Transverse Strength of Aluminous and Feldspathic Porcelain

C. A. SHERRILL and W. J. O'BRIEN*

School of Dentistry, University of Michigan, Ann Arbor, Michigan 48104, USA

The transverse strength of aluminous porcelain was compared with that of feldspathic porcelain and the effect of surface roughness and environmental moisture on these strengths was determined. Aluminous porcelain was superior to feldspathic porcelain in transverse strength and the transverse strength of both types of porcelain was affected adversely by environmental moisture.

McClean[1] and McClean and Hughes[2] have described the composition of several alumina-containing dental porcelains that contain up to 50% of fused alumina crystals plus a glass phase. The veneer porcelain that was used in conjunction with this aluminous core was essentially a conventional feldspathic porcelain.

Binns[3] has reported that the strength and elasticity of crystalline grains or zircon or alumina increased proportionally with the proportion of the crystalline phase when these mixtures were used as dispersed phases and when they were introduced into a glass of similar thermal expansion. Differences in thermal expansion between phases always reduced strength and elasticity; the reductions were greater when the thermal expansion of the glass phase was higher. These changes in properties were explained in terms of crack systems that were observed in the glass matrix.

Hasselman and Fulrath[4] have proposed a fracture theory which hypothesizes that hard crystalline dispersions in a glass matrix would limit the size of surface flaws and would strengthen the composite. The strength of a composite should be a function of the volume fraction of the dispersed phase at low volume fractions and it should depend on both the volume fraction and particle size at high volume fractions. Crack propagation takes place through the glass matrix and alumina spheres seem to resist crack propagation.

The influence of moisture at the fracture site has been studied by Mould,[5] and his results indicated that the static fatigue is produced by the slow growth of surface cracks and that it involves an interaction between the glass surface and some contaminating medium, generally water or water vapor.

Bascom[6] has reviewed the subject of moisture-induced failure in glass-resin composites with respect to the fundamental surface chemistry and fracture mechanics involved. These disciplines offered substantial information on water adsorption in polar solids, including glass.

Materials and Methods

PREPARATION OF FELDSPATHIC PORCELAIN SPECIMENS.—A mixture of feldspathic dentin porcelain[a] powder and distilled water was vibrated, to overflowing, into a specimen mold, and it was blotted and vibrated alternately until no further excess moisture was seen at the surface. The excess powder was scraped away and the sample was expressed through a removable floor in the mold (Fig 1).

The specimen was transferred to a porcelain furnace,[b] predried, and fired to 2,100 F at a rate of 100 F/minute and a reduced pressure of 27 inches of mercury. The vacuum was then released, and the specimens were removed and allowed to cool under glass to room temperature. The specimens

Based on a thesis submitted to the graduate faculty, University of Michigan School of Dentistry, in partial fulfillment of the requirements for the MS degree.

This investigation was supported by USPHS Research Grant DE-00181 from the National Institute of Dental Research, National Institutes of Health, Bethesda, Md.

Received for publication August 11, 1972.

* Present address: University of California School of Dentistry, San Francisco, Calif, 94143.

[a] Trubyte Bioform VF, 2,100 F, porcelain, shade B66, lot no. 429, Dentsply International, Inc., York, Pa.

[b] Huppert Airfire Furnace, Model 1AFM, serial no. 174, type 1, K. H. Huppert Co., South Holland, Ill.

