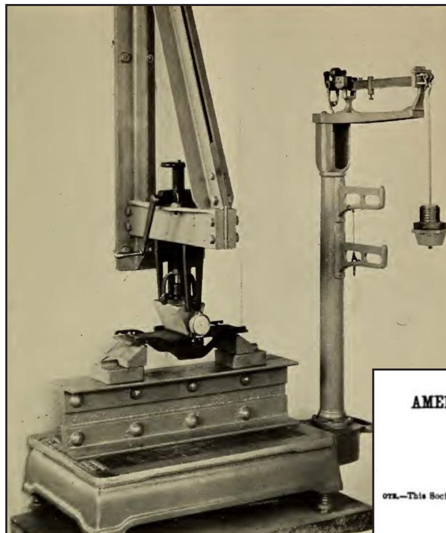
ORIGINS OF ASTM C406

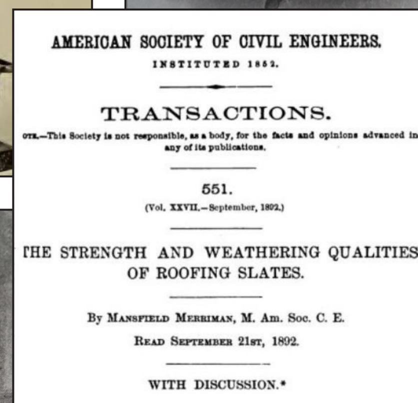
BY JEFFREY S. LEVINE
CHAIR, NSA STANDARDS COMMITTEE

A Commemorative Booklet

20th Anniversary/Centennial
Saratoga Springs Conference

National Slate Association
October 6-9, 2022
Saratoga Springs, New York





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INSTITUTED 1852.

TRANSACTIONS.

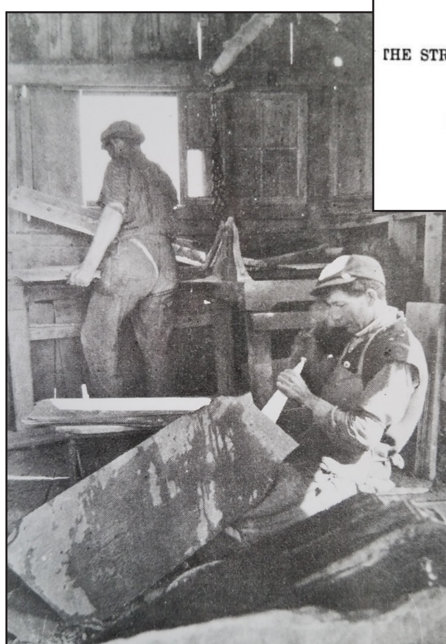
...ote.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

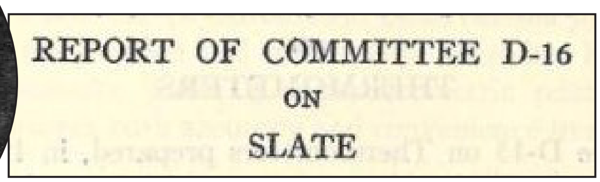
551.
(Vol. XXVII.—September, 1892.)

THE STRENGTH AND WEATHERING QUALITIES OF ROOFING SLATES.

By Mansfield Merriman, M. Am. Soc. C. E.
Read September 21st, 1892.

WITH DISCUSSION.*





REPORT OF COMMITTEE D-16
ON
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Hello and welcome to the 20th Anniversary conference of the National Slate Association. It has been 20 years since a group of quarriers, contractors, design professionals, and distributors met in Saratoga Springs, New York, with the idea of reviving a trade association that could represent the slate industry's interests, promote its products, and inspire high quality construction through the dissemination of technical literature, undertaking materials testing, supporting a contractor certification program, and organizing conferences like the one you are about to attend.

Anniversaries tend to be a time to look back at one's origins. As you may know, the National Slate Association was first organized in 1922. (Yes, we are also recognizing the centennial of the original founding of NSA!) And, while the paper written by Jeff Levine, a past President of NSA, focuses on the origins of a document critical to our industry, ASTM C406, it also touches on the broader history of the slate industry in the United States; its challenges, its people, and its scientific literature. We, therefore, present it to you as a booklet commemorating our gathering to celebrate both NSA's modern platinum anniversary and its centennial.

If nothing else, this Anniversary conference and Jeff's paper highlight one thing; the incredible dedication and hard work that members of our industry have contributed to make slate shingles the best roofing material on earth. Jeff wrote about Bowles, Boyd, Dale, Kessler, Merriman, Sligh and others, titans of our industry, all. In 2002, individuals you might recognize – Millen, Leeland, Papay, Large, Hicks, Smid, Hill, Markcrow, Stearns, Lerch, and at least two dozen others – lead the revitalization of the National Slate Association after too many years of dormancy. For all of you who have since contributed your time, your treasury, and your support – whether by serving on a committee, manning our booth at a conference, soliciting memberships, creating copy for our website, shooting ice balls at test panels, arguing over the definition of a "raggle," taking on a leadership position, or simply becoming a member – we are extremely grateful. You are what makes NSA great and what will ensure our success over the next 20 years. Let us, now, go forth and make our mark. Who knows, in a hundred years, some slate nerd with a penchant for writing might take pen in hand and author a paper about the current generation of slate roofing professionals.

NSA Board
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ORIGINS OF ASTM C406

By Jeffrey S. Levine, Chairman NSA Standards Committee

Introduction

ASTM C406, Standard Specification for Roofing Slate, classifies slates according to their physical characteristics as determined by three test methods: ASTM C120, Standard Test Methods of Flexural Testing of Slate; ASTM C121, Standard Test Method for Water Absorption of Slate; and, ASTM C217, Standard Test Method for Weather Resistance of Slate. Based on test results, slate used for roofing purposes is classified as either S_1, having an expected service life of over 75 years; S_2, service life of 40 to 75 years; or, S_3, service life of 20 to 40 years (Table 1). Service lives are stated to be dependent upon the slate roof's geographic location and environmental exposure. For purposes of the Standard, service life is defined as "a period of time over which the slate material is expected to require no repair or replacement due to weathering."[1]

Table 1: Classification of Roofing Slates, ASTM C406/C406M-15

CLASSIFICATION	ASTM C120 Breaking Load (min. lbs.)	ASTM C121 Absorption (max. %)	ASTM C217 Depth of Softening (max., in.)	Service Life (years)
S_1	575	0.25	0.002	over 75
S_2	575	0.36	0.008	40 to 75
S_3	575	0.45	0.014	20 to 40

ASTM C406 as we know it today was first issued in 1957 as a tentative standard, ASTM C406-57T, Tentative Specification for Roofing Slate. The ancestry of the test methods referenced within C406 date back even further, to the 1920s and 1940s, long after roofing slate production in the United States reached its peak, in 1902. Prior to the issuance of ASTM C406-57T, quarries graded their own material according to physical appearance - color, color permanence and uniformity, surface texture, flatness, squareness, thickness, and, in the case of the Pennsylvania Soft-Vein slates, whether they were clear or contained ribbons. Declining market share very likely inspired slate producers and distributors to standardize the description, sizes, and grading of roofing slate to help minimize waste, increase production efficiencies, and better take on the competition from other steep-slope roofing materials, such as clay tile, metal, and, especially, asphalt shingles. At the same time, the desire of the Federal government to have more defensible, standardized grading rules in effect as it moved to replace the aging roofs on Federal properties and erect new buildings during the Great Depression, thereby putting people to work, also helped to push the industry toward more precise measures of physical properties that could be used in the grading of slate shingles. In fact, the Federal Specification Board issued "Federal Specification for Slate; Roofing SS-S-451" in 1932, on the heels of a massive study on the physical properties and weathering characteristics of roofing slate undertaken by the National Bureau of Standards at the direction of D.W. Kessler and W.H. Sligh. SS-S-451 contained three standardized test methods - modulus of rupture, absorption, and acid resistance - and is understood to be the immediate predecessor to ASTM C406 and its allied standardized test methods. SS-S-451 built on the work of ASTM Committee D-16 on slate, which issued two tentative standards in 1925: ASTM D221-25T, Tentative Method of Test for Water Absorption of Slate and ASTM D222-25T, Tentative Methods of Flexural Testing of Slate, both of

Table 2: Chronological Summary of Slate Roofing Standards and Publications

DATE	ASTM INTERNATIONAL			OTHER INDIVIDUALS/ORGANIZATIONS
1892				Mansfield Merriman - ASCE, Transactions "The Strength and Weathering Qualities of Roofing Slates"
1894				Manfield Merriman - ASCE, Transactions "The Strength and Weathering Qualities of Roofing Slates"
1898	ASTM Organized			
1905				Merriman - Reported in Dale, *Slate in the United States*, 1914 "Tests of Certain Maine, New York, Pennsylvania, Vermont, and Virginia Slates"
1922				National Slate Association (NSA) Founded
1923	Oliver Bowels, ASTM Proceedings: "The Characteristics of Slate"			
1924	Committee D-16 on Slate Organized			Simplified Practice Recommendation (SPR) R14-24 - Bureau of Standards, "Roofing Slate"
1925	ASTM D222-25T Tentative Methods of Flexural Testing of Slate	ASTM D221-25T Tentative Method of Test for Water Absorption of Slate		
1926				NSA: *Slate Roofs* Published
1927	ASTM D222-27T Tentative Methods of Flexural Testing of Slate	ASTM D221-27T Tentative Method of Test for Water Absorption of Slate		
1931	ASTM D222-31 Standard Methods of Flexural Testing of Slate	ASTM D221-31 Standard Method of Test for Water Absorption of Slate		
1932				D.W. Kessler & W.H. Sligh - National Bureau of Standards "Physical Properties and Weathering Characteristics of Slate"
				Roofing SS-S-451 - Federal Specification Board "Federal Specification for Slate"
1938	Committee D-16 merged into Committee C-18 on Natural Building Stones			
1948	ASTM C120 Standard Methods of Flexural Testing of Slate	ASTM C121 Standard Method of Test for Water Absorption of Slate	ASTM C217-48T Tentative Method of Test for Durability of Slate for Roofing	
1957	ASTM C406-57T, Tentative Specification for Roofing Slate			
1958	ASTM C406-58, Standard Specification for Roofing Slate			

which were updated in 1927 and then adopted in 1931. See Table 2 for a chronological summary of standards and publications related to slate roofing.

The question of what makes for a good roofing slate or, more specifically, how to show that a specific roofing slate does or does not meet certain criteria, dates back centuries. Practically speaking, a good slate should be hard, but not so hard as to be brittle or to break during trimming or punching on the roof, and not so soft that nail holes will become enlarged, causing the slate to come loose over time. It should resist the deleterious actions of wet/dry cycling and atmospheric acids, and be able to withstand the various loads imposed upon it, such as those caused by wind, diurnal temperature changes, foot traffic, and hail impact. A good slate should also be tough enough to hold out against the stresses associated with the quarrying, fabrication, shipment, handling, and installation of the shingles.

