

รายการอ้างอิง

ภาษาไทย

ปรีดา พิมพ์ขาวชา, รศ. เซรามิกส์. สำนักพิมพ์จุฬาลงกรณ์มหาวิทยาลัย, พ.ศ. 2532.

ศุลากร, กรม. ปริมาณการส่งออกและนำเข้าของผลิตภัณฑ์เซรามิกส์. 2532-2534,
22 หน้า.

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อาวีวรรณ บุญเพ็ญ. การเตรียมและศึกษาลักษณะเฉพาะผลิตภัณฑ์อลูมินาเซรามิกส์ที่มีความหนาแน่นสูงสำหรับงานด้านทนทานต่อการสึกกร่อน. วิทยานิพนธ์ปริญญาโทมหาบัณฑิต จุฬาลงกรณ์มหาวิทยาลัย, 2535.

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- ____. Standard Test Method for Flexural Properties of Ceramic Whiteware Materials : ASTM C674-88 (Reapproved 1994). ASTM, 1995, 204-207.
 - ____. Standard Test Method for Flow Rate of Metal Powder : ASTM B 213-90. ASTM, 1990, 46-47.
 - ____. Standard Test Method for Free Moisture in Ceramic Whiteware Clay : ASTM C324-86 (Reapproved 1992). ASTM, 1995, 89.
 - ____. Standard Test Method for Particle Size Distribution of Alumina or Quartz by X-Ray Monitoring of Gravity Sedimentation : ASTM C958-92. ASTM, 1995, 310-311.
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ภาคผนวก

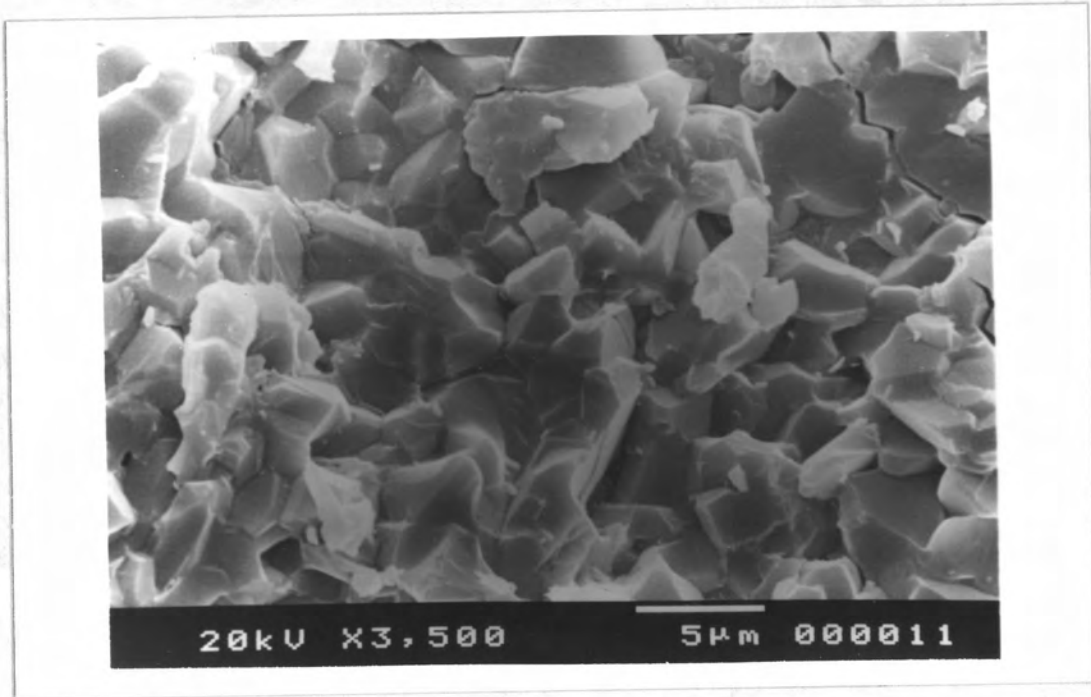
ภาคผนวก ก.

ผลวิเคราะห์ทาง เคมีและโครงสร้างภายในของผลิตภัณฑ์ที่มีจำหน่ายในท้องตลาด

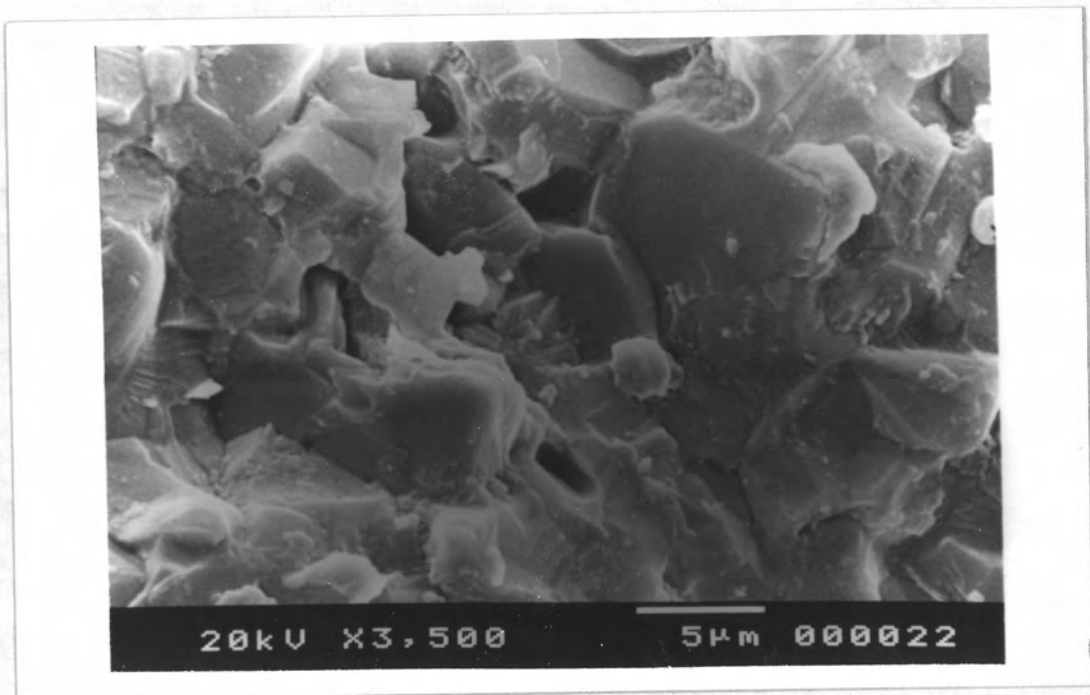
เนื่องจากงานวิจัยนี้มีจุดประสงค์ในทางการค้า ดังนั้น ในที่นี้จึงได้ใช้ตัวอักษร ก, ข, ค, ข และ ง แทนการระบุชื่อผลิตภัณฑ์ดังกล่าว ผลวิเคราะห์ทาง เคมีของตัวอย่างสินค้ายี่ห้อต่าง ๆ ด้วยเครื่อง เอกซ์เรย์ฟลูออเรสเซนซ์แบบกระจายพลังงานได้แสดงดังตารางที่ ก.1 ซึ่งพบว่าปริมาณอลูมินาและซิลิกาของแต่ละผลิตภัณฑ์มีความแตกต่างกันมาก คือปริมาณอลูมินาจากร้อยละ 64.30 ถึง 91.62 และภาพถ่ายของผิวรอยแตกจากผลิตภัณฑ์ยี่ห้อต่าง ๆ แสดงดังรูปที่ ก.1 ถึง ก.5 พบว่าส่วนมากจะมีขนาดของ เกรน เล็กละเอียด และมีรูพรุนขนาดเล็กกระจายอยู่ทั่วไป ยกเว้นในตัวอย่าง ข ที่มีเกรนขนาดค่อนข้างใหญ่และมีรูพรุนขนาดใหญ่ด้วยเช่นกัน

ตารางที่ ก.1 ผลวิเคราะห์ปริมาณของอลูมินาและซิลิกาของชิ้นส่วนของฉนวนหัวเทียนบางยี่ห้อที่มีจำหน่ายภายในประเทศโดย เครื่อง เอกซ์เรย์ฟลูออเรสเซนซ์แบบกระจายพลังงาน

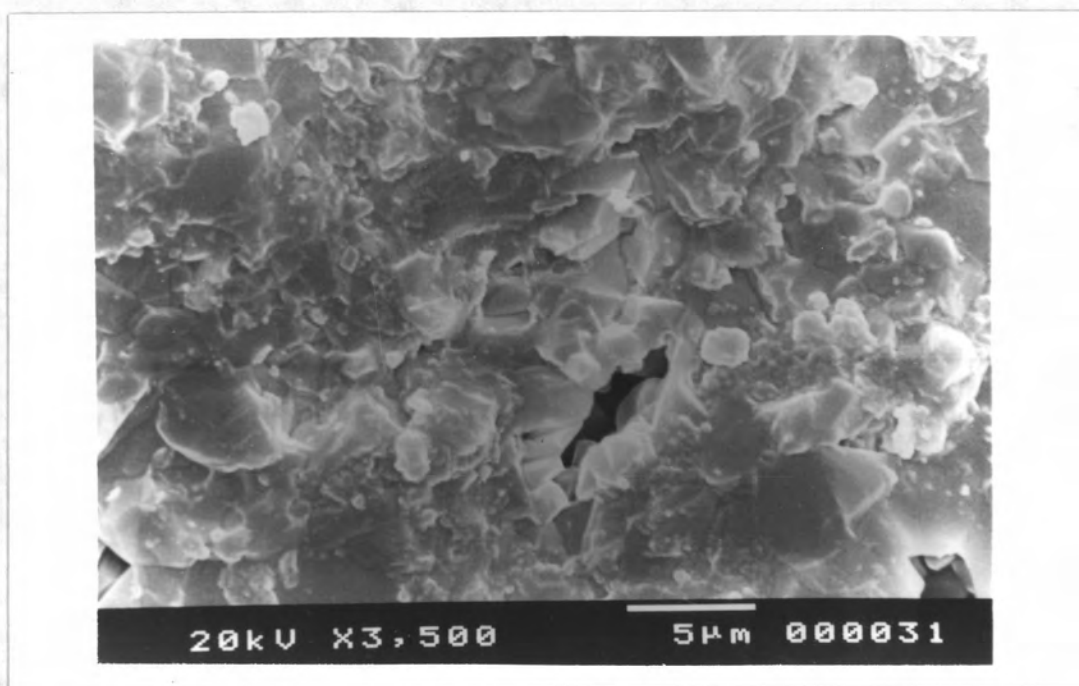
ยี่ห้อ	อลูมินา (ร้อยละโดยน้ำหนัก)	ซิลิกา (ร้อยละโดยน้ำหนัก)
ก	86.09	10.15
ข	77.07	18.58
ค	80.73	17.43
ข	91.72	6.52
ง	64.30	20.82