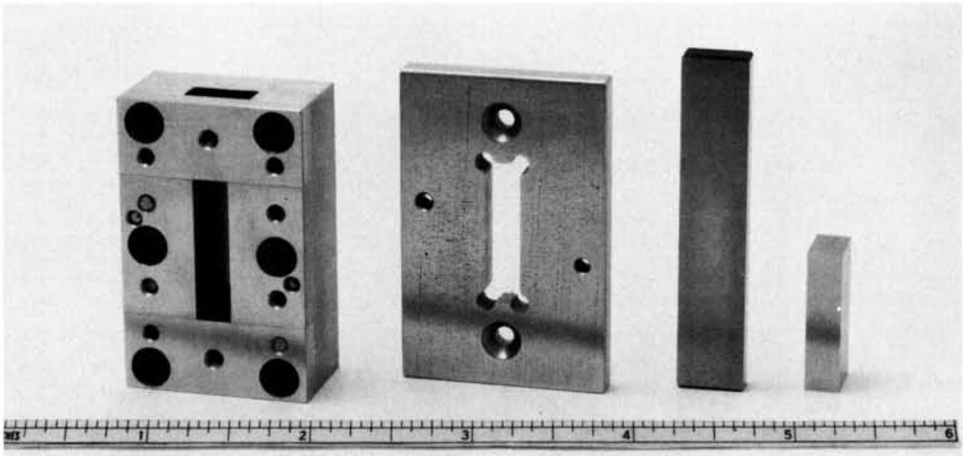

FIG 1.—Partially disassembled specimen mold.

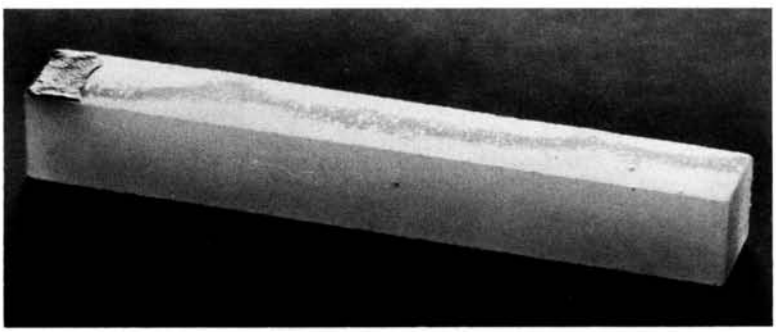

FIG 2.—Glazed feldspathic porcelain specimen.

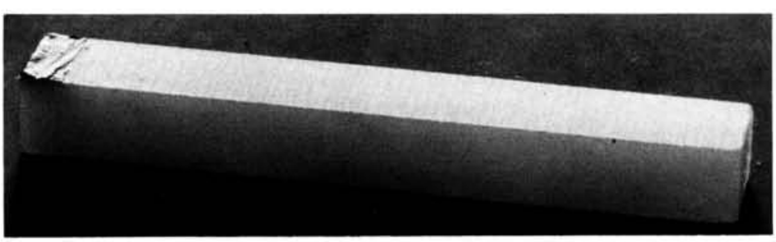

FIG 3.—Ground feldspathic porcelain specimen.

were ground[c] to uniform shapes and dimensions. The pressure was not reduced for glazing, and a temperature of 2,100 F was maintained for 1 minute. Those samples to be tested in a glazed condition were selected randomly and they were ground on a surface grinder to remove the surface glaze from their edges (Fig 2). Those samples to be tested in the ground condition were ground to remove the glaze from all surfaces (Fig 3). The length, width, and thickness of each specimen was measured with a metric micrometer.[d]

[c] Reid Surface Grinder, Model 618H, Reid Mfg., Beverly, Mass.

[d] L. S. Starrett Co., Athol, Mass.

[e] Vitadur-S, Opaque 341S, Unitek Corp., Monrovia, Ca.

Preparation of aluminous porcelain specimens.—The aluminous core laminates[e] were formed and they were removed from a shallower mold according to the same method (Fig 4). The laminates were transferred into the furnace, predried, and fired to 2,048 F at the rate of 50 F/minute and a reduced pressure of 27 inches of mercury. After cooling under glass, the core laminates were ground to a regular shape and the thickness of each was measured. Each core laminate was returned to the deeper mold for the addition of dentin porcelain.[f]

The specimens, now consisting of a fired core laminate and an unfired dentin addition, were returned to the furnace, predried, and fired to 1,720 F at the rate of 50 F/minute with a reduced pressure of 27 inches of mercury. The specimens were cooled under glass to room temperature. Each specimen was then ground to return the exposed base of its core laminate to a flat condition, and a record was kept to the required reduction. The tops and edges of all specimens were ground to regular shapes. The specimens were returned to the oven, predried, and the temperature was raised to 1,700 F at the rate of 50 F/minute at atmospheric pressure. Maintenance of this temperature for one minute produced a moderate glaze of the dentin porcelain. The specimens were cooled under glass to room temperature.