The best test procedure for determining whether a slate has the aforementioned properties might be to install all of the different slates on a roof every year, then examine them periodically over their entire service lives. Such a test is not very practical, however. A better way was needed. The search for a test, or series of test procedures that could be sufficiently standardized, conducted using common equipment, and carried out at reasonable cost in a short time frame actually began in the late nineteenth century, with the work of Mansfield Merriman, a civil engineer.

From there the search snow-balled into thousands of tests caried out by numerous laboratories, looking into dozens of properties ranging from toughness, porosity, and absorption to hardness, density, and corrodibility. Chemical composition and microscopic analysis, although discussed widely in the scientific papers of the times, were ultimately deemed too expensive and not able to fully capture the sought-after physical characteristics of a "good" roofing slate.[2,3] And while such properties as sonorousness (the sound emitted while tapping the shingle with a hard object), cleavability, compressive strength, and the presence of clay as determined by breathing on a piece of slate and smelling it for an argillaceous odor received some attention, they appear to have quickly given way to more rigorous test methodologies.[4,5,6] Even as test results started to point toward a series of three tests that might suffice to define the necessary physical properties, even more testing was needed to refine the test procedures - how many samples are needed, what size should the samples be, should the edges be mechanically trimmed or cut with a saw, should the samples be pre-conditioned with regard to moisture content and, if so, at what temperature and for what duration, should the drying oven be vented or not, and how should the samples be dried after soaking?

Many involved with the quarrying, distribution, specifying, and installation of slate shingles today are curious about the origins of ASTM C406 and the test methods referenced therein. This paper is intended to examine C406's pedigree and recognize at least some of those who labored for years, decades in some cases, attempting to answer the question: what makes for a good roofing slate?

1892: Mansfield M. Merriman, "The Strength and Weathering Qualities of Roofing Slates"

Mansfield M. Merriman (1848-1925) spent the bulk of his professional career as a professor of civil engineering at Lehigh University in Bethlehem, Pennsylvania. A graduate of Yale University's Sheffield Scientific School, class of 1871, Merriman researched and published widely in the fields of hydraulics, bridges, strength of materials, and mathematics.

Merriman published some of the earliest test results on the physical properties of slate in the United States. In fact, his paper entitled The Strength and Weathering Qualities of Roofing Slates, which appeared in the September 1892 edition of the American Society of Civil Engineers' Transactions, although predating the organization of the American Society for Testing and Materials (ASTM) by six years, is where the evolution of ASTM C406 begins. Prior studies focused on the chemical composition of slate and microscopic analysis of thin sections taken of the stone. Francis J. Williams had published data in the August, 1884 edition of Van Nostrand's Magazine, but the results (see Table 3) were only for a single property (modulus of rupture) and not widely recognized. Merriman was interested in providing engineers and designers with test data, precise and easily obtained, that could be used to evaluate the physical properties of roofing slates, specifically those properties at the forefront of resisting the stresses to which the material is exposed during its fabrication, transport, installation, and service on a roof.

Merriman selected 24 specimens from nearby quarries for testing: 12 from the Albion Quarry, Pen Argyle, PA, largest in the Pen Argyle region, measuring 300 x 500 feet in area, by 250 feet deep at the time, and 12 from the Old Bangor Quarry, Bangor, PA, oldest in the Bangor region, having been opened in 1866. Specimens measured 12 in. x 24 in. x 3/16 to 1/4 in. thick. Six tests of the stones' physical properties were undertaken at Lehigh University's laboratories as follows. Test results are shown in Table 3.

Strength (Modulus of Rupture): A roofing slate's strength was believed to be important in preventing breakage during fabrication, shipping, and installation as well as after installation in resisting the stresses im posed by hail, foot traffic, wind loads, and freezing water around and under the shingles. The full size samples were supported on knife edges spaced 22 inches apart and the load applied via a third knife edge placed at the midpoint between supports. (Note that sample size and thickness, grain orientation, spacing of the supports, and whether to test before and/or after acid digestion are some of this test method's procedures that would receive intense scrutiny in later years as the industry moved toward development of an appropriate standard test method for modulus of rupture (MOR).)

Toughness (Deflection): Using the same test method as that used for measuring the slate's strength, Merriman used the slate's ultimate deflection under load as an indication of the slate's toughness, stating: "As the load was increased, the deflection of the slate could be observed upon a scale and the ultimate deflection was recorded. The greater the ultimate deflection of a bar, the less is its brittleness, and the greater its toughness."[7]

Porosity (Absorption): Low porosity might indicate a roofing slate's ability to resist deterioration caused by repeated freezing and thawing of

Table 3: Summary of Early Test Results on the Physical Properties of Roofing Slate[a]

			Strength	Toughness	Softness	Porosity	Corrodibility	Density	Weather Resistance
Date/Tester Color and Source	Number of Samples	Thickness (inches)	Modulus of Rupture (psi)	Ultimate Deflection (inches) on Supports 22" Apart	Amount Abraded by 50 Turns of a Grindstone (grams)[d]	Percent of Water Absorbed in 24 Hours	Percent of Weight Loss in 63 Hours in Acid Solution	Specific Gravity	Depth of Softening After 7 Days in Sufuric Acid Solution (inches)
1884: Francis J. Williams; as reported by Merriman, 1894									
Purple, quarry unknown, New York/Vermont District	Unknown	1	10,800						
Red, quarry unknown, New York/Vermont District	Unknown	1	7,310						
Green, quarry unknown, New York/Vermont District	Unknown	1	8,840						
1892: Merriman									
Dark Gray, Albion Quarry, Pen Argyl, PA	12	3/16 to 1/4	7,150	0.270	5.184	0.238	0.547	2.775	
Dark Gray, Old Bangor Quarry, Bangor, PA	12	3/16 to 1/4	9,810	0.312	8.294	0.145	0.446	2.780	
1894: Merriman									
Bluish Black, quarry unknown, Peach Bottom, PA	12	0.210 to 0.290	11,260	0.293	5.831	0.224	0.226	2.894	
1905: Merriman; as reported by Dale, Bulletin 275, 1906									
Dark Gray, Chapman Slate Co., Chapman Quarries, PA	4	0.204 to 0.228	9,460	0.212	0.208	0.231	0.383	2.764	
Dark Gray, Williams Slate Co., Arvonia, VA	4	0.195 to 0.263	9,040	0.227	0.060	0.143	0.394	2.781	
Dark Gray, A.L. Pitts, Arvonia, VA	4	0.194 to 0.232	9,850	0.225	0.108	0.216	0.323	2.791	
Dark Gray, Merrill Brownville Slate Co., Brownville, ME	3	0.195 to 0.220	9,880	0.200	0.265	0.148	0.305	2.798	
Dark Gray, Monson Consolidated Slate Co., Monson, ME	4	0.225 to 0.238	9,130	0.205	0.256	0.188	0.286	2.794	
Green, Vermont Unfading Green Slate Co., Fair Haven, VT	2	0.222 to 0.262	6,410	0.225	0.341	0.231	0.295	2.771	
Green, Rising & Nelson Slate Co., West Pawlet, VT	4	0.167 to 0.260	7,250	0.207	0.190	0.325	0.768	2.736	
Green, Mathews Consolidated Slate Co., Boston, MA[b]	4	0.187 to 0.222	8,050	0.190	0.226	0.374	0.379	2.783	
Red, Mathews Consolidated Slate Co., Boston, MA[b]	4	0.174 to 0.190	9,220	0.232	0.148	0.243	0.373	2.848	
1927: ASTM Committee D-16 on Slate			Across the Grain						
North Bangor Slate Co. & Amalgamated Slate Quarries Co; Bangor District, PA	6	3/8	13,200			0.20			
Jackson Bangor Slate Co. & Structural Slate Co.; Pen Argyl District, PA	6	3/8	12,200			0.15			
Amalgamated Slate Quarries Co. & Strucutral Slate Co.; Slating District, PA	6	3/8	13,700			0.37			
Blue Ridge Slate Co., Esmont, VA	6	3/8	8,900			0.13			
Sea Green from Vermont, Norton Brothers, Granville, NY	6	3/8	6,800			0.13			
1932: Kessler and Sligh[c]				3/16" Slate on Supports 16" Apart					
Blue Black, ME	21	1/8 to 3/16	11,700	0.178		0.05			0.002
Green, Gray, Red, Purple, and Black, VT-NY	68	1/8 to 3/16	10,600	0.163		0.13			0.001
Quarry Run, Hard-Vein, PA	73	1/8 to 3/16	13,600	0.204		0.16			0.003
Dark Gray, Clear and Ribbon, Bangor, PA	156	1/8 to 3/16	12,500	0.205		0.28			0.014
Deep Bed, Gray Bed, Albion, Clear and Ribbon, Pen Argyl, PA	431	1/8 to 3/16	11,500	0.205		0.30			0.006
Gray, Clear and Ribbon, Wind Gap, PA	21	1/8 to 3/16	10,900	0.196		0.38			0.010
Gray, Slatington, PA	35	1/8 to 3/16	11,800	0.197		0.29			0.009
Blue Black, Greenish Gray, Arvonia, Ore Bank, & Esmont, VA	62	1/8 to 3/16	10,500	0.164		0.06			0.000
Blue Black, Purple, Green, MD	6	1/8 to 3/16	11,400	0.135		0.21			0.002
Green, TN	2	1/8 to 3/16	9,200	0.169		0.10			0.001
Green, GA	3	1/8 to 3/16	11,000	0.126		0.57			0.001
Black, Green, Red, AR	20	1/8 to 3/16	7,110	0.137		0.66			0.002

[a]Mean values for the number of samples indicated. [b]Quarried in Granville, New York.
[c]Number of samples given is for the MOR test. [d]1905 test results for softness cannot be compared to those from 1892 and 1894 because the grindstone used in the earlier testing was destroyed by fire and the replacement had less abrading capacity.

rainwater absorbed by the slate. (Note that Kessler and Sligh would later show wet/dry cycling to be a far more important factor than freeze/thaw cycling in the degradation of slate.) Merriman cut a 3 in. x 4 in. piece of roofing slate with rough edges from each of the 24 specimens. The test procedure consisted of drying the samples in an oven at 135º Fahrenheit (F) for 24 hours, cooling to room temp, weighing the samples, immersing the samples in water for 24 hours, then weighing the samples again. The difference between the dry weight and wet weight, divided by the dry weight, yielded the percentage of water absorbed by a specimen. (Note that sample size, edge condition, drying temperature, method of dabbing the samples dry upon removal from the soaking bath, type of oven (ventilating or not), are some of this test method's procedures that would be examined carefully in later years as the industry moved toward development of an appropriate standard test method for absorption.)