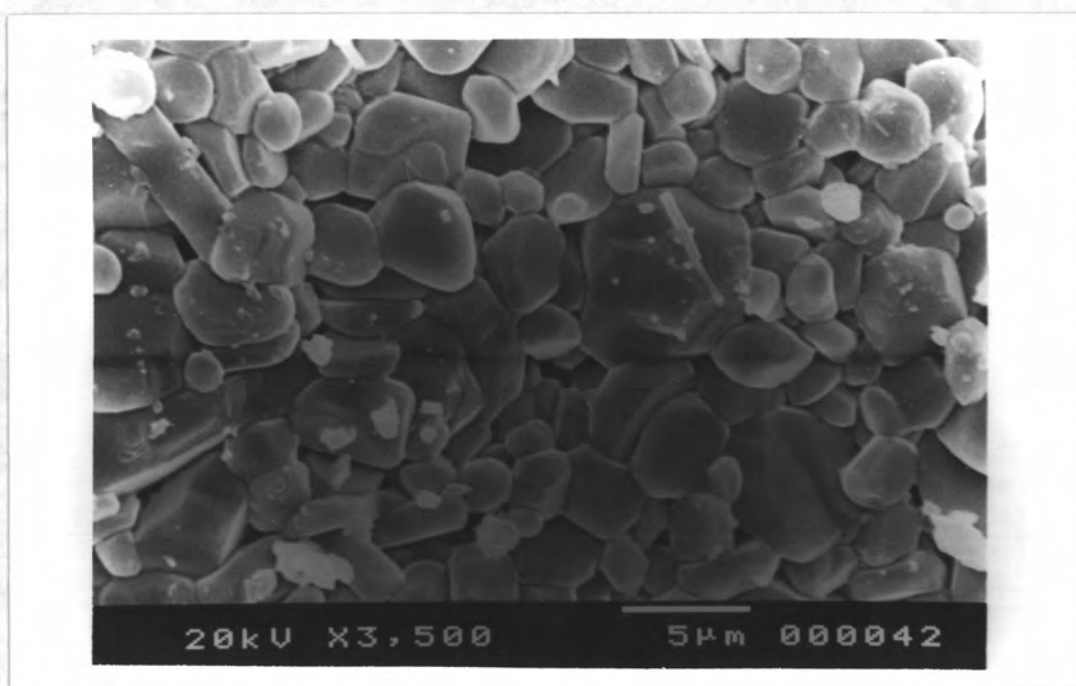
รูปที่ ก.1 ภาพถ่ายผิวรอยแตกของผลิตภัณฑ์ที่ข้อ ก



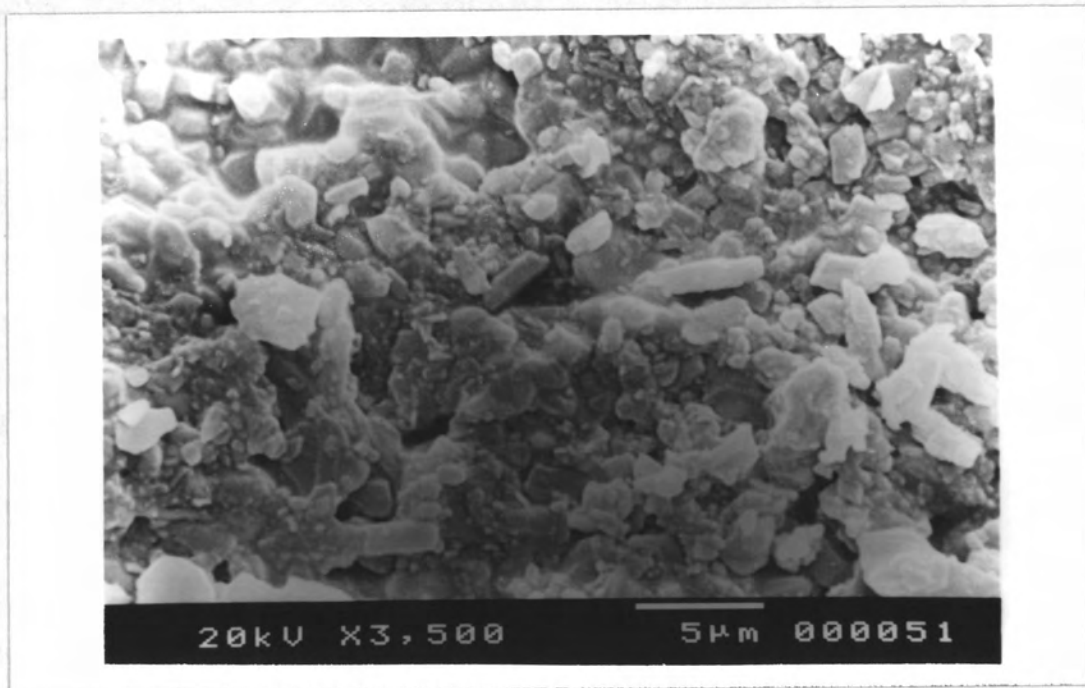
รูปที่ ก.2 ภาพถ่ายผิวรอยแตกของผลิตภัณฑ์ที่ข้อ ข



รูปที่ ก.3 ภาพถ่ายผิวรอยแตกของผลิตภัณฑ์หือ ค



รูปที่ ก.4 ภาพถ่ายผิวรอยแตกของผลิตภัณฑ์หือ ข



รูปที่ ก.5 ภาพถ่ายผิวรอยแตกของผลิตภัณฑ์ห้อง ง

ภาคผนวก ข.

ภาพแสดงลักษณะของอุปกรณ์ที่ใช้ในการทดลองบางชนิด



รูปที่ ข.1 เครื่องวัดความหนักแบบรูคฟิลล์



รูปที่ ข.2 หม้อบคาหลิพรหิเสนและลูกบคอรูมินา



รูปที่ ๕.๓ เครื่องชั่งอย่างละเอียด



รูปที่ ๕.๔ เครื่องวิเคราะห์ขนาดและการกระจายขนาดของอนุภาค



รูปที่ ๕.๕ เครื่องวัดขนาดพื้นที่ผิวของอนุภาค



รูปที่ ข.6 เครื่องวัดอัตราการไหลตัวของอนุภาคแบบฮอลล์



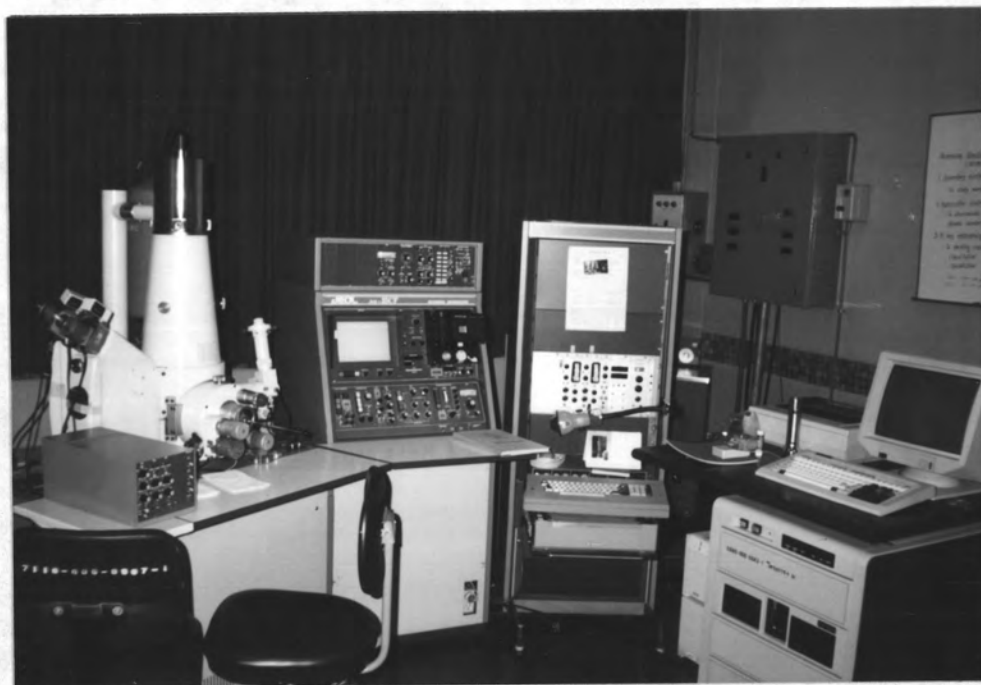
รูปที่ ข.7 เครื่องหาความหนาแน่นหลังการเคาะของอนุภาคแบบกระแทก



รูปที่ ข.8 เครื่องเอกซเรย์ดิฟแฟร็กโทมิเตอร์



รูปที่ ข.9 เครื่องวิเคราะห์สมบัติทางความร้อนของวัสดุ



รูปที่ ข.10 กล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด และ เครื่อง เอกซ์เรย์ฟลูออเรสเซนซ์
แบบกระจายพลังงาน



รูปที่ ข.11 เครื่องขึ้นรูปชนิดให้ความดันเท่ากันทุกทิศทางแบบแม่เฟาหรือ
โกลด์ไฮดรอสแตติก เพรสซึ่งแบบเบียด



รูปที่ ข.12 เตาเผาตัวอย่าง



รูปที่ ข.13 เครื่องทดสอบแรงดึงและแรงกดของวัสดุ



รูปที่ ข.14 เครื่องค้ำขึ้นตัวอย่างความเร็วรอบสูง



รูปที่ ข.15 เครื่องวัดความต้านทานไฟฟ้า



รูปที่ ข.16 เครื่องฮอยส์เทสเทอร์วัดความแข็งแรงทางโคอีเลคทริก

ภาคผนวก ค.

มาตรฐานที่ใช้ในการทดสอบครั้งนี้

ประกอบด้วย

- XRD card ของแร่บางชนิดที่พบในการทดสอบ
- ASTM C135-86 สำหรับหาความต่างจาเพาะของผงตัวอย่าง
- ASTM C324-82 สำหรับหาร้อยละความชื้นของผงตัวอย่าง
- ASTM C958-92 สำหรับหาขนาดการกระจายของผงตัวอย่าง
- ASTM C1089-86 สำหรับหาพื้นที่ผิวรวมต่อน้ำหนักผงตัวอย่าง
- ASTM B213-83 สำหรับหาอัตราการใช้ของผงตัวอย่าง
- ASTM B527-70 สำหรับหาค่าความหนาแน่นหลังการ เคาะของผงตัวอย่าง
- ASTM C693-93 สำหรับหาความหนาแน่นของตัวอย่าง
- ASTM C373-88 สำหรับหาความหนาแน่น, ร้อยละของการดูดซึมน้ำ และปริมาณ
รูพรุนของตัวอย่างหลัง เพา
- ASTM C326-82 สำหรับหาค่าการหดตัวหลัง เพาของตัวอย่าง
- ASTM C674-88 สำหรับหาค่าโมดูลัสของการแตกหักของตัวอย่าง

5-0490 MINOR CORRECTION

d	3.34	4.26	1.82	4.26	SiO ₂	★
I/I ₁	100	35	17	35	SILICON OXIDE QUARTZ, LOW	
Rad.	CuKα ₁	λ 1.5405	Filter Ni	Dia.		
		Cut off	Coll.			
I/I ₁	G.C. DIFFRACTOMETER		d corr. abs.?			
Ref.	SWANSON AND FUYAT, NBS CIRCULAR 539, VOL. III (1953)					
Sys.	HEXAGONAL		S.G. D ₃ ⁴	P _{3,21}		
a ₀	4.913	b ₀	c ₀ 5.405	A	C 1.10	
α	β	γ	Z	3		
Ref.	Ibid.					
ε α	n ω β 1.544 γ 1.553		Sign	+		
2V	Dx 2.647 mp		Color			
Ref.	Ibid.					
SAMPLE FROM LAKE TOXAWAY, N.C.	SPECT. ANAL.:					
<0.01% AL; <0.001% CA, CU, FE, MG.						
X-RAY PATTERN AT 25°C.						
	d Å	I/I ₁	hkl	d Å	I/I ₁	hkl
	4.26	35	100	1.229	2	220
	3.343	100	101	1.1997	5	213
	2.458	12	110	1.1973	2	221
	2.282	12	102	1.1838	4	114
	2.237	6	111	1.1802	4	310
	2.128	9	200	1.1530	2	311
	1.990	6	201	1.1408	<1	204
	1.817	17	112	1.1144	<1	303
	1.801	<1	003	1.0816	4	312
	1.672	7	202	1.0636	1	400
	1.659	3	103	1.0477	2	105
	1.608	<1	210	1.0437	2	401
	1.541	15	211	1.0346	2	214
	1.453	3	113	1.0149	2	223
	1.418	<1	300	0.9896	2	402, 115
	1.382	7	212	.9872	2	313
	1.375	11	203	.9781	<1	304
	1.372	9	301	.9762	1	320
	1.288	3	104	.9607	2	321
	1.256	4	302	.9285	<1	410
REPLACES	1-0649, 2-0458, 2-0459, 3-0427, 3-0444, 2-0471, 3-0419.					