Each core laminate was then reduced by grinding to a thickness of 1 mm and the edges were reduced to produce uniform widths and lengths (Fig 5). Specimens were selected randomly and they were given additional surface glazes with dentin porcelain on their exposed core bases. Other specimens that did not receive the additional surface glaze were given the same heating cycle.

Surface roughness measurements.—The surface roughness of all specimens in the study was measured with a surface analyzer[g] (Fig 6). The measurements were made on the surfaces to be placed in tension during transverse strength testing.

Transverse strength testing.—Three-point loading[h] was used to perform the transverse strength testing (Fig 7). The crosshead speed was set at 0.05 cm/minute. A crosshead extension was used to align and to center the flexure-testing jig. In each test the specimen was positioned with the surface of known roughness down. Half of the specimens were tested while they were submerged in water. The formula that was used to obtain the transverse strength was:

$$R = \frac{3WL}{2bd^2},$$

where R is transverse strength; W is the breaking load; b is width; d is thickness; and L, is the distance between bearing edges.

Results

Mean surface roughness values are given in Table 1. Ground aluminous and feldspathic porcelain were considerably rougher than the corresponding glazed specimens. There was little difference in surface roughness between ground aluminous porcelain and ground feldspathic porcelain. Considerable difference in surface roughness was found between glazed aluminous porcelain and glazed feldspathic porcelain. The surface roughness tracings for both types of porcelain are given in Fig 8.

Table 2 shows the mean transverse strength values for both types of porcelain. The results of an analysis of variance (Table 3) indicate that aluminous porcelain specimens were approximately 40% stronger than feldspathic porcelain specimens ($\alpha = 0.01$); specimens that were tested dry were approximately 27% stronger than those that were tested wet ($\alpha = 0.01$); and specimens with ground surface finishes were approximately

TABLE 1

Mean Surface Roughness Values of Aluminous Porcelain and Feldspathic Porcelain (in microinches)

	Mean Surface Roughness	N	SD*
Aluminous porcelain			
Rough	40.8	10	10.5
Smooth	21.1	10	10.1
Feldspathic porcelain			
Rough	44.0	9	3.2
Smooth	9.5	10	4.0

* SD, standard deviation.

[f] Vitadur-S, Dentin 352, Unitek Corp., Monrovia, Ca.

[g] Gould-Brush 280 Surfanalyzer Recorder, Gould Surfanalyzer 150 Drive (model 21-1410-01), Gould Surfanalyzer Control (model 21-1330-20), and Probe (model 21-3100-00), Clevite Corp., El Monte, Ca.

[h] Instron, Model TT-BM, serial no. 1947, Instron Corp., Canton, Mass.