Specific Gravity (Density): Density was investigated on the theory that greater density might contribute to greater strength. Merriman determined the specific gravity of the specimens by weighing them in air, weighing them in water and then applying the following formula:

SG = A/(A-W), where
SG is the specific gravity (a dimensionless quantity that has no units)
A is the weight of the specimen in air, measured in pounds
W is the weight of the specimen in water, measured in pounds[8]

Hardness/Softness (Abrasion): Greater or less hardness might be beneficial depending on its contribution to a slate's density and brittleness. Merriman measured the relative hardness of the slate specimens by subjecting samples of known weight to abrasion by 50 revolutions of a grindstone under a constant pressure of 10 pounds. The loss in weight was then calculated. The greater the abrasion, the softer the slate and vice versa.

Corrodibility: Subjecting slates to immersion in acid solutions was seen as a possible indicator of its susceptibility to deterioration stemming from the chemical action of atmospheric pollutants. The test method consisted of immersing 3 in. x 4 in. pieces of slate in a solution of 98 parts water, 1 part hydrochloric acid, and 1 part sulfuric acid for 63 hours to imitate the action of atmospheric smoke and sulfurous fumes from industrial sites, the samples having first been weighed. After being taken out of the solution, the specimens were allowed to dry for 2 hours, then re-weighed. The results were converted to percentage weight loss by dividing the difference between the weight of the original specimen and the soaked specimen by the weight of the original specimen, thereby giving a measure of the acid digestion or "corrosion."

After analyzing the test results, Merriman defined the relationship among the properties tested, thus: "The strongest slate being [also] the toughest and softest, [and] also the least porous and corrodible."[9] He went on to conclude that "the test for transverse strength is the one which is the most satisfactory for roofing slates, if only one test is to be made."[10] Merriman, thereby, sets the precedent for use of the MOR test. Justifying this conclusion, Merriman points to the simplicity of the test and the fact that it does not rely on the size of the specimen. Of course, what Merriman could not have recognized at the time was that the MOR test would essentially be perceived as penalizing quarries whose standard run of production was thicker than 3/16 in. to 1/4 in., since thickness is in the denominator of the formula for determining a specimen's MOR. This came to a head in the early twenty-first century, when the ASTM standard for testing the strength of roofing slates was changed from MOR to the simpler breaking load, it having been acknowledged that the bulk of roofing slate production had shifted from the Pennsylvania Soft-Vein District to the New York/Vermont District and with it a thickness increase in the quarry run of production from 3/16-1/4 in. to 1/4-3/8 in.

While recognizing the limitations associated with a small sample size, Merriman foretells the creation of a future standardized test method for roofing slate by making the follow ing recommendations:

• Architects and engineers who write specifications for roofing slate will probably obtain a more satisfactory quality if they insert requirements for a flexural [strength/MOR] test to be made on several specimens picked random out of each lot.[11]

• It is suggested that such specifications should require roofing slates to have a modulus of rupture, as determined by the flexural test, greater than 7,000 pounds per square inch.[12]

1894: Mansfield M. Merriman, "The Strength and Weathering Qualities of Roofing Slates"

In 1894, Merriman published a second paper in ASCE Transactions, under the same title as the first, providing test data for an additional 12 specimens taken from the Peach Bottom District of Pennsylvania/Maryland. Using the same test methods as those outlined in his 1892 analysis of Pennsylvania Soft-Vein District slates, this second round of testing largely confirmed the first, with several exceptions, uncovered by the testing of slates from different geographic regions:

• Merriman now places a bit more emphasis on the corrodibility results: "The tests for strength and corrodibility are probably those of greatest importance in forming an opinion regarding the value of the slate under actual conditions of service.[13]
• Recognizing that the varying condition of the grindstone can affect the results, the efficacy of the softness test is downgraded.
• Comparing the test results of both his 1892 and 1894 studies (see Table 3), Merriman concludes:

> The tests for density and softness, although of importance for slates of the same locality, are not good indications of the strength and weathering qualities of those of different regions; that the tests for porosity, corrodibility and flexural strength give good indications of these properties; that the results found for strength and corrodibility when mentally combined give on the whole an excellent idea of the value of the slate.[14]

In actuality, in addition to the tests for flexural strength (MOR) and porosity (absorption), it will eventually be the tests for corrodibility and softness that, in essence, get combined to form the depth of softening test referenced within ASTM C406.

The importance of Merriman's 1892 and 1894 test results can be gauged by the fact that they are re-published numerous times in forthcoming years in various publications, including The Mineral Industry (1898)[15], the Nineteen Annual Report of the United States Geological Survey (1898),[16] T. Nelson Dale's Slate Deposits and Slate Industry of the United States (1906)[17], and Dale's Slate in the United States (1914).[18]

In 1905, Merriman, once again, expands the reach of his physical testing of roofing slates, this time on a total of 33 specimens taken from nine quarries located in the Maine, New York, Vermont, Pennsylvania, and Virginia slate districts. The specimens, all measuring 24 in. x 12 in. and from 3/16 in. to 1/4-in. in thickness, were tested in substantially the same manner in which his 1892 and 1894 tests were conducted. As before the tests were conducted at Lehigh University, now under the aegis of the United States Geological Survey. Test results are given in Table 3.

So compelling were Merriman's physical test data that independent quarries began to undertake their own testing and promote the results in their marketing literature, this despite the fact that no consensus industry standard yet existed for any type of test method, to say nothing about what the test results might mean with regard to the quality of the slate proffered for sale. The Genuine Bangor Slate Company, Inc., Easton, PA, for example, was one of about eight entities advertising in the 1909 edition of *Sweet's Catalogue* (Figure 1). It reported its MOR as 9,000 to 10,000 pounds per square inch (psi), its toughness or ultimate deflection as 0.270 in. to 0.313 in., and its absorption as 0.099 to 0.303 percent, concluding that: "Thus it will be seen that Genuine Bangor Slate is one of the densest and strongest stones in transverse strength, elasticity and non-absorption."[19] In another advertisement, the Peach Bottom Slate Producers (a conglomerate of nine quarries) got together to reproduce data from T. Nelson Dale's 1906 publication, Bulletin 275, "Slate Deposits and Slate Industry of the United States," reporting a MOR of 11,260 psi and a toughness (ultimate deflection) of 0.93 in.[20] The latter result is most surely a typographical error in Dale's work as such a deflection is far out of range from anything reported before or since. In fact, Dale cites Merriman as the source of the data and Merriman's value, as published in the 1894 ASCE Transactions, is 0.293 in. (see Table 3).

1914: T. Nelson Dale, "Slate in the United States"

Thomas Nelson Dale (1845-1937), born in New York, New York and educated in mineralogy at the University of Cambridge in Great Britain and in petrography at Harvard University, taught natural sciences at Drury and Vassar Colleges starting in c.1878 (Figure 2). Dale was hired as a geologist by the United States Geological Survey (USGS) in 1880, a position he held for 40 years, while also serving as a professor of geology and botany at Williams College from 1893 to 1901.[21] Dale's work with the USGS focused on the Taconic and Green Mountain ranges

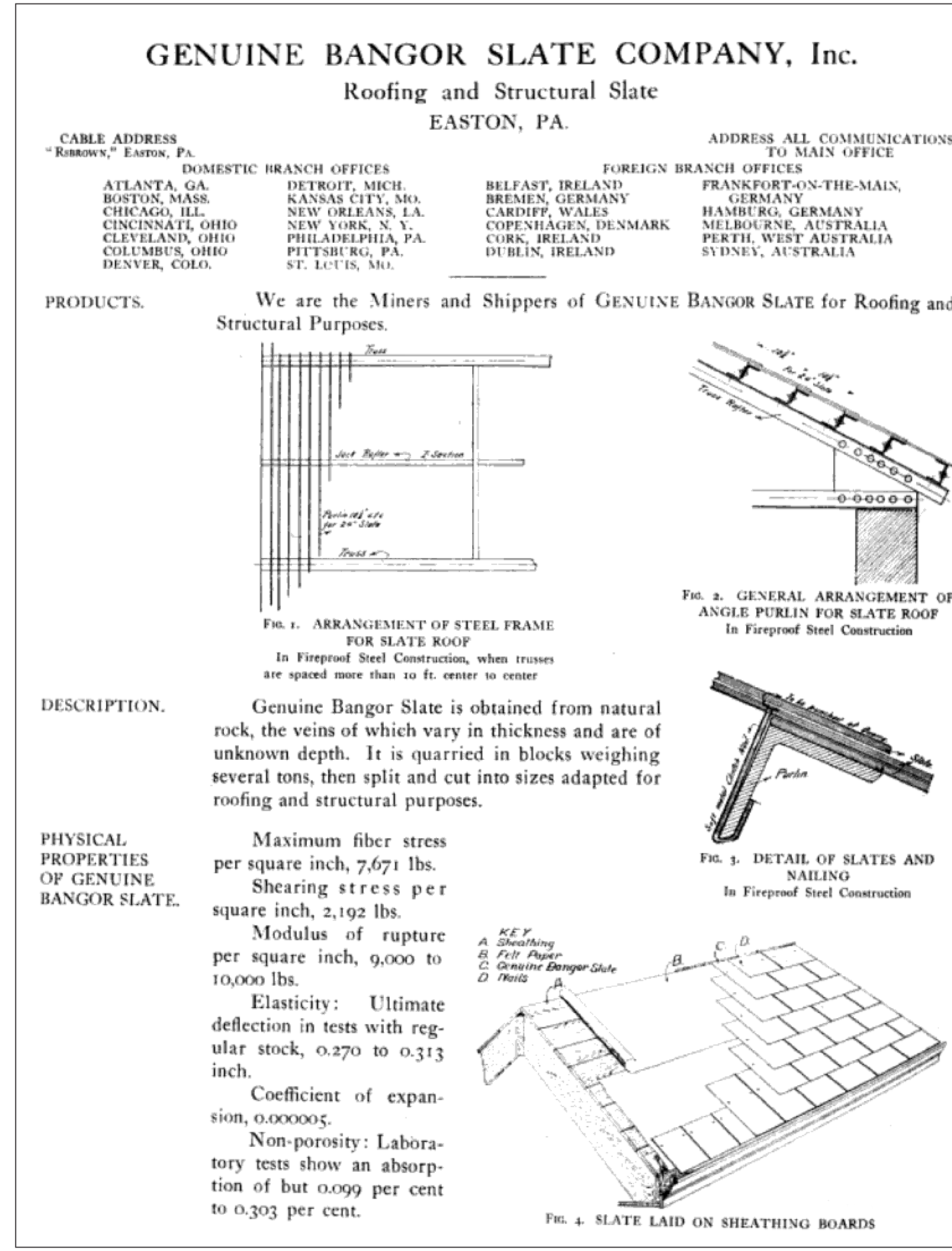
Figure 2: T. Nelson Dale at work. (Source: Dale, T. Nelson, *Outcomes of the Life of a Geologist: An Autobiography,* New Haven, CT: Connecticut Academy of Arts & Sciences, 2009, cover.)

