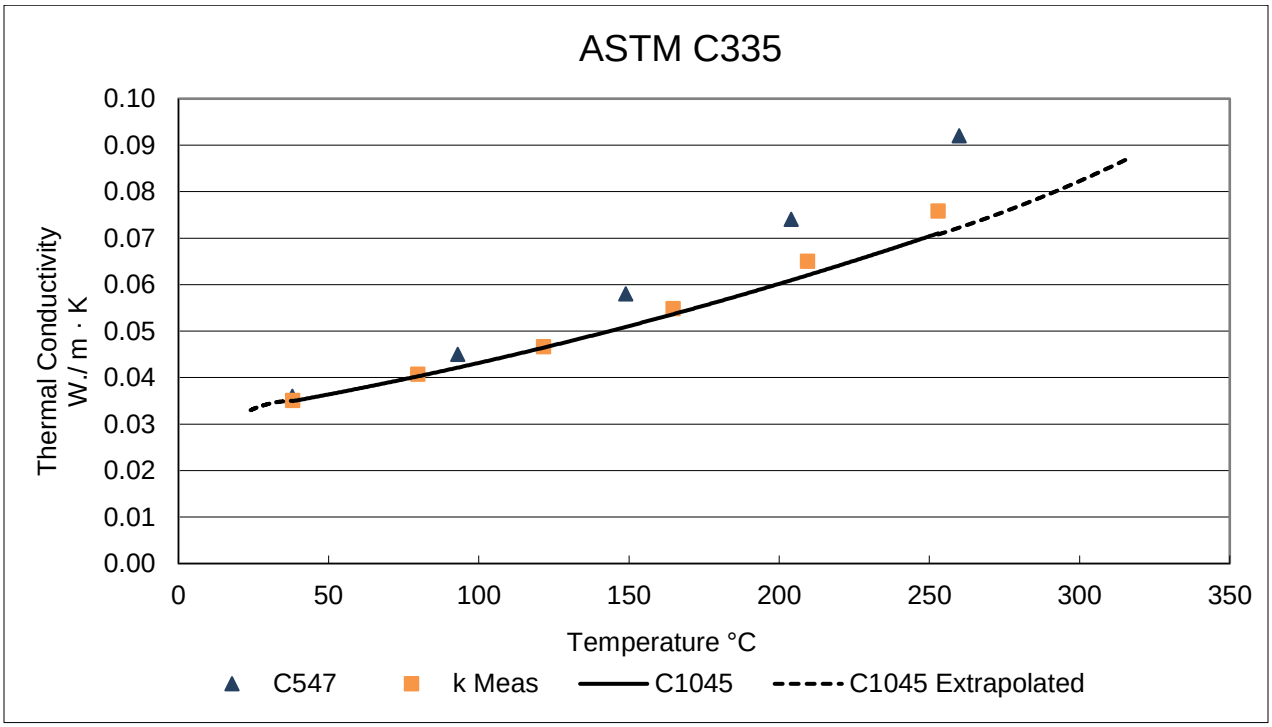

Figure 8. Apparent Thermal Conductivity

Summary

The Power-teK PS 450 Mineral Fiber Pipe Insulation manufactured by Knauf Insulation (Slovenia) meets the thermal conductivity requirements of ASTM C547, when tested according to ASTM C335 and ASTM C1045 at a surface temperature range of 38°C to 316°C for a Type I product.

The results in this report are limited to the material that was tested.