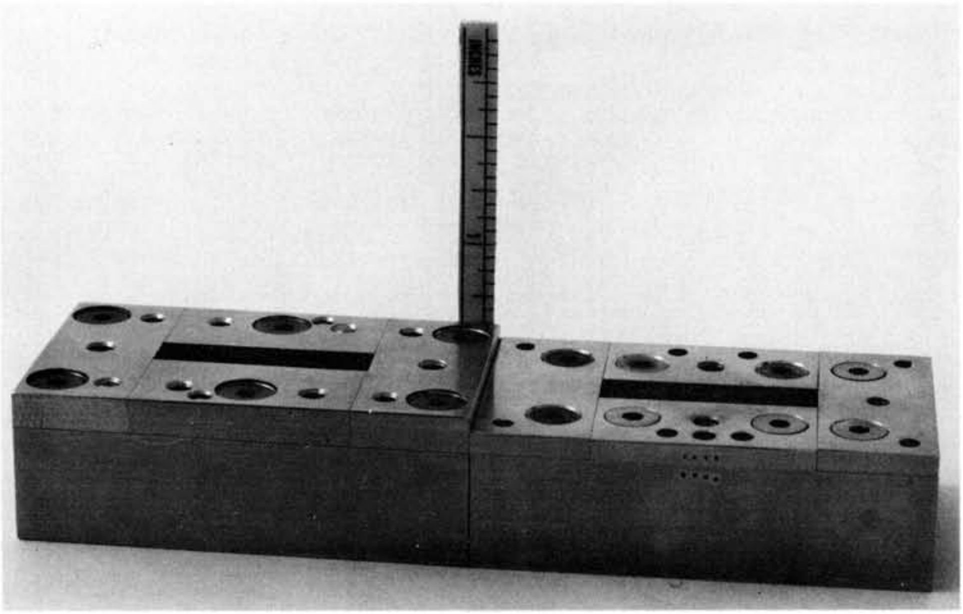

FIG 4.—Shallower and deeper specimen molds.

13% stronger than those with smooth surface finishes ($\alpha = 0.01$). An interaction existed between type and finish ($\alpha = 0.01$).

Table 4 gives the results of the analysis of variance for aluminous porcelain. The transverse strength for specimens that were tested dry was approximately 25% stronger than those that were tested wet ($\alpha = 0.01$). Ground specimens were 27% stronger than those with a surface glaze ($\alpha = 0.01$).

Table 5 gives the analyses of variance for feldspathic porcelain. Specimens that were tested dry were approximately 29% stronger than those that were tested wet ($\alpha = 0.01$). No statistically significant difference was found between the transverse strength of glazed porcelain and the transverse strength of ground porcelain specimens.

Discussion

Aluminous porcelain yields higher transverse strength values than feldspathic por-

TABLE 2

MEAN TRANSVERSE STRENGTHS OF ALUMINOUS PORCELAIN AND FELDSPATHIC PORCELAIN (kg/mm²)

	N	Mean (kg/mm²)	Psi	SD*	Psi
Aluminous porcelain (wet)					
Rough	5	11.2	16,200	0.63	896
Smooth	5	8.77	12,600	1.8	2,520
Aluminous porcelain (dry)					
Rough	5	14.0	19,900	1.1	1,510
Smooth	5	11.0	15,600	1.6	2,220
Feldspathic porcelain (wet)					
Rough	4	6.6	9,400	0.61	870
Smooth	5	7.3	10,000	0.67	950
Feldspathic porcelain (dry)					
Rough	5	9.0	13,000	0.25	360
Smooth	5	9.0	13,000	1.3	1,800

* SD, standard deviation.

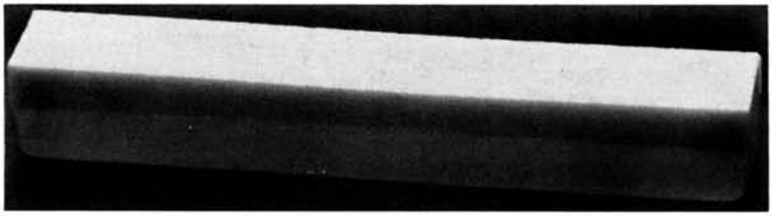

FIG 5.—Ground aluminous porcelain specimen.

celain. Values of 8.77 kg/mm^2 (12,600 psi) to 14.0 kg/mm^2 (19,900 psi) were obtained for aluminous porcelain; values of 6.6 kg/mm^2 (9,400 psi) to 9.0 kg/mm^2 (13,000 psi) were obtained for feldspathic porcelain. These values for aluminous porcelain agree with those that were reported by McLean for his compositions that contained 40% alumina.

No surface roughness values along with transverse strengths are reported in the literature for either aluminous or feldspathic porcelain. However, McLean[1] indicated that some of his test specimens were fired to produce vitrification, whereas others were ground before testing.