of western New England, the mapping and characterization of which involved some 12,000 miles of walking in remote regions and resulted in several reports for which Dale was the primary author, among them those on "The Chief Commercial Granites of Massachusetts, New Hampshire, and Rhode Island" (USGS Bulletin 354, published in 1908), "The Granites of Vermont" (Bulletin 404, published in 1909), and "The Commercial Marbles of Western-Vermont (Bulletin 521, published in 1912). The exploits of Dale's life, which spanned the eras of the Civil War, Reconstruction, and the Gilded Age, are captured in his last work, *The Outcomes of the Life of a Geologist: An Autobiography*, published posthumously in 2009.[22]

In 1914, Dale published his seminal work on the slate industry, USGS Bulletin 586, "Slate in the United States."[23] In it he describes 18 test methods that have the potential to help characterize the physical properties of slate for economic purposes, ranging from strength, toughness, and absorption to electrical resistance, sonorousness, cleavability, and microscopic analysis. Dale had the following to say about the test methods that would eventually be referenced in ASTM C406:

- Strength (MOR): Referring to Merriman's test results, presumably from 1892, 1894, and 1905, Dale states "According to these tests the modulus of rupture in the best slate should range from 7,000 to 10,000 pounds [per square inch]."[24] It is noted that the later 9,000 psi requirement contained in ASTM C120 falls within this range.
- Porosity (Absorption): After citing Merriman's results, Dale goes on to describe three other test methods, one simpler and two more complex than Merriman's. The simpler test involves placing a slate shingle edgewise in water and observing how far the water rises by capillary action. No quantifiable data is given. Rather it is noted that "In good slates it [the water] ought to rise but very little." The two more complex absorption tests attempt to take into account the affect of chemical degradation and hot/cold cycling on the absorption of slate, the former, by Reverdin and De la Harpe, involving acids, an oil bath, creating a vacuum, and no less than 24 cycles of heating and cooling, and the latter, by Fresenius, involving freezing for 24 hours, heating to exceedingly high temperatures of 250 to 350 degrees Fahrenheit for 5 to 6 hours, then immersing in water, drying, and weighing.[26]

Dale concludes his summary of the 18 test methods by stating that "The most decisive of all these tests are probably those for strength and toughness, as applied by Merriman, and the microscopic analysis."[27] Influential as Dale was at the time, his insight would come to be overruled by future research on the most relevant, practical, and repeatable methods for testing the physical properties of roofing slate.



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Roofing and Structural Slate

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PRODUCTS. We are the Miners and Shippers of GENUINE BANGOR SLATE for Roofing and Structural Purposes.

FIG. 1. ARRANGEMENT OF STEEL FRAME FOR SLATE ROOF
In Fireproof Steel Construction, when trusses are spaced more than 10 ft. center to center

FIG. 2. GENERAL ARRANGEMENT OF ANGLE PURLIN FOR SLATE ROOF
In Fireproof Steel Construction

DESCRIPTION. Genuine Bangor Slate is obtained from natural rock, the veins of which vary in thickness and are of unknown depth. It is quarried in blocks weighing several tons, then split and cut into sizes adapted for roofing and structural purposes.

FIG. 3. DETAIL OF SLATES AND NAILING
In Fireproof Steel Construction

PHYSICAL PROPERTIES OF GENUINE BANGOR SLATE.

Maximum fiber stress per square inch, 7,671 lbs.

Shearing stress per square inch, 2,192 lbs.

Modulus of rupture per square inch, 9,000 to 10,000 lbs.

Elasticity: Ultimate deflection in tests with regular stock, 0.270 to 0.313 inch.

Coefficient of expansion, 0.000005.

Non-porosity: Laboratory tests show an absorption of but 0.099 per cent to 0.303 per cent.

KEY
A. Sheathing
B. Felt Paper
C. Genuine Bangor Slate
D. Nails

FIG. 4. SLATE LAID ON SHEATHING BOARDS

Figure 1: 1909 advertisement for the Genuine Bangor Slate Company listing the physical properties of Genuine Bangor Slate. (Source: *Sweet's Indexed Catalogue of Building Construction for the Year 1909,* New York: The Architectural Record Co., 1909, p.412.)

1923: Oliver Bowles, "The Characteristics of Slate"

While facing increasing competition from other steep-slope roofing products in the 1920s, most notably asphalt shingles, Oliver Bowles, called-out the slate industry as contributing to its own misfortune via the use of disreputable practices and lack of attention to the end use of its product. Oliver Bowles (1877-1958), a geologist and mineral engineer who worked for the U.S. Bureau of Mines for 44 years, becoming Chief of its Nonmetal Division in 1942, was an authority on asbestos, building stone, and other non-metallic mineral commodities. Born in northern Ontario, Canada, Bowles received his bachelors and master's degrees from the University of Toronto and his PhD from George Washington University (Figure 3). In the slate industry Bowles is perhaps best known for Bulletin 218, "The Technology of Slate," published by the U.S. Bureau of Mines in 1922[28] and which was also Bowles' doctoral thesis, and for introducing the wire saw into the slate quarries, which saved the industry $250,000 annually by speeding up production and reducing waste.[29] In his "Characteristics of Slate," published in 1923, Bowles recognizes the need for industry standards to address the long-held nefarious practices of producers, including those relating to the following:

- Thickness: There was an incl ination at the time to split slate shingles as thin as possible so as to maximize production from each block raised out of the quarry. Unfortunately, this lead to excessive breakage during transit to the job site and installation on the roof, thereby sullying the reputation of slate. Recognizing that thickness is a factor in determining the strength of slate, but that standardized test data was not yet available for the various slate regions, Bowles advocated for a minimum shingle thickness that "would cover all slates of reasonable quality. . . It is generally regarded that 3/16 in. should be the minimum thickness allowed, and if this were established as a standard it is highly probable that greater satisfaction would exist among consumers, and that the reputation of slate would thereby be enhanced."[30]
- Color Stability: Bowles noted that consumers were confused by misleading trade names: "It is unfortunate that some of the trade names applied to slates mask the permeance of their colors."[31] Bowles proposed that standard terms be used to clearly distinguish fading from unfading material.
- Endurance: To enhance their product's appeal to architects, some producers offered what was sometimes referred to as "golden pheasant" slate, an attractive mix of variegated, highly colorful, thick slates. Unfortunately, the vibrant colors were due to the surface leaching of iron contained in the overlying soil and/or weathering/disintegration of the slate itself. Interesting as this slate may have been, Bowles fretted for the reputation of the product and the producers, and called for definitive testing standards to help protect both users and the quarries.

Figure 3: Oliver Bowles as a young man. (Source: Parson, A.B., Ed., *Seventy-Five years of Progress in the Mineral Industry,* 1871-1946. New York: The American Institute of Mining and Metallurgical Engineers, 1947, p.303.)

- Installation: At the same time slate shingle producers were taking liberties with the thickness and color stability of its materials and hawking "toppy slate" (weathered slate taken from too close to the surface), installers were shortchanging customers by "cheating the headlap," that is, employing a 2-in. headlap where a 3-in. headlap was called for, in order to make a square of purchased slate cover more than 100 square feet on the roof. Bowles advocated that "a 3-in. headlap should be the universal standard," but also advocated for standards with regards to the type of nail used to install the slate shingles, spacing of framing members, the nature of the roof decking employed, as well as the use of underlayment beneath the slate.[32]

Interestingly, each of the above issues would be addressed by the National Slate Association and its forthcoming manual, *Slate Roofs*, and, ultimately, as part of ASTM C406.

1922: National Slate Association Organized

Roofing slate production in the U.S. peaked during the period from 1897 to 1914. The Highest production occurred in 1902, with 1,435,168 squares sold. In 1915, output fell below 1 million squares and by the end of the decade would fall even further, to 396,230 squares.[33] While World War I contributed to the decline in sales, it was clearly time to get organized. The National Slate Association (NSA) was founded in 1922 with the stated goals of promoting the general interests of the industry, extending markets through advertising, obtaining favorable freight rates, and encouraging research.[34] Rather than each quarry offering its own sizes and grading its own output based on physical appearance, it was time to standardize the industry's offerings, improve methods of production, and develop reliable standards on which design professionals could rely. To these ends, the NSA had, by 1924, published standardized sizes, thickness, and pieces per square through the U.S. Bureau of Standards based on agreement among manufacturers, suppliers, and users of roofing slate. Quarries started to adopt labor saving equipment, no doubt with encouragement from Bowles, converting foot-treadle powered trimmers to electrical trimmers, removing waste via conveyor belts rather than manual hauling, and sawing across the grain of the blocks taken out of the quarries. Between 1922 and 1926, Bowles reported an improvement for a splitter and trimmer team from seven to eight squares per day to 10 to 15 squares.[35] Regarding research, NSA was instrumental, in 1924, in the formation of the American Society for Testing and Materials' Committee D-16 on Slate, later to be merged into Committee C-18 on Natural Building Stones, the purpose of which was "to accumulate all necessary fundamental data as a basis for the establishment of slate standards, including the material's physical properties."[36]

NSA's seminal work at the time, *Slate Roofs*, published in 1926, was a comprehensive manual for roof designers and installers meant, if not explicitly, to address some of the criticisms aimed at the industry by Bowles in 1923. Included in its content is information on the characteristics and geology of the various domestic roofing slates, the installation of slate shingles and flashings, roof construction and construction details, and even standard specifications for uniform, textural, and graduated roofs for use by architects and specifiers "on any type of structure from the smallest bungalow to the largest mansion."[37]

Among the information in *Slate Roofs* that would appear some 31 years later in the first, tentative version of ASTM C406 (C406-57T), albeit in somewhat different language and with somewhat different requirements, is the following:

- Corners: "Reasonably full corners on exposed ends with no broken corners on covered ends that would sacrifice nailing strength or the laying of a water tight slate roof."[38]
- Curvature: "The maximum bend shall not exceed 1/4" in lengths up to 16", nor exceed 3/8" in lengths from 16" to 24"."[39]
- Texture: "Shall be free from knots or knurls that in any way interfere with the safe conveyance or laying of the slate on the roof."[40]
- Nail Holes: "No slate shall have less than two nail holes. The standard practice is to machine punch two holes in all architectural roofing slate 1/4" and thicker at the quarry and also commercial standard slate when so ordered. . . Holes are punched from one-quarter to one-third the length of the slate from the upper end, and 1-1/4" to 2" from the edge."[41]

The equivalent language found in ASTM C406-57T is as follows:

- Corners: "The slates shall be rectangular with reasonably full corners. . . Broken corners on the exposed ends of shingles may be considered cause for rejection when either the base or leg of the right triangular piece broken off is greater than 1-1/2 in."