ค. หินเขียวทึบ

15-776 MINOR CORRECTION

d	3.39	3.43	2.21	5.39	Al ₆ Si ₂ O ₁₃	3Al ₂ O ₃ · 2SiO ₂	★
I/I ₁	100	95	60	50	Aluminum Silicate	(Mullite)	
Rad.	CuKα ₁	λ 1.5405	Filter Ni	Dia.			
Cut off	I/I ₁ Diffractometer						
Ref.	National Bureau of Standards (U.S.) Monograph 25 Sec. 3 3 (1964)						
Sys.	Orthorhombic		S.G. Pbam (55)				
a ₀	7.5456	b ₀ 7.6898	c ₀ 2.8842	A0.98124 C 0.37506			
α	β	γ	Z	3/4 Dx 3.170			
Ref.	Ibid.						
ε α	1.637	n ω β 1.641	ε γ 1.652	Sign			
2V	D mp		Color	Colorless			
Ref.	Ibid.						
SAMPLE PREPARED AT NBS BY C. ROBBINS.	SPEC. ANAL.:						
0.01 to 0.1% Fe, and 0.001 to 0.01% each of Ca, Cr, Mg, Mn, Ni, Ti, and Zr.							
Pattern was made at 25°C.							
Chem. anal. showed 61.6 Al ₂ O ₃ , 38 (mole. %) SiO ₂							
	d Å	I/I ₁	hkl	d Å	I/I ₁	hkl	
	5.39	50	110	1.7125	6	240	
	3.774	8	200	1.7001	14	321	
	3.428	95	120	1.6940	10	420	
	3.390	100	210	1.5999	20	041	
	2.886	20	001	1.5786	12	401	
	2.694	40	220	1.5644	.2	141	
	2.542	50	111	1.5461	2	411	
	2.428	14	130	1.5242	35	331	
	2.593	<2	310	1.5067	<2	150	
	2.308	4	021	1.4811	<2	510	
	2.292	20	201	1.4731	<2	241	
	2.206	60	121	1.4605	8	421	
	2.121	25	230	1.4421	18	002	
	2.106	8	320	1.4240	4	250	
	1.969	2	221	1.4046	8	520	
	1.923	2	040	1.3932	<2	112	
	1.887	8	400	1.3494	6	341	
	1.863	<2	140	1.3462	6	440	
	1.841	10	311	1.3356	12	151	
	1.7954	<2	330	Plus 24 lines	to 1.0065		

ข. มัลลิต์



Standard Test Method for True Specific Gravity of Refractory Materials by Water Immersion¹

This standard is issued under the fixed designation C 135; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

^{ε1} NOTE—Section 9 was added editorially in January 1995.

1. Scope

1.1 This test method covers the determination of true specific gravity of refractory materials under prescribed conditions. It is not applicable to materials attacked by water.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- C 604 Test Method for True Specific Gravity of Refractory Materials by Gas-Comparison Pycnometer²
- D 153 Test Methods for Specific Gravity of Pigments³
- E 11 Specification for Wire-Cloth Sieves for Testing Purposes⁴

3. Significance and Use

3.1 The true specific gravity of a material is the ratio of its true density, determined at a specific temperature, to the true density of water, determined at a specific temperature. Thus, the true specific gravity of a material is a primary property which is related to chemical and mineralogical composition.

3.2 For refractory raw materials and products the true specific gravity is a useful value for: classification, detecting differences in chemical composition between supposedly like samples, indicating mineralogical phases or phase changes, calculating total porosity when the bulk density is known, and for any other test method which requires this value for the calculation of results.

3.3 This test method is a primary standard method which is suitable for use in specifications, quality control, and research and development. It can also serve as a referee test method in purchasing contracts or agreements.

3.4 Fundamental assumptions inherent in this test method are the following:

3.4.1 The sample is representative of the material in general,

3.4.2 The total sample has been reduced to the particle size specified,

3.4.3 No impurity has been introduced during processing of the sample,

3.4.4 The sample itself is not magnetic and all magnetic material introduced during processing of the sample has been removed,

3.4.5 The material is not hydratable or reactive with water, and

3.4.6 The test method has been conducted in a meticulous manner.

3.4.7 Deviation from any of these assumptions negates the usefulness of the results.

3.5 In interpreting the results of this test method it must be recognized that the specified sample particle size does not guarantee that all closed pores have been eliminated. The amount of residual closed pores may vary between materials or even between samples of the same or like materials, and the specified sample particle size is not the same as that specified for Test Method C 604. The values generated by this test method may, therefore, be close approximations rather than accurate representations of true specific gravities. Thus, comparisons of results should only be judiciously made between like materials tested by this test method or with full recognition of potentially inherent differences between the materials being compared or the test method used.

4. Apparatus

4.1 *Analytical Balance*, accurate to 0.1 mg.

4.2 *Pycnometer Bottle*, 50-mL, with ground-joint fitted thermometer and capillary side tube with cap.

4.3 *Vacuum Source*, capable of 0.5 to 1.0 in. (13 to 25 mm) Hg, for use with alternative method (Note 1).

NOTE 1—A suitable alternative evacuation method is described in Test Method D 153.

5. Preparation of Sample

5.1 Extract two pieces of walnut size from different positions in a solid specimen in such a way as to exclude any part of the original exterior surface (skin surface). When an average value of specific gravity is desired, prepare a composite sample by taking pieces in this manner from at least five different specimens.

5.2 Crush the pieces between hardened steel surfaces to a

¹ This test method is under the jurisdiction of the ASTM Committee C-8 on Refractories and is the direct responsibility of Subcommittee C08.03 on Physical Tests and Properties.

Current edition approved July 25, 1986. Published September 1986. Originally published as C 135 - 38. Last previous edition C 135 - 66 (1976)^{ε1}.

² *Annual Book of ASTM Standards*, Vol 15.01.

³ *Annual Book of ASTM Standards*, Vol 06.03.

⁴ *Annual Book of ASTM Standards*, Vol 14.02.

maximum size of $\frac{1}{8}$ in. (3 mm). Thoroughly mix the crushed material and reduce by quartering or riffing to a test sample of 50 g.

5.3 If the material submitted for test is already crushed or ground, a representative portion of at least 500 g shall be thoroughly mixed and reduced by quartering or riffing.

5.4 Grind the entire 50-g sample to pass an ASTM No. 100 (150- μm) sieve (equivalent to a 100-mesh Tyler Standard Series) (Note 2). The grinding may be done by hand or by a mechanical sample grinder of such material and construction as to prevent the introduction of any impurity. Remove any magnetic material introduced during crushing or grinding by a magnet. Special care should be taken in all stages of preparation of the test sample not to exclude any portions that are difficult to crush or grind.

NOTE 2—Detailed requirements for this sieve are given in Specification E 11.

5.5 Transfer the 50-g sample to a glass-stoppered weighing bottle and dry to constant weight at 105 to 110°C (220 to 230°F).

6. Procedure

6.1 Make duplicate tests on material from the 50-g sample. Make all weighings to the nearest 0.1 mg.

6.2 Dry the pycnometer at 105 to 110°C (220 to 230°F), cool in a desiccator, and weigh on an analytical balance. Record the weight as p . Fill the pycnometer with distilled water at room temperature, t , which should be between 60 and 75°F (16 and 24°C) and should not vary more than 0.5°F (0.3°C) during the test, and again weigh, recording the weight as W_1 . In filling the pycnometer, there should be an overflow of water through the capillary when the thermometer (stopper) is inserted. Wipe the excess water from the tip in such a manner as not to withdraw any water from the capillary. Place the cap on the capillary tube, thoroughly dry any water adhering to the outside of the pycnometer, and weigh as directed above.

6.3 Empty the pycnometer and again dry it at 105 to 110°C (220 to 230°F). Place approximately 1.5 mL of the sample in the dry pycnometer, weigh, and record the weight as W . Fill the pycnometer to one fourth to one half of its capacity with distilled water, and boil the water either under reduced pressure (Note 2) or at atmospheric pressure for 10 to 15 min. Boiling should not be so vigorous as to cause loss of sample due to popping. Where boiling is done at atmospheric pressure, it is advisable to insert a thin strip of paper with the stopper before the boiling operation. After boiling, fill the pycnometer with distilled water, cool to room temperature, t , in a water bath, insert the thermometer stopper, wipe off excess water from the tip of the capillary tube, replace the cap, and thoroughly dry the pycnometer with a lintless towel. Weigh the pycnometer and contents and report the weight as W_2 .

7. Calculation

7.1 Calculate the true specific gravity as follows:

$$\text{Sp gr, } t/t = (W - p) / [(W_1 - p) - (W_2 - W)]$$

where:

t = material and water temperature, °C,

p = weight of the stoppered pycnometer, g,

W = weight of the stoppered pycnometer and sample, g,

W_1 = weight of the stoppered pycnometer filled with water, g, and

W_2 = weight of the stoppered pycnometer, sample, and water, g.

8. Reproducibility of Results

8.1 Both determinations shall be reported to the nearest 0.01. The results shall check to within 0.03, or additional determinations shall be made in duplicate.

9. Keywords

9.1 nonhydratable; pycnometer; refractory material; true specific gravity; water immersion

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Standard Test Method for Free Moisture in Ceramic Whiteware Clays¹

This standard is issued under the fixed designation C 324; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

^{ε1} NOTE—Section 2, Referenced Document, was added editorially in December 1992.

1. Scope

1.1 This test method covers the determination of free moisture in ceramic whiteware clays. Whiteware clays may be shipped as a bulk shipment in lumps, a bulk shipment of shredded or coarsely ground clay, or in bagged lots of ground or airfloated clay. Directions are given in this test method for obtaining representative samples of the clay shipment to be used in subsequent tests for the properties of the clay in the shipment.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

- 2.1 *ASTM Standard:*
C 322 Practice for Sampling Ceramic Whiteware Clays²

¹ This test method is under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.04 on Clays.