Table 3 shows that the mean surface roughness values that were obtained for the rough (ground) specimens were higher than those that were obtained for smooth (glazed) specimens. However, average roughness values alone do not give a complete picture of surface finish. Aluminous porcelain with a surface glaze has a maximum average roughness value that is lower than that of ground aluminous porcelain (Fig 8). The surface

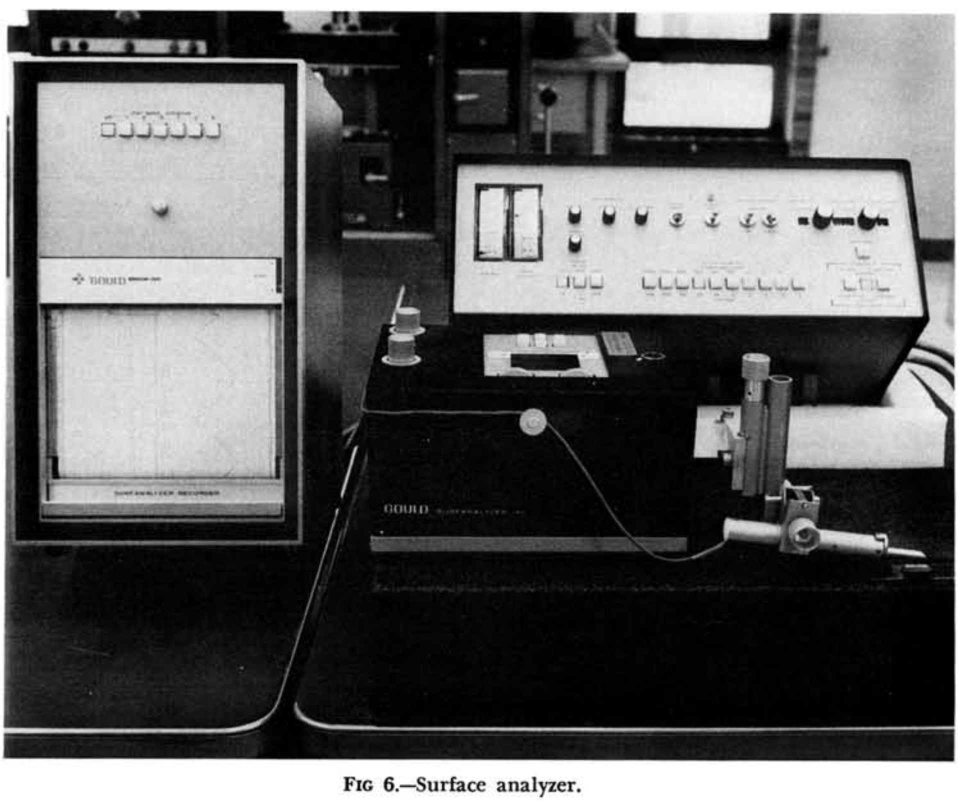

FIG 6.—Surface analyzer.

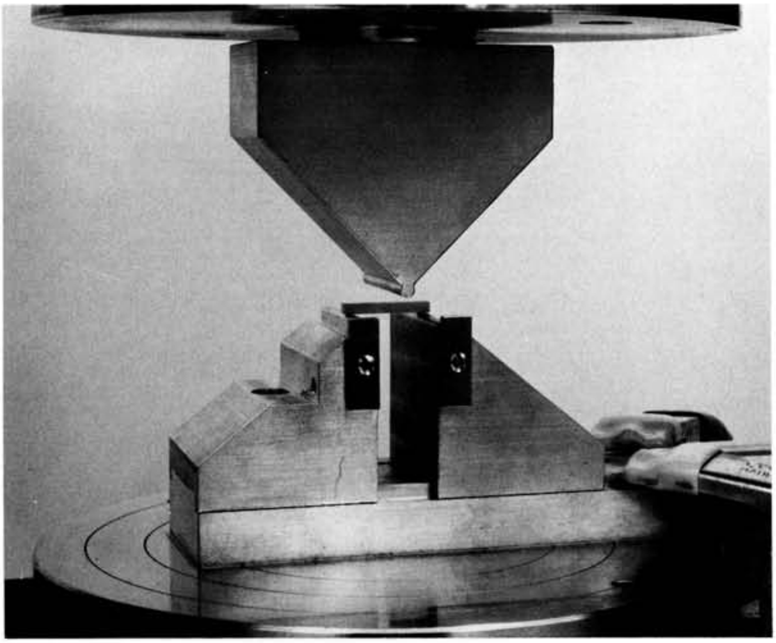

FIG 7.—Flexure-testing apparatus.