- Curvature: "The curvature of shingles shall not exceed 1/8 in. in 12 in."
- Texture: Knots and Knurls "are not objectionable on the exposed portion of the top face but on other parts they may prevent as close contact of shingles as desired. Shingles having knots and knurls on the lower face or covered portions may be rejected if the protuberances project more than 1/16 in. beyond the split surface."
- Nail Holes: "Slate shingles for sloping roofs shall be machine punched or drilled for two nails properly located for 3 in. head lap."

1924: "Roofing Slate," Simplified Practice Recommendation R14-24

The Division of Simplified Practice was established within the Department of Commerce by then Secretary Herbert Hoover to assist American industries in reducing waste resulting from "unnecessary variety in shape, size, classification, or any other characteristic or process connected with the product."[42] In so doing, the program's overarching aim was to stabilize businesses, conserve natural resources, extend national commerce, and provide better service at less cost. By the time the second edition of Simplified Practice Recommendation R14 was published in 1928 (SPR R14-28), roofing slate was one of 90 SPRs, ranging from metal lath (No. 3), to paper grocer's bags (No. 42), to vitreous china plumbing fixtures (No. 52), to hack saw blades (No. 90).

The process began in 1923, when the slate industry developed simplification recommendations covering the sizes and nomenclature of roofing slate and then submitted them at the annual meeting of the National Slate Association held in New York, New York in January 1924. At the last day's session, held under the auspices of the Division of Simplified Practice, it was resolved to reduce the number of standard sizes of roofing slate from 60 down to 30, reduce the number of thicknesses from 21 to 10, and reduce the number of descriptive terms from 17 to eight. Those in attendance at the annual conference included many who would become key players in the development of the ASTM standardized test methods for slate and, hence, ASTM C406, including D. Knickerbacker Boyd, Structural Service Bureau, Philadelphia, PA, Oliver Bowles, U.S. Bureau of Mines, D. W. Kessler, U.S. Bureau of Standards, and W. S. Hays, Secretary, National Slate Association, Philadelphia, Pennsylvania. Also in attendance were numerous quarry and distributor representatives (e.g., Henry Chapman, Chapman Slate Co., Chapman Quarries, Pennsylvania, William L. Doney, Diamond Slate Co., Pen Argyl, Pennsylvania, E. J. Johnson, Knickerbocker Slate Corp, New York, New York, W. A. Le Sueur, The Le Sueur Slate Co., Ore Bank, Virginia, and O. B. Pyle, Monson-Maine Slate Co., Boston, Massachusetts) and scores of roofing contractors, 82 in all.

Interestingly, the standardized size and nomenclature information contained within SPR R14, as originally published in 1924, appear in their exact same form in the NSA's *Slate Roofs*, published in 1926 and is referenced as such. Table 1, Dimensions of Slate Shingles for Sloping Roofs, from SPR R14-28 is reproduced below in Figure 4. With regard to color nomenclature, R14 stated the following:

> It is recommended that the following color nomenclature be used by architects, contractors, engineers, and others in their specifications.

Black	Green
Blue Black	Red
Gray	Mottled Purple and Green
Blue Gray	Purple Variegated[43]
Purple	

Other information contained in SPR R14 that transferred directly into *Slate Roofs* included "Sizes of Slate for Miscellaneous Purposes" (e.g., short lengths for use on pent, porch, and dormer roofs, and the use of random width slates to help minimize waste within the industry), "Dimension Nomenclature" (the introduction of the term "Commercial Standard Thickness" as the quarry run of production allowing for tolerable variations above or below 3/16 in. thick), and "A Square of Roofing Slate" (codifying the meaning as a sufficient number of slate shingles of any size to cover 100 square feet of roof area when laid with a three inch headlap).

SPR R14's standard sizes and colors for roofing slates will, in fact, endure for some time. They next appear in the "Federal Specification for Slate; Roofing SS-S-451," first published in July, 1932, and then again in the very first version of ASTM C406 issued in 1957 (C406-57T) in substantially the same form.

TABLE 1.—*Dimensions of slate shingles for sloping roofs; minimum to a square*

[Each size split[1] to thickness of 3/16, 1/4, 3/8, 1/2, 3/4, 1, 1 1/4, 1 1/2, 1 3/4, and 2 inches[2]]

Face dimensions,[3] in inches	Minimum number to square (3-inch lap)	Face dimensions,[3] in inches	Minimum number to square (3-inch lap)	Face dimensions,[3] in inches	Minimum number to square (3-inch lap)
10 by 6	686	14 by 9	290	18 by 12	160
10 by 7	588	14 by 10	261	20 by 10	169
10 by 8	515	14 by 12	218	20 by 11	154
12 by 6	533	16 by 8	277	20 by 12	141
12 by 7	457	16 by 9	246	20 by 14	121
12 by 8	400	16 by 10	221	22 by 11	138
12 by 9	355	16 by 12	185	22 by 12	126
12 by 10	320	18 by 9	213	22 by 14	109
14 by 7	374	18 by 10	192	24 by 12	115
14 by 8	327	18 by 11	175	24 by 14	98

[1] The art of splitting slate blocks consists in progressively reducing resultant halves until the desired roofing slate thickness has been reached or approximated. This hand-wrought characteristic appeals to architects and owners. It is not a simple matter to precisely control the splitting of this natural rock, nor can a uniformity of thickness throughout be assured. The recommended range of thicknesses to be aimed at by operative splitters will meet all normal requirements and will insure the maximum of economy in the utilization of the many sizes of quarried blocks.

[2] It is customary to regard a thickness falling between two standard thicknesses as a "special," and it is the practice to base the price of the "special" upon the greater of the two standard thicknesses.

[3] For thicknesses one-half inch and more, it is not generally considered practicable to use lengths that are less than 16 inches, although for roofs of special treatment it may be done in small quantities. In carrying out a desired design on special roofs, it is sometimes necessary to make shingles longer than 24 inches, in which case the thicker slates are used.

Figure 4: Standard sizes and thicknesses of roofing slate shingles as presented in Simplified Practice Recommendation R14-28. This same table appears in the National Slate Association's *Slate Roofs*, published in 1926 and, in a somewhat different format, in ASTM C406-57T, Tentative Specification for Roofing Slate, issued in 1957.

1924-1931: Report of ASTM Committee D-16 on Slate

While Dale and others reported on the results of slate testing that took place during the late 19th and early 20th centuries, not much further testing would take place for some time. The industry was in no hurry. Slate sales were booming. More than 25 million squares of roofing slate were sold between 1892 (the year of Merriman's first tests) and 1914, the first year of World War I. In fact, nearly a quarter century would elapse before any further testing on the physical properties of roofing slate would be performed.

ASTM's Committee D-16 on Slate was first organized in January, 1924, with 14 members, D.W. Kessler as Chairman, and D. Knickerbacker Boyd as Secretary. Not much is known about Kessler, other than that he was a geologist at the National Bureau of Standards in Washington, D.C. and, along with his colleague W.H. Sligh, published widely on the physical properties of slate and other building stones. D. Knickerbacker Boyd (1872-1944) was a prominent architect practicing primarily in Philadelphia and New York (Figure 5). Over the span of 50 years Boyd was responsible for the design of thousands of residential, industrial, office, ecclesiastical, and library buildings, first in association

Figure 5: D. Knickerbacker Boyd, c.1913. (Source: "Who's Who Among The Architects," *The Philadelphia Real Estate Record and Builder's Guide*, V. 28, No. 9, February 26, 1913, p. 140; *The Philadelphia Real Estate Record and Builder's Guide*, George E. Thomas Collection, The Athenaeum of Philadelphia.)

with his brother Laurence, under the name Boyd & Boyd, and later as a sole practitioner and partner with Victor Abel and Francis Gugert, under the name Boyd, Abel, & Gugert. Outside of his practice, Boyd's influence on the architectural profession was strongly felt by his stalwart involvement in numerous community action groups and professional organizations, including the Philadelphia Fire Prevention Commission, the War and Industries Board in Washington, D.C., the American Institute of Architects, and, of course, the National Slate Association, to name but a few.[44] Boyd was elected a fellow in the American Institute of Architects in 1906.

During the period from 1924 to 1931, Committee D-16 on Slate focused much of its attention first on the testing necessary for issuing the two, original, tentative ASTM standards for testing of the physical properties of slate; ASTM D221-25T (Tentative Method of Test for Water Absorption of Slate; precursor to ASTM C121) and ASTM D222-25T (Tentative Methods of Flexural Testing of Slate; precursor to ASTM C120) and later on modifying and improving these tentative methods of tests, which resulted in the publication of a second set of tentative standards (D221-27T and D222-27T), as well as corresponding, official standards adopted in September, 1931 (D221-31 and D222-31). The latter work, carried out by Sub-Committee I on Methods of Testing (Chaired by Kessler), involved comparative testing (testing the same material by the same methods) carried out by Committee members at three university laboratories (R.J. Fogg and M.O. Fuller, Lehigh University; W.B. Plank and Charles W. MacDougal, Lafayette College; and T.R. Lawson, Rensselaer Polytechnic Institute), plus those of Kessler and Sligh at the Bureau of Standards. The Sub-Committee found wide variations in the results reported by the labs, especially for the absorption test, where the average variation was reported to be almost 30 percent. Issues identified/conclusions reached with regard to the initial tentative standards (D221-25T and D222-25T) included:

- Thin slabs were the best shape for the absorption test, rather than cylinders or cubes such as used for other types of stone
- The need existed for greater precision in weighing the specimens due to the very low absorption rates
- A rubbed (smooth), or natural cleft surface was best for the absorption test
- Thinner specimens might be better for the modulus of elasticity (MOE) test, rather than relatively thick slabs, as the deflection would be larger and easier to measure
- Sample preparation was an issue for both the absorption and MOR tests; surface irregularities were leading to difficulty in consistently measuring the thickness of specimens and rocking on the knife edges used in the MOR test; at the same time, fractured edges were thought to be a factor in higher than expected results in the absorption tests

Among the major changes to the initial standards that became approved and incorporated into the revised tentative standards dating to 1927 were the following:

- D221 - Preparation of Samples: Although honed surfaces were still recommended, the standard was amended to state where this was "not practical," the slate may be split to the desired thickness, then sawed into 6 in. x 6 in. squares using a hacksaw (to avoid fractured edges). In addition, the number of samples required for the tests was changed from simply six to the somewhat more nuanced 'six if a honed surface finish was imparted on all faces and nine if the faces were natural cleft and the edges sawn.'
- D222 - Specimen Shape: The standard was amended to allow for determination of MOR and MOE using the same test method and, if this were to be the case for the testing of roofing slate, that the specimens be cut to a size of 12 in. x 4 in. and honed to a final thickness of 3/8 in.