Current edition approved June 25, 1982. Published August 1982. Originally published as C 324 - 53 T. Last previous edition C 324 - 56 (1981).

² *Annual Book of ASTM Standards*, Vol 15.02.

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3. Sampling

3.1 The sample shall be obtained in accordance with Practice C 322. The sample submitted for testing shall weigh not less than 1000 g, and shall be kept in an airtight container to prevent loss of water prior to testing.

4. Procedure

4.1 Remove the sample of clay from its container. Weigh about 500 g of the sample to the nearest 0.1 g. Spread out the weighed portion of the sample in a weighed shallow metal or porcelain container, and dry at 100 to 110 C for 24 h in a drying oven. Reweigh the dried clay, as quickly as possible, to the nearest 0.1 g.

5. Calculation

5.1 Calculate the percentage of free moisture to the nearest 0.1 % as follows:

$$\text{Free moisture, wet weight basis, \%} = [(A - B)/B] \times 100$$

$$\text{Free moisture, dry weight basis, \%} = [(A - B)/A] \times 100$$

where:

A = "as-received" weight of the portion of the sample used,
and

B = weight of sample after drying.



Standard Test Method for Particle Size Distribution of Alumina or Quartz by X-Ray Monitoring of Gravity Sedimentation¹

This standard is issued under the fixed designation C 958; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the particle size distribution of alumina or quartz powders in the range from 0.5 to 50 μm and having a median particle diameter from 2.5 to 10 μm using a sedimentation method. This test method is one of several found valuable for the measurement of particle size. Instruments used for this test method employ a constant intensity X-ray beam that is passed through a sedimenting dispersion of particles.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific hazard statements, see Section 7.*

2. Referenced Documents

2.1 ASTM Standards:

- C 242 Terminology of Ceramic Whitewares and Related Products²
- E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods³
- E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method³

3. Terminology

3.1 For definitions of terms used in this test method, refer to Terminology C 242.

4. Summary of Test Method

4.1 An aqueous homogeneous dispersion of the specimen is permitted to settle in a cell. The decrease in particle concentration over a programmed settling distance is monitored by an X-ray beam passing through the sedimenting dispersion to a detector. The specimen concentration at any given sedimentation distance is inversely proportional to the X-ray flux and the equivalent diameter (spherical) is calculated from Stokes' law.

NOTE—Refer to Terminology C 242. Most equipment manufacturers refer to this as the equivalent spherical diameter.

5. Apparatus

5.1 X-Ray Sedimentation Apparatus.⁴

5.2 *Ultrasonic Probe or Bath*—An ultrasonic probe approximately 13-mm ($\frac{1}{2}$ -in.) in diameter and approximately 50 to 100 W or an ultrasonic bath of approximately 0.3 W/cm² (2 W/in.²).

6. Reagents

6.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.⁵ Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

6.2 Distilled or Deionized Water.

6.3 *Dispersing Liquid*—Dissolve 1.0 g/L of reagent grade sodium hexametaphosphate in distilled or deionized water. Discard any remaining solution after six weeks from date of preparation.

7. Hazards

7.1 Precautions applying to the use of low-intensity X-rays should be observed.

7.2 Users should be aware that sample concentrations used in this test method may be higher than those considered ideal by some authorities and that the range of this test method extends into the region where Brownian motion could be a factor in conventional gravity sedimentation. Within the range of this test method neither the sample concentration nor Brownian motion are believed to be significant.

8. Procedure

8.1 Prepare the instrument for use according to the manufacturer's instructions.

8.2 If necessary, manually zero the instrument with the cell filled with the dispersing liquid.

⁴ Instruments available from Quantachrome Corp., 5 Aerial Way, Syosset, NY 11791, and Micromeritics Instrument Corp., One Micromeritics Drive, Norcross, GA 30093, have been found satisfactory for this purpose.

⁵ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

¹ This test method is under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.07 on Nonplastics.

Current edition approved Aug. 15, 1992. Published December 1992.

² *Annual Book of ASTM Standards*, Vol 15.02.

³ *Annual Book of ASTM Standards*, Vol 14.02.

8.3 Transfer 2.5 g of the dry specimen (or an equivalent amount of a slurried specimen) into a 50-mL beaker and add 30 mL of the dispersing liquid. Mix well using a rubber policeman to break up any clumping.

8.3.1 The amount of specimen required may vary between instruments. Adjust the specimen weight to reduce the X-ray intensity according to the manufacturer's recommended conditions.

8.4 Disperse the specimen using either of the instrument's, given in 8.4.1 and 8.4.2:

8.4.1 *Ultrasonic Bath*—Place the beaker in the bath and disperse the specimen for 5 min with frequent stirring. It is beneficial to cause the liquid level in the bath and beaker to match.

8.4.2 *Ultrasonic Probe*—Insert the probe into the beaker and disperse the specimen for 1 min. Do not allow the temperature of the dispersion liquid to rise more than 2°C.

8.5 Add a 25-mm (1-in.) magnetic stirring bar to the beaker, and place the beaker in the instrument's cell compartment. Adjust the stirring rate to produce a slight vortex.

8.5.1 If an instrument provides a different method for stirring and circulating the dispersion, be sure to follow the appropriate procedure.

8.6 Fill the cell with the dispersed slurry according to the manufacturer's instructions, making sure that no air bubbles remain in the cell.

8.7 Run the particle size distribution in the "Percent Finer Than" mode using a starting diameter of 50 µm. Calculate the instrument rates using a density of 3.95 g/m³ for alumina and 2.65 g/m³ for silica.

8.7.1 It is recommended that 8.6 and 8.7 be repeated in order to increase confidence in the analysis and to ensure that good dispersion has been achieved.

8.8 Upon completion of the analyses, rinse or clean the

instrument for the following run as suggested by the manufacturer.

9. Precision and Bias⁶

9.1 *Interlaboratory Test Program*—An interlaboratory study of the particle size distribution of alumina and quartz was run in 1989. Nine laboratories participated in the study, which included three different models of instruments, with each laboratory testing five specimens of each material. Except for the use of only two materials, Practice E 691 was followed for the design and analysis of the data.

9.2 *Test Result*—The precision information given in 9.3 in the units of equivalent spherical diameter (in micrometres) is for the comparison of two test results, each of which is the average of five test determinations.

9.3 Precision:

Test range	1 to 50 µm
95 % repeatability limit (within laboratory)	10 % (5 to 21 %) of the test result
95 % reproducibility limit (between laboratories)	15 % (8 to 29 %) of the test result

The above terms repeatability limit and reproducibility limit are used as specified in Practice E 177. The respective percent coefficients of variation among test results may be obtained by dividing the above numbers by 2.8.

9.4 *Bias*—No absolute method of particle size determination is recognized. Therefore, no justifiable statement can be made on the bias of the procedure in this test method.

10. Keywords

10.1 alumina; gravity sedimentation; particle size distribution; quartz

⁶ Supporting data are available from ASTM Headquarters. Request RR: C21-1004.

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Standard Test Method for Specific Surface Area of Alumina or Quartz by Nitrogen Adsorption¹

This standard is issued under the fixed designation C 1069; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the specific surface area of aluminas and silicas used in the manufacture of ceramics. The test method is a general one permitting the use of any modern commercial nitrogen adsorption apparatus but strictly defining the outgassing procedure. Calculations are based on the Brunauer-Emmett-Teller (BET) equation.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

2.1 ASTM Standard:

E 173 Practice for Conducting Interlaboratory Studies of Methods for Chemical Analysis of Metals²

3. Summary

3.1 An appropriate size sample is degassed for 1 h at 423 K before proceeding with the analysis as prescribed by the manufacturer of the instrument used. The sample is accurately weighed after analysis.

3.2 Calculations are based on the BET equations, adapted where necessary for the equipment being used. The cross-sectional area of the nitrogen molecule is taken as 0.162 nm².

4. Significance and Use

4.1 Both sellers and purchasers of alumina and quartz will find the test method useful to determine the specific surface area and indirectly as a measure of the particle size for material specifications, manufacturing control, and research and development.

5. Apparatus

5.1 *Specific Surface Area Analyzer*, recently (after 1970) manufactured commercial equipment employing low-temperature (77 K) nitrogen adsorption. This test method may be dynamic or static.

5.2 *Degassing Equipment*, suitable to the instrument used.

5.3 *Analytical Balance*, having a sensitivity of 1.0 mg.

6. Reagents and Materials

6.1 Liquid Nitrogen.

6.2 Cylinder of compressed nitrogen gas, high purity as specified by manufacturer, with pressure regulator.

6.3 Cylinder of compressed helium gas, high purity as specified by manufacturer, with pressure regulator, for static instruments or for dynamic instruments having gas mixing ability and employing the multipoint procedure or.

6.4 Cylinder of compressed, approximately 0.30 mol fraction, nitrogen in helium with pressure regulator, for other dynamic instruments employing the single point procedure.

7. Procedure

7.1 *Sample Preparation*—Blend the gross sample very well. For non-free-flowing materials mechanical agitation is necessary (for example, V-type blender with intensifier). If sample splitting of free-flowing materials is necessary, use a spinning riffler.³

7.2 Sample Degassing

7.2.1 Sample size is related to the equipment being used and shall conform to the equipment manufacturer's recommendations for highest precision.

7.2.2 The degassing technique (for example, vacuum, no-vacuum) shall conform to the equipment manufacturer's recommendations.

7.2.3 The degassing temperature shall be 1 h at 423 K.

7.2.4 Samples must be analyzed immediately after degassing.

7.3 *Analysis*—The analysis procedure recommended by the manufacturer as their most precise shall be followed.

8. Calculations

8.1 The procedure recommended by the manufacturer as being the most complete shall be followed.

9. Report

9.1 Report the following information:

9.1.1 *Results*—As m²/g.

9.1.2 Specific surface area as the average of two determinations, each made on separately degassed samples. If the results do not agree within 5% the procedure should be reviewed, the equipment checked, and the test repeated a third time.

¹ This test method is under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.07 on Nonplastics.

Current edition approved Aug. 29, 1986. Published October 1986.

² *Annual Book of ASTM Standards*, Vol 03.05.

³ Spinning riffles manufactured by Quantachrome Corp., Six Aerial Way, Syosset, NY 11791 or by Gilson Screen Co., P.O. Box 99, Malinta, OH 43535 have been found suitable for this purpose.

9.1.3 From a practical standpoint it is recommended that the following guidelines be used in reporting data:

9.1.3.1 From 1 to 99 m²/g—No more than two significant figures.

9.1.3.2 From 100 to 200 m²/g—To the nearest 1 m²/g.

9.1.3.3 From 200 m²/g and above—To the nearest 5 m²/g.

10. Precision and Bias

10.1 *Precision*—Six laboratories cooperated in a testing program involving various materials having specific surface areas ranging from 1 to 200 m²/g. The determinations were made in duplicate on separate samples and days. Practice E 173 was used to obtain the analyses of variance in Table 1.

TABLE 1 Analyses of Variance

Surface Area, m ² /g ^A	Repeatability Interval, R ₁ , m ² /g	Reproducibility Interval, R ₂ , m ² /g
1.1	0.05	0.19
1.3	0.12	0.26
8.4	0.40	2.07
9.3	0.44	0.86
25	0.63	5.2
101	4.8	11.0
205	8.2	33.2

^A Averages from round-robin study.