Ongoing comparative testing based on the revised tentative standards continued to find wide variations in the absorption test results. The Sub-Committee believed this might be due to some laboratories using a higher drying temperature than others and the understanding that appreciable quantities of water might remain in the slate if drying was undertaken at temperatures below the boiling point of water. Thus, in 1930, 30 samples were sent to each of five laboratories (Lehigh, Lafayette, RPI, the Bureau of Standards, and Bell Telephone Laboratories, users of electrical slate) representing each of three slate districts (Pennsylvania, Maine, and Vermont/New York), with the objectives of: a) determining if it is feasible to dry slate at a temperature below the boiling point of water (212ºF) and, if so, determining what temperature (e.g., 120, 150, 180ºF, etc.) and drying period is necessary to drive off the free moisture and give reasonably consistent results, b) studying the difference in absorption results based on drying before immersion of the slate in water versus immersion before drying, c) studying the impact of reporting the percent absorption based on the initial weight or final weight of the specimen, and d) examining the usual variation in results than can be expected when testing samples of slate in substantially the same manner.[45]

Interestingly (because this is not the case now), the Sub-Committee recommended that the standard test procedure include soaking the slate samples first, followed by drying, to avoid any harmful effects of drying on the slate prior to immersion (i.e., that drying first might harm the slate specimens enough so as to artificially increase their absorption). At the same time, the Subcommittee recognized, based on its test results, that soaking first yields slightly higher absorption results.

Committee D-16's purview encompassed slate for use in structural, electrical, and roofing slate applications. As such, Sub-Committee I on Methods of Testing was considering whether a breaking load test of the most popular sizes (e.g., 16 x 8, 18 x 10, and 22 x 11) of actual slate shingles might be more useful than MOR for roofing slate given the types of loads to which roofing slate are typically exposed (foot traffic, rafter deflection, vibration under wind load). Although breaking load was not incorporated into the Standard at the time, the requirements for preparation of the roofing slate specimens to be tested were modified with respect to a) the source of the samples (sawed directly from slate shingles), b) the thickness of the samples (changed from 3/8" to "a thickness equal to that of the slate shingle"), and c) surface finish (changed from honed to natural cleft). Of course, with changes in the quarry run of production in the late twentieth century, a switch was made from MOR to breaking load starting with the 2005 edition of ASTM C406.[46]

Subcommittee I on Methods of Tests worked toward perfecting the tentative test methods for water absorption and flexural strength of slate and, in fact, advanced D 221-27T, Tentative Method of Test for Water Absorption of Slate and D 222-27T, Tentative Methods of Flexural Testing of Slate (Determination of Modulus of Rupture and Modulus of Elasticity) to official standards of the Society in 1931. At the same time several other sub-committees were advancing other aspects related to a standardized specification for the physical properties of roofing slate. These included the following:

- Sub-Committee V on Weathering Characteristics, chaired by Charles H. Behre,[47] which was developing methods for determining the weathering characteristics of slate, laying the groundwork for the issuance of a tentative standard in 1948, ASTM C217-48T, Tentative Method of Test for Durability of Slate For Roofing, precursor to C217, Standard Test Method for Weather Resistance of Slate (first issued as a tentative standard in 1956). Studying the effects of freezing, and belaboring the difficulty of the task, the Sub-Committee famously reported in 1926, "The fact that the specimens have been so slightly affected during 1000 regulation alternate freezing and thawing tests seems to indicate that the only feasible weathering test will necessarily be an accelerated one."[48] The Sub-Committee also studied color changes in slate, at one point proposing the term "color-aging" in lieu of "weathering."

• Sub-Committee II on Abrasive Hardness, chaired by J.W. Ginder, the work of which was reported delayed by the difficulty of developing the equipment and procedures necessary for comparative tests.

• Sub-Committee III on Machining and Workability, chaired by Oliver Bowles, whose efforts focused on bringing technologies from other industries to bear on the fabrication of slate products, one such technology being the new alloy known as tungsten carbide, which would prove to aid in the drilling and cutting of slate.

• Sub-Committee IX on Utilization and Performance, chaired by R.S. Tibbals, which, in addition to investigating the applicability of the tentative test methods for absorption and strength to roofing slate was, in 1930, collecting samples of in-service slate shingles for testing at the U.S. Bureau of Standards by none other than D.W. Kessler and W.H. Sligh.

1932: D.W. Kessler & W.H. Sligh, "Physical Properties and Weathering Characteristics of Slate"

D.W. Kessler and W.H. Sligh published widely on slate. The 1932 publication, "Physical Properties and Weathering Characteristics of Slate," is perhaps the pinnacle of their work on the subject. In it they conducted over 5,100 tests on 343 freshly quarried samples of slate from the various slate districts - Maine, Vermont/New York, Pennsylvania (Hard-Vein, Bangor, Pen Argyl, Wind Gap, and Slatington regions), Virginia, Maryland (Peach Bottom), Tennessee, Georgia, and Arkansas). The tests encompassed eight physical properties: Strength (MOR), Elasticity, Toughness (deflection), Abrasive Hardness, Absorption, Porosity, Specific Gravity, and Weight per Cubic Foot. In what may be the first testing of its kind, they also subjected 57 in-service slate shingles to MOR, toughness, and absorption testing. The shingles derived from the Maine, Vermont/New York, Pennsylvania Hard-Vein, Pennsylvania Soft-Vein (Bangor and Pen Argyl regions), and Virginia slate districts and had been exposed to the weather for various periods of time ranging from 12 to 131 years, with an average exposure of about 50 years. Lastly, Kessler and Sligh completed 682 accelerated weathering tests, including wet/dry cycling, hot/cold cycling, freeze/thaw cycling, and, of critical importance, depth of softening after soaking in sulfuric acid for seven days.

A summary of Kessler and Sligh's test results on freshly quarried material are shown in Table 3. Kessler and Sligh succinctly summarized their own results as follows:

> Tests on 343 samples of slate from the various districts gave the following average values: Modulus of Rupture, 11,700 lbs./in.^{2}; modulus of elasticity in flexure, 13,500,000 lbs./in.^{2}; toughness [deflection], 0.192 [in.]; abrasive hardness, 7.6; absorption, 0.27 per cent by weight; porosity, 0.88 per cent; bulk density, 2.771; weight per cubic foot, 172.9 pounds. The strength, elasticity, and toughness values given above were obtained on oven-dried specimens tested in the strongest grain direction. Strength determinations on specimens that had been soaked in water for several days showed considerably lower values.[49]

Key findings contained within Kessler and Sligh's paper include the following:

• Grain Direction for the MOR Test: Grain direction matters when undertaking MOR testing, with a higher MOR resulting in samples tested across the grain[50] compared to those tested parallel to the grain. It is noted that Merriman did not report on grain direction in his studies. Merriman used full shingles, laid bevel-side down, the results from which would have depended on whether the slate shingles were produced "on-grain" (grain parallel to the long dimension of the shingle), or not.

The consequence of Kessler and Sligh's finding is seen when comparing the second tentative standard for MOR to the first edition of the adopted standard. ASTM C222-27T states that "Half of these [test specimens] shall be cut with the length parallel to the grain and the other half with the length perpendicular to the grain." ASTM C120-48, was updated such that all specimens would be cut with the long dimension parallel to the length of the shingle, noting that "this gives a specimen parallel to the grain and when broken transversely, the fracture will occur across the grain. Ordinarily, it is not considered necessary to test roofing slate in both directions of the grain."[50]

• Conditioning of Specimens for the MOR Test: Kessler and Sligh carried out MOR tests on dried specimens as well as specimens that had been immersed in water for 14 days. The latter exhibited a reduction in strength ranging from seven to 68 percent, but generally on the order of 20 to 40 percent. This was thought to be due to the lubricating effects of the absorbed water on the slate. To account for naturally occurring moisture contained in slate samples submitted for testing, it was, concluded that drying specimens in preparation for the MOR test would provide more comparative results.

• Toughness: With regard to the toughness (deflection) of slate, Kessler and Sligh concluded that "Other properties being equal, a slate of high toughness is less apt to break under a given strain than one of lower toughness."[51] Hence, toughness might be an attribute to include in a standardized set of tests of the physical properties of roofing slate.

• Abrasive Hardness: Given the lack of consistency in the apparatus used, the abrasive hardness test results reported by Kessler and Sligh are in no way comparable to those of, say, Merriman. Moreover, Kessler and Sligh concluded that there is no general relationship between the hardness and durability of roofing slate and that the hardness test would be of greater value for some of the other architectural uses of slate, such as flooring, treads, sinks, thresholds, and sills.

• Absorption v. Porosity: Kessler and Sligh defined porosity of a material as "a percentage of the void space to the total volume."[52] Interestingly, they found the correlation coefficient between absorption and porosity to be 0.70, fairly low, and offered as explanation two factors: a) the rate of absorption and b) the mineral composition of the slate. It was suggested that letting the samples soak for a longer period of time and computing the absorption by the volume ratio rather than the weight ratio might yield a closer correlation between the two.

• Tests on the 57 samples of weathered slate revealed that, on average, all of the samples showed a considerable loss of strength (reduced MOR), a decrease in toughness (reduced maximum deflection under load), and increased absorption, when compared with test results of fresh samples.

• Slates containing sufficient amounts of calcite and pyrite are subject to decay due to the conversion of the calcite to gypsum with a consequent increase in molecular volume which, in turn, can push the slate laminae apart, causing the slate to scale, or delaminate. The chemical process is primarily induced by wet/dry cycling, but can also occur by hot/cold cycling, albeit at a slower rate.

• Delamination occurs more rapidly on the underside of slate shingles exposed on a roof due to the leaching and concentration of gypsum over time.

• Depth of Softening: The soaking and drying test gives results similar to those of actual weathering, but, given the large number of cycles required, can take a month or more to carry out. Recognizing that a more rapid test procedure was needed to gauge the impact of the presence of small amounts of calcite and iron sulfides contained within a slate on its weathering characteristics, Kessler and Sligh proposed that a test procedure that consisted of the following: soaking the slate samples in a one-percent solution of sulfuric acid for seven days then determining the depth of softening by a) first gauging the thickness of the slates at several points, then b) scraping off the softened layer at these points and gauging the thickness again. Kessler and Sligh postulated that "by using a dull blade for the scraping and standardizing the conditions of the process it is possible to obtain fairly consistent results."[53] The test converted calcite near the surface of the slate to gypsum and caused deterioration in the form of softening the slate (i.e., pushing apart the closely spaced laminae) similar to that in the drawn-out soaking and drying cycling tests.

• Freeze/thaw action is of negligible direct consequence in the weathering of slate shingles. That said, slate nailed too tightly when installed can be subject to breakage due to the freezing of water present between shingles.

• "There appears to be no general relation between the strength and durability of slates from different districts."[54] Although it had been long hoped that a single test would suffice, Kessler and Sligh recognized that more than one test (the MOR test) is needed to adequately specify the physical properties of slate for roofing purposes.

By 1932, the absorption test (ASTM D221-31) is being "frequently used in roofing-slate specifications,"[55] as a gauge of the in-service performance of roofing slate, and the flexural test (ASTM D222-31) is seen as "a ready means of comparing various slates"[56] and of particular relevance to roofing slate as an indicator of a slate's ability to withstand various stresses imposed on it when installed on a roof (e.g., those imparted by rafter deflection under wind loads as well as those stemming from workmen walking or placing ladders on the shingles).

There can be no doubt that Kessler and Sligh's testing, the most comprehensive ever undertaken before or since, not only solidified the acceptance of the absorption and MOR test standards, but contributed immensely to the inclusion of the depth of softening test in the suite of tests that would eventually be incorporated into ASTM C406. Although the first, tentative standard involving immersing slate specimens in a dilute solution of sulfuric acid (ASTM C217-48T, Tentative Method of Test for Durability Of Slate For Roofing) calculated the percent increase in absorption of the acid-immersed slate as compared to the slate's absorption when soaked in water, this soon changed to a depth of softening test similar to that undertaken by Kessler and Sligh with the first revision to ASTM C217 in 1956 (ASTM C217-56T, Tentative Method of Test for Weather Resistance of Natural Slate).

There are now three standardized tests - MOR, absorption, and depth of softening - coming to be generally accepted as relevant, repeatable, and relatively quick to carry out, the former for strength and the latter two for weathering qualities.

1932: Federal Specification for Slate

The Federal Specification Board issued its "Federal Specification for Slate; Roofing SS-S-451" on July 26, 1932. Its purpose was to set a standard by which all departments of the Federal Government could procure roofing slate. The Specification was limited to roofing slate of commercial standard thicknesses and sizes and of one of three Grades, A, B, or C. Although their issuance dates are separated by 25 years, much of which was occupied by the Great Depression and World War II, SS-S-451 is often referred to as the immediate predecessor to ASTM C406. Indeed, there are many things common to both regarding the characteristics and physical properties of roofing slate. SS-S-451 is also important in that it lays out, for the first time, specific requirements for "strength" (MOR), absorption, and "acid resistance" (depth of softening) for the different grades of slate. These are summarized as shown in Table 4, below.

Table 4: Physical Requirements for Roofing Slate per Federal Specification for Slate; Roofing SS-S-451

Grade Designation	MOR, Across the Grain average min., psi	Absorption average max., percent	Depth of Softening average max., in.
Grade A	9,000	0.25	0.002
Grade B	9,000	0.35	0.008
Grade C	9,000	0.45	0.014

These physical properties are identical to those contained in ASTM C406-57T/C406-58 (and, all later editions of C406, excluding those after 2004 when MOR was changed to breaking load; see Table 1), except for the absorption under Grade B, which was changed to 0.36 in ASTM C406. Note the use of the letter designations A, B, and C for grade, which can be found even today in some specifications for slate roofing, despite the fact that ASTM C406 always used the designations S_1, S_2, and S_3. There is no correlation between grade and service life in SS-S-451 as there is in C406, this coming later, presumably based largely on the work of Kessler and Sligh which was published in 1932, the same year as SS-S-451 was issued.

Further, there is no explanation as to the derivation, or basis, for the values required under each of the three test procedures. It is apparent, however, that based on Kessler and Sligh's 1932 test results, the slate from all of the significant eastern U.S. districts having had commercial production up to that time (with the exception of Sussex County, New Jersey, the production of which was not the subject of testing by Kessler and Sligh) could meet the 9,000 pound MOR requirement, except for the slates from Arkansas (see Table 3). We will likely never know, but perhaps the Federal Specification Board deemed production from the Arkansas deposits unsuitable for roofing purposes (given the slate's low MOR and high absorption), and were unwilling to lower the bar for MOR below 9,000 pounds. It can be assumed, as well, that the Federal Specification Board was well aware of all of the prior testing that had taken place between 1892 and 1927, the average MOR for which is approximately 9,400 pounds.

SS-S-451 outlines the test procedures for each of the physical properties given in Table 4. These are very similar to those which appear in the 1948/1956 editions of ASTM's standard test methods for slate referenced in ASTM C406. Key differences between the two are shown in Table 5.

In addition to specifying the minimum physical properties of roofing slate, SS-S-451 lists other pertinent characteristics that should be specified as part of each purchase. It is clear that the size and texture characteristics contained in ASTM C406-57T derive directly or indirectly from SS-S-451. As mentioned previously, the 30 standard sizes of slate, ranging from 10x6 to 24x14, which first appeared in Simplified Practice Recommendation R14 (1924/28) carried through to NSA's *Slate Roofs*, SS-S-451, and, ultimately, to ASTM C406.

ASTM C406-57T adopted SS-S-451's language with regard to the surface texture of roofing slate. Both refer to a slate shingle's texture as the character of the split surface, specifying it as smooth or rough. Further, both define the surface texture of the roofing slate from the various districts as:

- Smooth: Pennsylvania soft-vein and Maine
- Smooth and rough: Vermont, New York, Pennsylvania Hard-Vein, and Virginia

SS-S-451 lists slate from the Peach Bottom district as having a rough texture. This information was not included in ASTM C406-57T as most, if not all of the Peach Bottom quarries had closed by 1956.

Interestingly, ASTM C406-57T does not adopt the color change information contained in SS-S-451, which expounds on the weathering of some dark colored slates and the color change occurring in certain green slates, but rather just lists Weathering Green as a standard color, noting that it changes to buff or brown.

Section C, Material and Workmanship, Etc. and Section D, General Requirements, of SS-S-451 list the following requirements to which the slate must conform. Although very similar, the requirements contained in SS-S-451 generally exceed those in the earlier Simplified Practice Recommendation R14-28, while being somewhat less specific than those in the subsequent ASTM C406-57T:

- Protuberances: "Slate shall be free from knots or knurls that would lessen the durability of weather-tightness of the finished work." While SPR R14 is silent on protuberances, ASTM C406-57T offers similar guidance, but with more specificity, stating: Knots and knurls "are not objectionable on the exposed portion of the top face but on other parts they may prevent as close contact of shingles as desired. Shingles having knots and knurls on the lower face or covered portions may be rejected if the protuberances project more than 1/16 in. beyond the split surface."
- Shape: "Slate shall be rectangular, with straight cut edges." ASTM C406-57T is somewhat more specific, stating that face dimensions shall not differ from those specified by more than 1/8 inch.
- Corners: Corners "shall be reasonably full on exposed edges, with no broken corners on covered ends that would diminish the nailing strength or weather tightness." SPR R14 contains nearly identical language. ASTM C406-57T states further that broken corners may be cause for rejection when either the base or leg of the right triangular piece broken off exceeds 1-1/2 inches, but is silent on broken corners at the head of the slates (covered ends).
- Curvature: "The maximum bend shall not exceed one-eighth inch in 12 inches. Slate if curved shall be made so that it can be laid with the convex side up." C406-57T contains nearly identical language.
- Nail Holes: "Unless otherwise specified, holes shall be machine punched for a 3-inch double lap." SPR R14 specified two nail holes, but is silent on headlap. ASTM C406-57T goes a bit further than SPR 14 and SS-S-451, allowing for drilling of the nails holes and specifying two nails per shingle, thus: "Slate shingles for sloping roofs shall be machine punched or drilled for two nails properly located for 3 in. head lap."
- Thickness: "Thickness shall be approximately three-sixteen inch, measuring 22 to 25 inches per 100 pieces when closely piled for smooth-sur-

Table 5: Key Differences in Test Procedures, FS SS-S-451 vs 1948/1956 ASTM Standard Test Methods

	Flexural (MOR) Test		Absorption Test		Weather Resistance (Depth of Softening) Test*	
Test Procedure	FS SS-S-451	ASTM C120-48	FS SS-S-451	ASTM C121-48	FS SS-S-451	ASTM C217-56
Number of Samples	5	6			4	3
Conditioning Time in Oven (hours)	4	24			n/a	24
Specimen Thickness (in.)			That of Shingle	3/16 to 5/16		
Oven Temperature (°C)		110 (+/- 3)		105 (+/- 5)		
Cooling Temperature/Time			Not indicated	Room Temp., 15 min.		
Type of Water			Not indicated	Filtered/ Distilled		
Distance from Edge of Shingle When Cutting Samples (in., min.)					Not indicated	1
Sample Edges					Not indicated	Eased using no. 2/0 sand-paper
Surface Preparation					Not indicated	Ground smooth and finished with No. 80 abrasive
Drying Procedure					Surface dry with a cloth	Oven dry, 24 hrs. at 105° C +/- 2° C
Scraping Procedure					Vague	Detailed
Reporting of Results	Not indicated	Average value of all samples	Not indicated	Average value of all samples	Not indicated	Average value of all samples

*The tentative standard, ASTM C217-48T, did not measure the depth of softening, but rather measured the increase in absorption of the samples soaked in a 1-percent sulfuric acid solution for seven days as compared to those soaked in water for 24 hours.

face slate and 25 to 30 inches per 100 pieces for rough-surface slate." While both SPR R-24 and C406-57T both recognize a standard nominal thickness of 3/16 in., in this case it is SS-S-451 that is more expansive, specifying a means by which purchasers may verify the thickness received.[57] For thicknesses other than nominal 3/16 in., both SS-S-451 and C406-57T reference SPR R14, which delves into details concerning the inherent non-uniformity associated with hand-splitting slate shingles, thicknesses falling between two standard thicknesses, and the minimum length required for slates measuring 1/2 in. or more in thickness (see Figure 4).

• Breakage: "Slate shall be whole and clean. Not more than two per cent of broken slate will be accepted." While SPR R14 is silent on breakage, C406-57T includes the same two percent threshold as SS-S-451, while adding that slates having cracks that "materially affect the ring when sounded" shall be included in the two percent limit.

1938-1948: Committee C-18 on Natural Building Stone

During the throes of the Great Depression, ASTM Committee D-16 on Slate seems to have been largely inactive. By 1938, the Committee was incorporated into Committee C-18 on Natural Building Stone and Slate and membership was down to a total of just 15, with Theodore I. Coe, an architect in the Washington, D.C. area, serving as Chairman. In the early 1940s, the slate industry is further subjugated, with "Slate" being dropped from the Committee's name. On the bright side, however, membership numbers are up, D. W. Kessler is back, serving as Secretary of the Committee, and a nine member subcommittee has been formed to start working on a standard slate specification - what will eventually become ASTM C406, Standard Specification for Roofing Slate. The Committee, in association with the National Bureau of Standards, is set to investigate the fading and nonfading varieties of slate as "a necessary step in attempting to draft a specification,"[58] but the ongoing war effort will, ultimately, stymie this effort.