10.2 *Bias*—No absolute method for surface area determinations is recognized and, therefore, it is not possible to discuss bias of results obtained.

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Standard Test Method for Flow Rate of Metal Powders¹

This standard is issued under the fixed designation B 213; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval. B 213

1. Scope

1.1 This test method covers the determination of the flow rate of metal powders and is suitable only for those powders which will flow unaided through the specified apparatus.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 The flow rate of a metal powder determines the rate of filling of a die cavity in the pressing of sintered metal parts or bearings. High flow rates (low flow times) are usually desired for high productivity. The test method may be part of the purchase agreement between powder manufacturer and P/M parts producers, or it may be an internal quality control test for powder blended by a parts producer. It is commonly applied to ferrous powders and copper base alloys, but may be used on other powders as well. The test is not applicable to wet or pasty mixtures of metal powders, since they will not flow through the funnel and are not commonly used in P/M processing.

3. Apparatus

3.1 *Powder Flowmeter Funnel*—A standard flowmeter funnel² (Fig. 1) having a calibrated orifice of 0.10 in. (2.54 mm) in diameter.

3.2 *Stand*²—A stand (Fig. 1) to support the powder flowmeter funnel.

3.3 *Base*—A level, vibration-free base to support the powder flowmeter.

3.4 *Stop Watch*.

3.5 *Balance*—A balance suitable for weighing accurately to 0.01 g.

4. Test Specimen

4.1 The test specimen shall be 50 g, weighed to the nearest 0.1 g.

5. Procedure

5.1 The test specimen shall be tested as sampled. It should be noted, however, that moisture, oils, stearic acid, stearates, waxes, etc., may alter the characteristics of the powder.

5.2 Carefully load the test specimen into the flowmeter funnel while keeping closed the discharge orifice at the bottom of the funnel by placing a dry finger under it. Take care that the short stem of the funnel is filled.

5.3 Start the stop watch simultaneously with removal of the finger from the discharge orifice and stop it at the instant the last of the powder leaves the funnel. Record the elapsed time in seconds.

6. Report

6.1 The elapsed time shall be multiplied by the correction factor (see Note) and the result reported in seconds to the nearest second.

NOTE—The manufacturer supplies the funnel calibrated as follows: Using the procedure described in Section 5, the flow rate of standard 150-mesh Turkish emery is determined. The average of five determinations (the extremes of which shall not differ by more than 0.4 s) is stamped on the bottom of the funnel. The correction factor of the unused funnel is 40.0 divided by this number. It is recommended that the factor be periodically verified by the user by determining, by the above method, the flow rate of the standard 150-mesh Turkish emery.³ If the flow rate has changed from that stamped on the instrument, the new correction factor will be 40.0 divided by this new flow rate. Before adopting the new correction factor, however, it is recommended that the cause of the change be investigated. If the flow rate has increased, it is probable that repeated use has burnished the orifice and the new correction factor may be used. A decrease in flow rate may indicate a plating of soft powder upon the orifice. This should be carefully removed with the aid of a pipe cleaner and the calibration test rerun, the new correction factor being calculated if required. It is recommended that the use of a funnel be discontinued after the flow rate of the standard sample has increased such that the time of flow is less than 37 s. The manufacturer's experience indicates that, under conditions of almost continuous daily use, a decrease in time of flow of 3 s should be expected after 5 years of service.

7. Precision and Bias

7.1 The precision of this test method is presently being determined by Subcommittee B09.02.

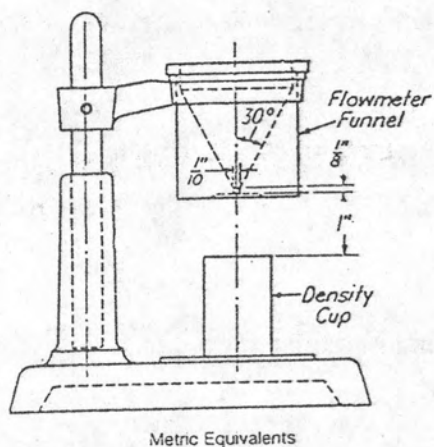
¹ This test method is under the jurisdiction of ASTM Committee B-9 on Metal Powders and Metal Powder Products and is the direct responsibility of Subcommittee B09.02 on Base Metal Powders.

Current edition approved Feb. 23, 1990. Published April 1990. Originally published as B 213 - 46 T. Last previous edition B 213 - 83.

² The powder flowmeter funnel, density cup, and stand are available from Alcan Powders and Pigments, 901 Lehigh Ave., Union, NJ 07083-7632.

³ Standardized No. 150 emery grit is no longer being sold. In those instances where the user desires to verify the correction factor and does not possess the No. 150 emery grit, the funnel may be returned to Alcan Powders and Pigments, 901 Lehigh Ave., Union, NJ 07083-7632, for re-calibration and re-certification. It is recommended that verification be done at least annually depending on frequency of use.

E 213



Metric Equivalents

in.	mm
1/10	2.54
1/8	3
1	25

FIG. 1 Flowmeter Apparatus

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Standard Test Method for Determination of Tap Density of Metallic Powders and Compounds¹

This standard is issued under the fixed designation B 527; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method specifies a method for the determination of tap density (packed density) of metallic powders and compounds, that is, the density of a powder that has been tapped, to settle contents, in a container under specified conditions.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- B 212 Test Method for Apparent Density of Free-Flowing Metal Powders²
- B 215 Practice for Sampling Finished Lots of Metal Powders²
- B 243 Terminology of Powder Metallurgy²
- B 329 Test Method for Apparent Density of Powders of Refractory Metals and Compounds by Scott Volumeter²
- B 417 Test Method for Apparent Density of Non-Free-Flowing Metal Powders²
- B 703 Test Method for Apparent Density of Metal Powders Using the Arnold Meter²

3. Significance and Use

3.1 This test method covers the evaluation of the tapped density physical characteristic of metallic powders and compounds. The degree of correlation between the results of this test method and the quality of powders in use will vary with each particular application and has not been fully determined.

4. Apparatus

4.1 *Balance*, of appropriate capacity and accuracy to satisfy the requirements shown in Table 1.

4.2 *Graduated Glass Cylinder*³, calibrated to contain 100 cm³ at 20°C, the height of the graduated portion being approximately 175 mm. The graduations shall be at 1 cm³

¹ This specification is under the jurisdiction of ASTM Committee B-9 on Metal Powders and Metal Powder Products and is the direct responsibility of Subcommittee B09.03 on Refractory Metal Powders.

Current edition approved Dec. 15, 1993. Published April 1994. Originally published as B 527 - 70. Last previous edition B 527 - 85 (1991).¹

² *Annual Book of ASTM Standards*, Vol 02.05.

³ Corning No. 3046. Pyrex brand has been found suitable.

TABLE 1 Accuracy and Capacity of Balance

Cylinder Capacity, cm ³	Apparent Density, g/cm ³	Mass of Test Portion, g
100	>1	100 ± 0.5
100	<1	50 ± 0.2
25	>7	100 ± 0.5
25	2 to 7	50 ± 0.2
25	<2	20 ± 0.1

intervals, thus allowing a measuring accuracy of ± 0.5 cm³. For apparent densities over 4.0 g/cm³, do not use the 100 cm³ cylinder.

4.2.1 Alternatively, the following may be used:

4.2.1.1 *Graduated Glass Cylinder*, calibrated to contain 25 cm³ at 20°C, the height of the graduated portion being approximately 135 mm. The graduations shall be at 0.2 cm³ intervals.

4.2.1.2 A 25-cm³ cylinder shall be used for powders of apparent density higher than 4 g/cm³, in particular for refractory metal powders, but may also be used for powder of lower apparent density.

4.3 *Tapping Apparatus*,⁴ which permits the tapping of the graduated cylinder against a firm base. The tapping shall be such that a densification of the powder can take place without any loosening of its surface layers. The stroke shall be 3 mm (0.118 in.) and the tapping frequency shall be between 100 and 300 taps/min. An example of a tapping apparatus is shown in Fig. 1.

5. Test Specimen

5.1 For the quantities of powder required for each test, see Table 1. Obtain test powder samples according to Practices B 215.

5.2 In general, the powder should be tested in the as-received condition. In certain instances the powder may be dried. However, if the powder is susceptible to oxidation, the drying shall take place in a vacuum or in inert gas. If the powder contains volatile substances, it shall not be dried.

5.3 The test shall be carried out on three test samples.

6. Procedure

6.1 Clean the inside the wall of the graduated cylinder (5.2) with a suitable clean brush or, if necessary, by rinsing with a solvent, such as acetone. If a solvent is used, thoroughly dry the cylinder before reuse.

⁴ The following have been found suitable: Shandon Southern Instruments, Inc., Tap-Pak Volumeter Model JEL-ST2 (Manufactured by J. Engelsmann A.G. of Ludwigshafen 9, Rh. West Germany), 515 Broad Street, Sewickly, PA 15143; Vankei Industries, Vanderkamp Tap Density Tester, 36 Meridian Road, Edison, NJ 08820; Quantachrome Corp., Dual Autotap, 6 Aerial Way, Syosset, NY 11791.

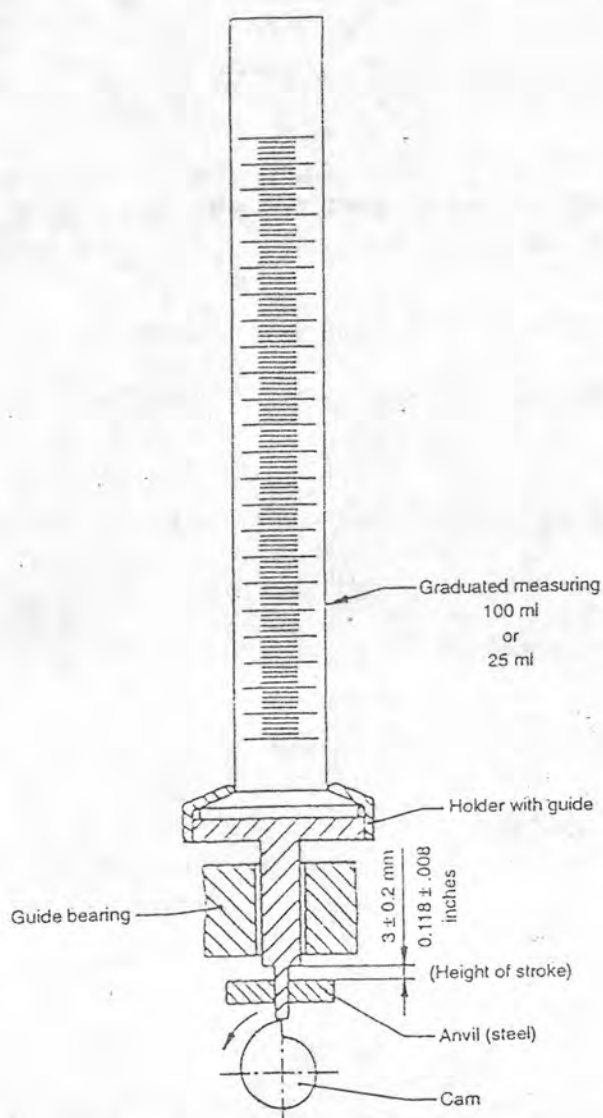


FIG. 1 Example of Tapping Apparatus

6.2 Weigh, to the nearest 0.1 g, the mass of the test portion as indicated in Table 1, using a balance (4.1).

6.3 Pour the test portion into the graduated cylinder. Take care that a level surface of the powder is formed. Place the cylinder in the tapping apparatus (4.3). Tap the cylinder until no further decrease in the volume of the powder takes

place (see Note 1).