In 1948, with Oliver Bowles as Chair, Subcommittee IV on Specifications seems to have a draft specification on slate ready for consideration. The specification is reported to be "similar to the Federal Specification [that is, Federal Specification for Slate; Roofing SS-S-451] on this product except for the means of determining durability."[59] The Subcommittee noted that the depth of softening determination contained within SS-S-451 was difficult to standardize. Testing had revealed good agreement, however, between SS-S-451's depth of softening and acid immersion testing wherein the deterioration of slate is measured on the basis of percent change in absorption. Hence, ASTM's tentative standard for Durability of Slate for Roofing (ASTM C217-48T), contained the latter test method. As mentioned earlier, by 1956, when C217 was formally adopted, the test procedure for measuring the depth of a scratch made in the surface of the slate before and after immersion in a sulfuric acid bath had been sufficiently standardized by means of a new device (a model 4010 abraser tool with a model 3720 shearing tool attachment, Taber Instrument Co., North Tonawanda, New York) that depth of softening became the standard test method for determining the weather resistance of slate, and that which would be incorporated into ASTM C406 by reference the following year.

Conclusion

The test methods and material specification that were to become ASTM C406 evolved over a span of roughly 65 years, from 1892 to 1957. The herculean effort, no doubt interrupted by World War I, the Great Depression, and World War II, was undertaken by leaders, legends really, in the industry - Merriman, Bowles, Kessler, Sligh, Boyd, Behre - with the assistance and cooperation of scores of other individuals, producers, and distributors as well as the U.S. Bureau of Standards, and several university laboratories. C406 is not perfect. In fact, it has been revised at least 11 times since being issued as a tentative standard in 1957 and criticized by many, including Stearns,[60] Hicks,[61] and Cárdenes.[62] Still, it is the best we have and, ostensibly, incorporates a simple, reasonably reproducible set of standardized test methods that are relied upon by many in the industry. No doubt, C406 will continue to develop and be updated over time with changes in technology and as our understanding of slate's core microstructure is refined.

[1]ASTM C406/C406M-15, Standard Specification for Roofing Slate. West Conshohocken, PA: ASTM International, 2015, p.1. (Note that the number immediately following the ASTM Standard designation indicates the year of original adoption or, in the case of revision, the year of last revision.)

[2]Merriman, Mansfield M., “The Strength and Weathering Qualities of Roofing Slates,” American Society of Civil Engineers, Transactions, 551, Vol. 27, (Nos. 3 and 6), September, 1892, p.336.

[3]Dale, T. Nelson, *Slate in the United States*, United States Geological Survey, Bulletin 586. Washington, D.C.: Government Printing Office, 1914, p.178.

[4]Merriman, 1892, p.348-349.

[5]Byrne, Auston T., *Inspection of the Materials and Workmanship Employed in Construction: A Reference Book for the Use of Inspectors, Superintendents, and Others Engaged in Construction of Public and Private Works,* 1st ed. New York: John Wiley & Sons, 1898, p.311.

[6]Dale, T. Nelson, “Methods of Testing Slate,” *Stone,* v.28, 1907, pp.228-229.

[7]Merriman, 1892, p.338-339.

[8]Archimedes, a Greek mathematician and scientist from the ancient city of Syracuse, discovered that the weight of an object in air minus its weight in water is equal to the weight of the water displaced by the specimen. Thus, specific gravity can be defined as the weight of an object relative to the weight of an equivalent amount of water.

[9]Merriman, 1892, p.343.

[10]Ibid., p. 344.

[11]Ibid., p.348.

[12]Ibid., p.348.

[13]Merriman, Mansfield M., “The Strength and Weathering Qualities of Roofing Slates,” American Society of Civil Engineers, Transactions, 741, Vol. 32, December, 1894, p.533-534.

[14]Ibid., p.539.

[15]Rothwell, Richard P., Ed., *The Mineral Industry,* Vol. VI. New York: The Scientific Publishing Company, 1898.

[16]Nineteenth Annual Report of the United States Geological Survey, Part VI, Annual Reports of the Department of the Interior for the Fiscal Year Ended June 30, 1898. Washington, D.C.: U.S. Department of the Interior, 1898.

[17]Dale, T. Nelson, *Slate Deposits and Slate Industry of the United States,* United States Geological Survey, Bulletin 275. Washington, D.C.: Government Printing Office, 1906.

[18]Dale, *Slate in the United States.*

[19]*Sweet’s Indexed Catalogue of Building Construction for the Year 1909*. New York: The Architectural Record, 1909, p.413. Per the still to come ASTM C406-58, the Genuine Bangor Slate Company’s MOR test data of 9,000 to 10,000 psi would meet the requirement for a Grade of S1 slate. Its absorption test data of 0.099 to 0.303 percent, however, place it at either S_1 (0.25%, max.) or S_2 (0.36%, max.). Of course, the depth of softening test had not been conceived as of 1909, so we cannot definitively grade the slate according to ASTM’s physical requirements.

[20]Sweet’s, 1909, p.425.

[21]“Mr. T. Nelson Dale,” *Nature,* V.141, 1938, p.149-150. https://doi.org/10.1038/141149b0

[22]Dale, T. Nelson, *Outcomes of the Life of a Geologist: An Autobiography.* New Haven, CT: Connecticut Academy of Arts & Sciences, 2009.

[23]Dale, *Slate in the United States.*

[24]Ibid., p. 176.

[25]Ibid., p.177.

[26]The full citations, as given by Dale are Reverdin, F., and De la Harpe, C., Chem. Zeitung, Vo. 14, pp.64-65, 94-95, 126-127, [nd] and Fresenius, R., Ueber die Prufung der Dachschiefer auf den Grad iher Verwitterbarkeit: Zeitschr. Anal. Chemie, vol 7, pp.72-78, Wiesbaden, 1868.

[27]Dale, *Slate in the United States,* p.181.

[28]Bowles, Oliver, “The Technology of Slate,” Bulletin 218. Washington, D.C.: Department of the Interior, Bureau of Mines, 1922.

[29]“Geologist Bowles Dies In Virginia,” *The Washington Post and Times Herald,* August 3, 1958, p.A20.

[30]Bowles, Oliver, “The Characteristics of Slate,” *ASTM Proceedings,* V.23. Philadelphia, PA: American Society for Testing Materials, 1923, p.529.

[31]Ibid., p.530.

[32]Ibid., p.531.

[33]“Historic Production Data - Quantity and Value of Roofing Slate Sold in the United States, 1866-1979,” *Technical Bulletin,* No. 5. National Slate Association, 2019, p.1. www.slateassociation.org.

[34]Bowles, Oliver, “Recent Progress in Slate Industry,” *Report of Investigations,* No. 2766. Washington, D.C.: Bureau of Mines, U.S. Department of Commerce, August 1926, p.8.

[35]Ibid., p.2.

[36]Ibid., p.9.

[37]*Slate Roofs*. Philadelphia, PA: National Slate Association, 1926, p.48.

[38]Ibid., p.11.

[39]Ibid.

[40]Ibid.

[41]Ibid., p.13.

[42]“Roofing Slate,” *Simplified Practice Recommendation R14-28*, 2d ed. Washington, D.C.: U.S. Department of Commerce, Bureau of Standards, July, 1928, p.9.

[43]Ibid., p.2. The second edition of SPR R14, was not published until 1928 and, therefore, too late for inclusion in NSA’s 1926 slate manual. As such, the information which appears in NSA’s *Slate Roofs* derives from the original SPR for slate roofing, published in 1924 (SPR R14-24). The revisions which appear in SPR R14-28, and which are reproduced herein, are relatively minor, but did include the addition of “purple variegated” to the color nomenclature.

[44]“Boyd, David Knickerbacker (1872 - 1944),” *Philadelphia Architects and Buildings.* Philadelphia, PA: The Athenaeum of Philadelphia. www.philadelphiabuildings.org, April 5, 2022.

[45]“Report of Committee D-16 on Slate,” *Proceedings of the Thirty-Fourth Annual Meeting,* Vol. 31. Philadelphia, PA: American Society for Testing Materials, 1931, pp. 576-580.

[46]The 9,000 psi MOR contained in previous versions of ASTM C406 was changed to a breaking load of 575 lbs. in ASTM C406-2005.

[47]Behre (1896-1986) was an authority on minable raw materials ranging from lead, zinc, and bauxite to slate, chert, and other mineral deposits. In addition to his doctoral thesis on the slate of Northampton County, Pennsylvania (1925), Behre authored several other papers on slate, including the definitive Pennsylvania Geological Survey Bulletin M16, “Slate in Pennsylvania,” published in 1933. Behre’s teaching career spanned 50 years, primarily at Columbia University, but also at Lehigh University, University of Cincinnati, and Northwestern University.

[48]“Report of Committee D-16 on Slate,” *Proceedings of the Twenty-Ninth Annual Meeting,* Vol. 26. Philadelphia, PA: American Society for Testing Materials, 1926, pp. 500.

[49]Kessler, D. W., and Sligh, W. H., “Physical Properties and Weathering Characteristics of Slate,” *Journal of Research,* Vol. 9, No. 3, Research Paper RP477. Washington, D.C.: U. S. Dept. of Commerce, National Bureau of Standards, June, 1932, p.377.

[50]ASTM C120-48, Standard Methods of Flexural Testing of Slate. Philadelphia, PA: American Society for Testing Materials, 1948, p.2.

[51]Kessler and Sligh, p.393.

[52]Ibid., p.397.

[53]Ibid., p.408.

[54]Ibid., p.388.

[55]Ibid., p.395.

[56]Ibid., p.388.

[57]Interestingly, in recent years there has been much discussion about amending ASTM C406 to include just such a method of confirming the thickness of the slate shingles in a given order. In our increasingly standardized world, there is misunderstanding among purchasers of natural slate shingles regarding the hand-wrought nature of the product and consequent inherent variability in thickness. This is, of course, at odds with the producers desire to minimize waste and maximize fabrication efficiency and the amount of material that can be gotten from each block raised from the quarry floor.

5[8]"Report of Committee C-18 on Natural Building Stones," *Proceedings of the Forty-Fourth Annual Meeting,* Vol. 41. Philadelphia, PA: American Society for Testing Materials, 1941, pp. 309.

[59]"Report of Committee C-18 on Natural Building Stones," *Proceedings of the Fifty-First Annual Meeting,* Vol. 48. Philadelphia, PA: American Society for Testing Materials, 1948, pp. 278.

[60]Stearns, Brian, Stearns, Alan, and Meyer, John, "Slate Roofing and Grading in the New Millennium," *Interface*, January 2000, p.15.

[61]Hicks, Matt, "Testing Standards for Slate Roofing," *Interface,* V.26, 2008, p.38-41.

[62]Cárdenes, Victor, et. al., "Roofing Slate Standards: A Critical Review," *Construction and Building Materials,* V. 115, April, 2016, pp.93-104.