NOTE 1.—In practice, the minimum number of taps, N , such that no further change in volume takes place would be determined. For all further tests on the same type of powder, the cylinder would be subjected to $2N$ taps, except where general experience and acceptance have established a specific number of taps (no less than N taps) as being satisfactory. For fine refractory metal powders, 3000 taps has been found to be satisfactory for all sizes.

6.4 If the tapped surface is level, read the volume directly. If the tapped surface is not level, determine the tape volume by calculating the mean value between the highest and the lowest reading of the tapped surface. Read the final volume to the nearest 0.5 cm³ when using a 100 cm³ cylinder and to the nearest 0.2 cm³ when using a 25 cm³ cylinder.

7. Calculation

7.1 The tap density is given in the following equation

$$P_t = \frac{M}{V}$$

where:

P_t = tap density, g/cm³,

M = mass of powder, g, and

V = volume of tapped powder, cm³.

8. Report

8.1 Report the following information:

8.1.1 Reference to this test method,

8.1.2 All details necessary for identification of the test sample,

8.1.3 The drying procedure, if the powder has been dried,

8.1.4 Cylinder capacity, mass of test portion and method used,

8.1.5 The result obtained,

8.1.6 All operations not specified in this test method or regarded as optional,

8.1.7 Details of any occurrence that may have affected the result.

9. Precision and Bias

9.1 Precision and bias cannot be stated at this time because this test method covers a broad range of powders and associated densities.

10. Keywords

10.1 apparent density; bulk density; density; density ratio; metal powders; packed density; powder metallurgy; tap density

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Standard Test Method for Density of Glass by Buoyancy¹

This standard is issued under the fixed designation C 693; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the density of glasses at or near 25°C, by buoyancy.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

2.1 ASTM Standard:

E 12 Terminology Relating to Density and Specific Gravity of Solids, Liquids, and Gases²

3. Terminology

3.1 Definition:

3.1.1 *density of solids*—the mass of a unit volume of a material at a specified temperature. The units shall be stated as grams per cubic centimetre (see Terminology E 12).

4. Significance and Use

4.1 Density as a fundamental property of glass has basic significance. It is useful in the physical description of the glass and as essential data for research, development, engineering, and production.

5. Apparatus

5.1 *Analytical Balance*, with sensitivity and accuracy of 0.1 mg.

5.2 *Beaker*, of convenient capacity (250 to 750 cm³) to fit inside the balance chamber and allow immersion of the basket or wire loop specimen holder in distilled water.

5.3 *Thermometers*, calibrated (20 to 30°C), sensitive to 0.1°C for determining air and water temperatures.

5.4 *Nickel-Chromium-Iron or Platinum-Alloy Wire*, less than 0.2 mm diameter for suspending the specimen either in a basket or a loop made of the same wire. The suspension wire shall be cleaned by degreasing or heating in a vacuum.³ An acceptable alternative method of cleaning the platinum-alloy wire is to heat in an oxidizing gas flame until there is no longer any color emitted from the gases passing around the wire.

5.5 *Weights*, with accuracy of 0.1 mg.

5.6 *Barometer*, with sensitivity of 1 mm Hg (optional, see Note 3).

6. Reagent

6.1 *Distilled Water*, fresh, boiled, and used within 24 h, allowed to stabilize at balance air temperature for at least 2 h in the beaker.

7. Test Specimen

7.1 Specimens weighing about 20 g, with a minimum of seeds or other inclusions (Note 1), shall be taken or cut from the sample object, preferably in cylindrical or rectangular bar form with smooth, slightly rounded surfaces having no cracks or sharp edges.

NOTE 1—For a specimen of 20 g with a density of approximately 2.5 g/cm³, a gaseous void of diameter 2 mm will cause an error in measured density of 0.05 %.

7.2 The specimens shall be cleaned, handling them with tweezers throughout subsequent operations, by immersion preferably in an ultrasonic bath of hot nitric acid, chromic-sulfuric acid, or organic degreasing solvent, followed by a rinsing in alcohol and distilled water. For samples only soiled by ordinary handling or exposure, adequate cleaning may be obtained using a warm 2 % volume MICRO-brand⁴ detergent, followed by a deionized or distilled water rinse.

8. Procedure

8.1 Hold the specimens and covered beaker of boiled distilled water near the laboratory balance until the water has cooled to ambient temperature before weighing.

8.2 Read the laboratory air temperature to the nearest 1°C. Read the barometric pressure to the nearest 1 mm Hg. A fixed laboratory average barometric pressure estimate is an acceptable alternative to the barometric pressure measurement (see Note 3). Determine the density, ρ_A , of the air from Table 1.

8.3 Weigh the glass specimen in air to the nearest 0.1 mg and record as W_A .

8.4 Place the beaker of water with immersed thermometer on a platform supporting it over the balance pan so that the pan or balance arm is free to swing.

8.5 Place the specimen in the basket or loop holder and hang this holder from the balance arm by means of a suitable hook and the suspension wire. Immerse the basket and specimen by raising the beaker of distilled water until the surface of the water is at a predetermined reference position on the suspension wire.

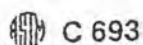
¹ This test method is under the jurisdiction of ASTM Committee C-14 on Glass and Glass Products and is the direct responsibility of Subcommittee C14.04 on Physical and Mechanical Properties.

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² *Annual Book of ASTM Standards*, Vol 15.05.

³ Bowman, H. A., and Schoonover, R. M., "Procedure for High Precision Density Determinations by Hydrostatic Weighing," *Journal of Research*, National Bureau of Standards, Vol 71C, No. 3, July-August 1967, pp. 179-198.

⁴ Manufactured by International Products Corporation, P.O. Box 70, Burlington, NJ 08016.

TABLE 1 Density of Dry Air, g/cm³

Temperature, °C	Pressure, mm Hg					
	720	730	740	750	760	770
20	0.001141	0.001157	0.001173	0.001189	0.001205	0.001221
21	137	153	169	185	201	216
22	134	149	165	181	197	212
23	130	145	161	177	193	208
24	126	142	157	173	189	204
25	122	138	153	169	185	200
26	118	134	149	165	181	196
27	115	130	146	161	177	192
28	111	126	142	157	173	188
29	107	123	138	153	169	184
30	104	119	134	150	165	180

TABLE 2 Density of Air-Free Water, g/cm³

Temperature, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
20	0.99820	818	816	814	812	810	808	806	804	801
21	799	797	795	793	791	788	786	784	782	779
22	777	775	773	770	768	766	763	761	759	756
23	754	752	749	747	744	742	740	737	735	732
24	730	727	725	722	720	717	715	712	710	707
25	705	702	700	697	694	692	689	687	684	681
26	679	676	673	671	668	665	662	660	657	654
27	652	649	646	643	640	638	635	632	629	626
28	624	621	618	615	612	609	606	603	600	598
29	595	592	589	586	583	580	577	574	571	568
30	565	562	559	556	553	550	547	543	540	537

NOTE 2—Prior to use, the beaker of water should be covered to minimize dust. Just prior to the weighing of the basket and specimen, the water surface near the suspension wire may be cleaned by a vacuum nozzle or pipet technique. The suspended assembly should be agitated slightly with a vertical motion to wet the suspension wire above the meniscus at the reference position and to ensure that no air bubbles are adhering to the glass or holder.

NOTE 3—A laboratory average barometric pressure estimate may be determined from the elevation of the laboratory estimated to the nearest 170 m (500 ft). The national average barometric pressure corrected to sea level (0 elevation) is 760 mm Hg. For each 341 m (1000 ft.) increase in elevation, barometric pressure decreases by approximately 25 mm Hg. For glass densities in the range of 2 to 6 g/cm³, a barometric pressure estimate based on this relationship will result in density measurement bias of less than 0.004% under normal atmospheric pressure variations.

8.6 Weigh the glass and holder in the distilled water to the nearest 0.1 mg and record as W_T .

8.7 Remove the glass from the holder. At the reference position, weigh the empty holder in the distilled water, to the nearest 0.1 mg and record as W_O .

8.8 Read the distilled water temperature to the nearest 0.1°C and determine the water density from Table 2. Record this as ρ_W .

9. Calculation

9.1 Calculate the weight of the specimen in water, W_W , as follows:

$$W_W = W_T - W_O$$

9.2 Calculate the glass density, ρ , at the average air-water laboratory temperature, T_L , as follows:

$$\rho = \frac{(W_A \rho_W - W_W \rho_A)}{(W_A - W_W)}$$

9.3 Calculate the glass density, ρ_S , at a standard reference temperature, T_S , as follows:

$$\rho_S = \frac{\rho}{1 + 3\alpha(T_S - T_L)}$$

where α is the approximate instantaneous coefficient of linear thermal expansion at T_S .

NOTE 4—For low expansion glasses or small temperature intervals or both, this correction is not required.

10. Report

10.1 Report the following information:

10.1.1 Identification of test sample, production, manufacturer, glass type, etc. as required,

10.1.2 Density of glass, ρ or ρ_S , in grams per cubic centimetre,

10.1.3 Temperature, T_S or T_L , for which glass density is reported,

10.1.4 Thermal history of specimen. If unknown, it should be so stated, and

10.1.5 Estimate of the volume of voids and inclusions.

11. Precision and Bias

11.1 Precision:

11.1.1 With proper precautions taken to minimize dissolved air in the water and adhering air bubbles during immersion of the specimen and holder, this procedure will yield glass density to a standard deviation within $\pm 0.1\%$.

11.1.2 With precautions taken to minimize air-water temperature differences and to correct for temperature, etc., effects on air and water density, this procedure will yield glass density to a standard deviation close to $\pm 0.03\%$.

11.2 Bias—Three glass density standard reference materials are available from the Standard Reference Materials Program, National Institute of Standards and Technology. Bias can be experimentally assessed by measurement of density by this procedure for these glasses.

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Designation: C 373 - 88 (Reapproved 1994)

Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products¹

This standard is issued under the fixed designation C 373; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for determining water absorption, bulk density, apparent porosity, and apparent specific gravity of fired unglazed whiteware products.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 Measurement of density, porosity, and specific gravity is a tool for determining the degree of maturation of a ceramic body, or for determining structural properties that may be required for a given application.

3. Apparatus and Materials

3.1 *Balance*, of adequate capacity, suitable to weigh accurately to 0.01 g.

3.2 *Oven*, capable of maintaining a temperature of $150 \pm 5^\circ\text{C}$ ($302 \pm 9^\circ\text{F}$).

3.3 *Wire Loop, Halter, or Basket*, capable of supporting specimens under water for making suspended mass measurements.

3.4 *Container*—A glass beaker or similar container of such size and shape that the sample, when suspended from the balance by the wire loop, specified in 3.3, is completely immersed in water with the sample and the wire loop being completely free of contact with any part of the container.

3.5 *Pan*, in which the specimens may be boiled.

3.6 *Distilled Water*.

4. Test Specimens

4.1 At least five representative test specimens shall be selected. The specimens shall be unglazed and shall have as much of the surface freshly fractured as is practical. Sharp edges or corners shall be removed. The specimens shall contain no cracks. The individual test specimens shall weigh at least 50 g.

5. Procedure

5.1 Dry the test specimens to constant mass (Note) by

heating in an oven at 150°C (302°F), followed by cooling in a desiccator. Determine the dry mass, D , to the nearest 0.01 g.

NOTE—The drying of the specimens to constant mass and the determination of their masses may be done either before or after the specimens have been impregnated with water. Usually the dry mass is determined before impregnation. However, if the specimens are friable or evidence indicates that particles have broken loose during the impregnation, the specimens shall be dried and weighed after the suspended mass and the saturated mass have been determined, in accordance with 5.3 and 5.4. In this case, the second dry mass shall be used in all appropriate calculations.

5.2 Place the specimens in a pan of distilled water and boil for 5 h, taking care that the specimens are covered with water at all times. Use setter pins or some similar device to separate the specimens from the bottom and sides of the pan and from each other. After the 5-h boil, allow the specimens to soak for an additional 24 h.

5.3 After impregnation of the test specimens, determine to the nearest 0.01 g the mass, S , of each specimen while suspended in water. Perform the weighing by placing the specimen in a wire loop, halter, or basket that is suspended from one arm of the balance. Before actually weighing, counterbalance the scale with the loop, halter, or basket in place and immerse in water to the same depth as is used when the specimens are in place. If it is desired to determine only the percentage of water absorption, omit the suspended mass operation.

5.4 After the determination of the suspended mass or after impregnation, if the suspended mass is not determined, blot each specimen lightly with a moistened, lint-free linen or cotton cloth to remove all excess water from the surface, and determine the saturated mass, M , to the nearest 0.01 g. Perform the blotting operation by rolling the specimen lightly on the wet cloth, which shall previously have been saturated with water and then pressed only enough to remove such water as will drip from the cloth. Excessive blotting will introduce error by withdrawing water from the pores of the specimen. Make the weighing immediately after blotting, the whole operation being completed as quickly as possible to minimize errors due to evaporation of water from the specimen.

6. Calculation

6.1 In the following calculations, the assumption is made that 1 cm^3 of water weighs 1 g. This is true within about 3 parts in 1000 for water at room temperature.

6.1.1 Calculate the exterior volume, V , in cubic centimetres, as follows:

$$V = M - S$$

¹ This test method is under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.03 on Fundamental Properties.

Current edition approved Sept. 30, 1988. Published November 1988. Originally published as C 373 - 55 T. Last previous edition C 373 - 72 (1982).

6.1.2 Calculate the volumes of open pores V_{OP} and impervious portions V_{IP} in cubic centimetres as follows:

$$V_{OP} = M - D$$

$$V_{IP} = D - S$$

6.1.3 The apparent porosity, P , expresses, as a percent, the relationship of the volume of the open pores of the specimen to its exterior volume. Calculate the apparent porosity as follows:

$$P = [(M - D)/V] \times 100$$

6.1.4 The water absorption, A , expresses as a percent, the relationship of the mass of water absorbed to the mass of the dry specimen. Calculate the water absorption as follows:

$$A = [(M - D)/D] \times 100$$

6.1.5 Calculate the apparent specific gravity, T , of that portion of the test specimen that is impervious to water, as follows:

$$T = D/(D - S)$$

6.1.6 The bulk density, B , in grams per cubic centimetre, of a specimen is the quotient of its dry mass divided by the exterior volume, including pores. Calculate the bulk density as follows:

$$B = D/V$$

7. Report

7.1 For each property, report the average of the values obtained with at least five specimens, and also the individual values. Where there are pronounced differences among the individual values, test another lot of five specimens and, in addition to individual values, report the average of all ten determinations.

8. Precision and Bias

8.1 This test method is accurate to $\pm 0.2\%$ water absorption in interlaboratory testing when the average value recorded by all laboratories is assumed to be the true water absorption. The precision is approximately $\pm 0.1\%$ water absorption on measurements made by a single experienced operator.

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Standard Test Method for Drying and Firing Shrinkages of Ceramic Whiteware Clays¹

This standard is issued under the fixed designation C 326; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of linear shrinkage of ceramic whiteware clays, both unfired and fired.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 The purpose of this test is to obtain values of shrinkage after drying and firing of clays or bodies or both, under various processing conditions to enable designers to determine the proper size of mold or die so as to produce a predetermined size of fired ware.

3. Test Specimens

3.1 Test specimens shall be either round bars approximately 25 mm in diameter by 115 mm in length, or bars of square cross section approximately 25 by 25 by 115 mm in dimensions.

3.2 Test specimens may be prepared either by casting or plastic forming, as circumstances require. At least five specimens shall be prepared. For cast specimens the molds may be either one-piece, or two- or more-part molds; in either instance sufficient space shall be provided to allow solid casting without piping. Where plastic-forming is employed, the clay-water mass shall be brought to a consistency that permits the making of specimens rigid enough to allow careful handling without distortion immediately after the test specimen is made. Plastic-formed test specimens shall be made either by extrusion or by pressing in a suitable metal mold. Where a vacuum pugmill is used, a vacuum of not less than 25 in. (635 mm) Hg shall be maintained during the forming operation. Where no vacuum attachment is used, the plastic clay shall be thoroughly hand-wedged to eliminate entrapped air as a preliminary to forming test pieces.

3.3 The test specimens, cast or plastic-formed, shall be suitably identified and marked with shrinkage reference lines 100 mm apart on the long axis of the specimen.

3.4 The marked specimens shall then be placed on a lightly oiled pallet and allowed to dry at 20 to 40°C for 24 h. During this preliminary drying period, bars of square cross section shall be turned 90 deg several times at 2-h intervals to eliminate possible warping. After the initial drying period,

the specimens shall be placed in a drying oven at 100 to 110°C and further dried for 24 h.

3.5 The drying shrinkage of the test specimens should be determined in accordance with Sections 4 and 5. The specimens can now be fired according to a suitable firing schedule to the desired temperature and the procedures of Sections 4 and 5 applied to determine the total shrinkage.

4. Shrinkage Measurement

4.1 Measure the distance between shrinkage reference marks on dried or fired specimens to the closest 0.1 mm with vernier calipers. Record the average of at least five measurements (one measurement on each of five specimens).

5. Calculation

5.1 Calculate the linear drying shrinkage as a percentage of plastic length, as follows:

$$S_d = \frac{L_p - L_d}{L_p} \times 100$$

where:

S_d = linear drying shrinkage, %,
 L_p = plastic length of test specimen, and
 L_d = dry length of test specimen.

5.2 Calculate the total linear shrinkage after drying and firing of clay shrinkage specimens as a percentage of plastic length, as follows:

$$S_t = \frac{L_p - L_f}{L_p} \times 100$$

where:

S_t = total linear shrinkage after drying and firing, %,
 L_p = plastic length of test specimen, and
 L_f = fired length of test specimen.

5.3 When desired, volume shrinkage may be calculated from linear shrinkage, as follows:

$$\text{Volume shrinkage, \%} = [1 - (1 - S/100)^3] 100$$

where:

S = linear shrinkage, %.

5.4 The shrinkage factor is used to convert fired sizes to plastic sizes or mold sizes. Calculate as follows:

$$\text{Shrinkage factor} = L_p/L_f$$

where:

L_p = plastic length of test specimen, and
 L_f = fired length of test specimen.

6. Precision and Bias

6.1 The direction of flow in forming influences the orientation of the clay particles and the shrinkage. The shrinkage value should be related to the method of forming

¹ This test method is under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.04 on Clays.

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as well as the dimension of the ware.

6.2 When the original reference points are 100 mm apart, the precision of the shrinkage measurement is $\pm 0.1\%$.

6.3 Measurements of drying shrinkage on one-dimension of specimens all formed by the same method should yield a

standard deviation of 0.1 % or less.

6.4 Measurement of total linear shrinkage after drying and firing on one dimension of specimens should yield a standard deviation of 0.25 % or less.

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Standard Test Methods for Flexural Properties of Ceramic Whiteware Materials¹

This standard is issued under the fixed designation C 674; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover determination of the modulus of rupture and the modulus of elasticity of fired ceramic whitewares bodies, formed by any fabrication method, and are applicable to both glazed and unglazed test specimens.

1.2 The values stated in inch-pound units are to be regarded as the standard. The metric equivalents of inch-pound units may be approximate.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Summary of Test Methods

2.1 The specimens, either cylindrical, or rectangular, are supported on knife edges over a suitable span and a direct load is applied at the midpoint between the supports at a uniform rate until breakage occurs. The modulus of elasticity may be determined by halting the applied load at definite intervals and measuring the deflection of the specimen at the midpoint to the nearest 0.001 in. (0.025 mm).

3. Significance and Use

3.1 These test methods provide a means for determining the modulus of rupture and the modulus of elasticity, which may be required in product specifications.

4. Apparatus

4.1 *Testing Machine*—Any suitable testing machine may be used, provided uniform rates of direct loading can be maintained.

4.1.1 For all specimens the loading rate should be such that the specimen should fail in approximately 1 min. Table 1 lists loading rates that shall be used for each size specimen. For strengths of specimens intermediate of those specified, interpolation can be used to obtain the equivalent loading rate.

4.1.2 For the prescribed rectangular specimens the loading rate shall be 1000 ± 150 lb (454 ± 68 kg)/min.

4.2 *Bearing Edges*—For the support of the test specimen, two steel (or high-strength ceramic) knife edges rounded to a radius of 0.125 in. (3.18 mm) shall be provided. The load

shall be applied by means of a third steel knife edge rounded to a radius of 0.125 in. When testing rectangular specimens the supporting members for the bearing edges shall be constructed to provide a means for alignment of the bearing surfaces with the surfaces of the test specimen (it being possible that the rectangular specimen may be wedge-shaped or twisted). The apparatus shown in Fig. 1 and Fig. 2 are suggested as suitable devices for ensuring proper spacing and alignment of the bearing edges for rectangular test specimens.

5. Test Specimens

5.1 *Preparation of Specimens*—Form, fire, and finish the specimens by the appropriate methods, following practices used in actual production.

5.2 *Dimensions*—The specimens shall be approximately 1.125 in. (28.6 mm), 0.750 in. (19.2 mm), 0.500 in. (12.7 mm), or 0.250 in. (6.4 mm) in diameter, whichever diameter is most comparable to that of the finished product. The length shall be 6 ± 0.50 in. (153 ± 12.7 mm) to permit an overhang of at least 0.25 in. (6.4 mm) at each end when mounted on the supports. Note that the 0.25-in. specimens may be 3.75 ± 0.25 in. (95 ± 7 mm) long.

5.2.1 The dry pressed specimens shall be rectangular bars approximately 1 in. (25.4 mm) by 0.50 in. (12.7 mm) in cross section and at least 4.50 in. (114 mm) in length to permit an overhang of at least 0.25 in. at each end when mounted on the supports.

5.3 *Handling*—Observe all due precautions in the forming, drying, and firing to produce straight test specimens of uniform cross section.

5.4 *Storage*—Cool test specimens taken warm from the kiln in a desiccator. If the testing must be delayed, store the bars in the desiccator, or in an electric oven at 110°C, and then cool in a desiccator before testing. When removing specimens from a hot kiln, take care to avoid thermal shock which will lead to erroneous results.

MODULUS OF RUPTURE

6. Procedure

6.1 Test at least ten dry specimens at room temperature.

NOTE—The modulus of elasticity may be determined as described in Sections 10 through 13 on the same type specimens used for the modulus of rupture test.

6.2 Place the cylindrical specimen on the bearing edges, spaced 5 in. (127 mm) $\pm 2\%$ between centers, with the specimen overhanging each end by at least 0.25 in. (6.4 mm). Apply the load at a right angle to the specimen and midway ($\pm 2\%$) between the supporting edges. Apply the load uniformly at the appropriate rate for the specimen size (see

¹ These test methods are under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and are the direct responsibility of Subcommittee C 21.03 on Fundamental Properties.

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TABLE 1 Loading Rates for Specimens

Specimen Size, in. (mm)	Span, in. (mm)	Nominal MOR, ksi (MPa)		
		10 (69)	30 (207)	50 (345)
		Loading Rate, lb/min (kg/s)		
1.125 (28.6) diameter	5 (127)	1100 (8.32)	3400 (25.70)	5600 (42.34)
0.750 (19.2) "	5 (127)	300 (2.27)	1000 (7.56)	1700 (12.85)
0.500 (12.7) "	5 (127)	100 (0.76)	300 (2.27)	500 (3.76)
0.250 (6.4) "	3 (76)	20 (0.15)	60 (0.45)	100 (0.76)
1 by 0.50 (25.4 by 12.7)	4 (102)	400 (3.02)	1250 (9.45)	2100 (15.88)

4.1.1) until failure occurs. Measure the diameter at four approximately equidistant points at the break, and take the average to the nearest 0.001 in. (0.0254 mm) for calculation purposes. Break the 0.25-in. diameter rods between 3-in. (76-mm) centers and note this in the report.

6.2.1 Place the rectangular test specimen on the bearing edges, spaced 4.0 in. (102 mm) between centers, with the specimen overhanging at each end by at least 0.25 in. (6.4 mm). Apply the load at a right angle to the 1-in. (25.4-mm) surface of the specimen and midway between the supporting edges. Break specimens glazed on only one of the 1-in. surfaces with the glazed surface either up or down, but break all of the specimens from any one lot in the same position and record this position. Apply the load uniformly at the rate of 1000 ± 150 lb (454 ± 68 kg)/min, until failure occurs. Measure the width and thickness at the break to the nearest 0.001 in. (0.0254 mm).

7. Calculation

7.1 Calculate the modulus of rupture of each circular cross section specimen as follows:

$$M = 8PL/\pi d^3$$

where:

- M = modulus of rupture, psi (or MPa),
- P = load at rupture, lbf (or N),
- L = distance between supports, in. (or mm)
- d = diameter of specimen, in. (or mm).

7.1.1 Calculate the modulus of rupture of each rectangular specimen as follows:

$$M = 3 PL/2bd^2$$

where:

- M = modulus of rupture, psi (or MPa),
- P = load at rupture, lbf (or N),
- L = distance between supports, in. (or mm),
- b = width of specimen, in. (or mm), and
- d = thickness of specimen, in. (or mm).

8. Report

8.1 Report the following information:

- 8.1.1 Identification of the material tested,
 - 8.1.2 Data and computed modulus of rupture for each specimen,
 - 8.1.3 The adjusted average of the computed modulus of rupture values (discarding those values from the bars which, upon inspection, show obvious defect), and
 - 8.1.4 In the case of glazed specimens, the position of the glazed surface or surfaces, with respect to the applied load.
- 8.2 The report may also include:
- 8.2.1 A description of type of fracture and the behavior of each specimen under load,
 - 8.2.2 Name and rating of the machine used to make the test, and
 - 8.2.3 A graph showing the individual values of modulus of rupture arranged in ascending order.

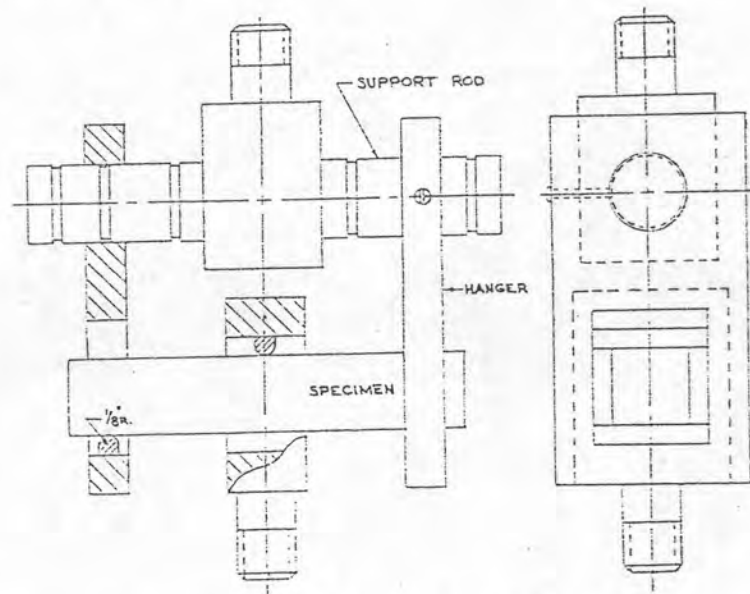


FIG. 1 Suggested Bearing Edge and Specimen Support

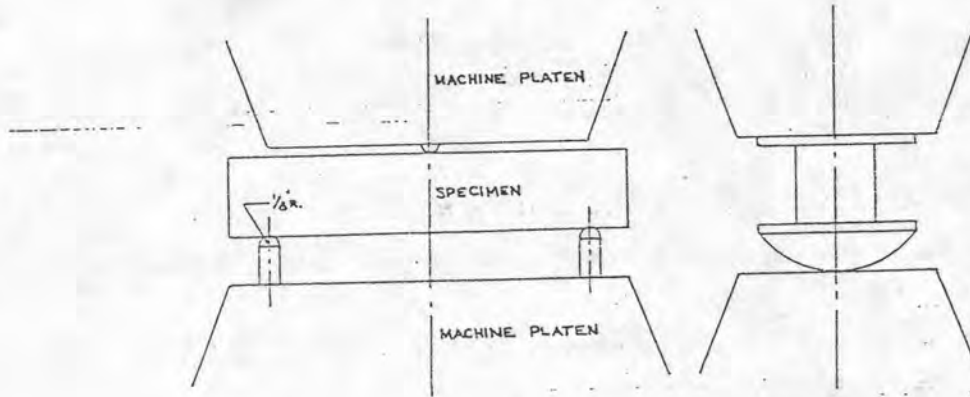


FIG. 2 Alternative Suggested Bearing Edge and Specimen Support

9. Precision and Bias

9.1 Precision:

9.1.1 *Interlaboratory Test Data*—An interlaboratory test was run in 1978 in which randomly drawn samples of five materials were tested in each of four laboratories. One operator in each laboratory tested ten specimens of each material. The components of variance for flexural strength results expressed as coefficients of variation were calculated as follows:

Single-operator component	2.42 % of the average
Between-laboratory component	18.79 % of the average

9.1.2 *Critical Differences*—For the components of variance reported in 9.1.1, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the following critical differences listed below:

Number of Observations in each Average	Critical Difference, % of Grand Average ⁴	
	Single-Operator Precision	Between-Laboratory Precision
10	6.72	52.10

⁴ The critical differences were calculated using $t = 1.960$ which is based on infinite degrees of freedom.

9.1.3 *Confidence Limits*—For the components of variance noted in 9.1.1, single averages of observed values have the following 95 % confidence limits:

Number of Observations in each Average	Width of 95 % Confidence Limits, Percent of the Grand Average ⁴	
	Single-Operator Precision	Between-Laboratory Precision
10	±4.75	±36.84

⁴ The confidence limits were calculated using $t = 1.960$ which is based on infinite degrees of freedom.

9.2 *Bias*—No justifiable statement on bias is possible since the true value of flexural strength of ceramic whiteware materials cannot be established and will be different for each specific material.

MODULUS OF ELASTICITY

10. Procedure

10.1 Support the specimen in the same way as for the

modulus of rupture determination. Set any type of deflectionometer capable of indicating to 0.001 in. (0.0254 mm) to measure deflection at mid-span relative to the ends of the span. Apply the load uniformly (see either 4.1.1 or 4.1.2) in accordance with the shape of the specimen. Stop the loading at 15 % increments of the expected total breaking load, as may previously have been determined in the modulus of rupture tests, and record the corresponding deflections.

11. Calculation

11.1 Plot the load-deflection readings to a convenient scale and draw a straight (stress-strain) line to represent, as nearly as possible, the average of the plotted points below the elastic limit. (In some materials, increasing departures from a straight line may be noted at the higher stress. Such evidence of plastic flow, or of non-recoverable strain, indicates that the elastic limit has been exceeded.) If the line does not pass through the zero point, draw a corrected line through this point parallel to the stress-strain line.

11.1.1 Calculate the modulus of elasticity, E , for rectangular specimens from the coordinates of some convenient point on the corrected line as follows:

$$E = W^1 L^3 / 4\Delta b d^3$$

where:

- W^1 = load coordinate of the selected point, lbf (or N),
- L = length of span, in. (or mm),
- Δ = deformation coordinate of the selected point, in. (or mm),
- b = width of specimen at the center, in. (or mm), and
- d = thickness of specimen at the center, in. (or mm).

11.1.2 Calculate the modulus of elasticity, E , for circular cross-section specimens from the coordinates of some convenient point on the corrected line as follows:

$$E = 4W^1 L^3 / 3\pi \Delta d^4$$

where:

- W^1 = load coordinate of the selected point, lbf (or N),
- L = length of span, in. (or mm),
- Δ = deformation coordinate of the selected point, in. (or mm), and
- d = diameter of specimen, in. (or mm).

12. Report

12.1 Report the following information:

12.1.1 Identification of the material tested,

12.1.2 Stress-strain data and modulus of elasticity for each specimen, and

12.1.3 In the case of glazed specimens the position of the glazed surface or surfaces.

13. Precision and Bias

13.1 Specific information to support a precision and bias statement for modulus of elasticity is not yet available.

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ประวัติผู้เขียน

นายสุรศักดิ์ ไทขวางศ์สกุล เกิดวันที่ 24 มกราคม พ.ศ. 2513 ที่บึงบัว กรุงเทพมหานคร สำเร็จการศึกษาปริญญาตรีวิทยาศาสตร์บัณฑิต สาขาวัสดุศาสตร์ ภาควิชาวัสดุศาสตร์ คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย ในปีการศึกษา 2534 และเข้าศึกษาต่อในหลักสูตร วิทยาศาสตร์มหาบัณฑิต สาขาวิชาเทคโนโลยีเซรามิก ที่จุฬาลงกรณ์มหาวิทยาลัย เมื่อ พ.ศ. 2535 และสำเร็จการศึกษาในเดือนตุลาคม พ.ศ. 2538