waviness of the glazed specimens is greater. This may account partially for the lower transverse strengths that were observed for those aluminous porcelain specimens with surface glazes. A difference in coefficients of thermal expansion between the core material and the dentin surface glaze may reduce transverse strength if the surface glaze has

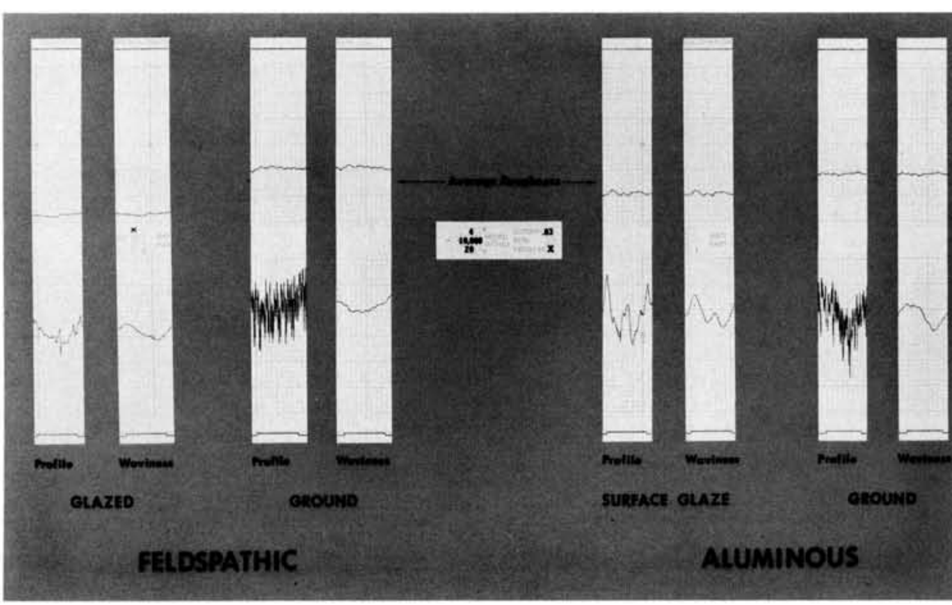

FIG 8.—Typical surface roughness tracings.

TABLE 3

ANALYSIS OF VARIANCE FOR COMPARISON OF ALUMINOUS PORCELAIN WITH FELDSPATHIC PORCELAIN

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Statistics
Material type	105.178	1	105.178	84.44*
Wet-dry	51.24	1	51.25	41.14*
Finish	13.752	1	13.752	11.04*
Material × wet-dry	0.5424	1	0.5424	0.435
Material × finish	23.09	1	23.09	18.538*
Wet-dry × finish	0.7167	1	0.7167	0.575
Material × wet-dry finish	0.00386	1	0.00386	0.0031
Error	38.615	31	1.2456	...

* Indicates significance at 0.01 level.

TABLE 4

ANALYSIS OF VARIANCE FOR ALUMINOUS PORCELAIN

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Statistics
Dry-wet	32.139	1	32.139	17.947*
Rough-smooth	37.34	1	37.34	20.872*
Interaction	0.31728	1	0.31728	.1771
Error	28.652	16	1.7908	...

* Indicates significance at 0.01 level.

TABLE 5

ANALYSIS OF VARIANCE FOR FELDSPATHIC PORCELAIN

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Statistics
Dry-wet	20.013	1	20.013	30.133*
Rough-Smooth	0.5839	1	0.5839	0.879
Interaction	0.4008	1	0.4008	0.6035
Error	9.9626	16	0.66417	...

* Indicates significance at 0.01 level.

residual stresses on cooling. The loss of dimensional uniformity during the addition of the surface glaze may be another explanation for the reduced strength of the glazed aluminous specimens.

All submerged specimens that were tested showed a significant decrease in their transverse strength. Other investigators[6,7] have reported the deleterious effects of moisture on the strength of ceramic materials. Further studies in this area may be necessary to determine the exact mechanisms that are involved and to reevaluate the applicability of results that are obtained from ambient testing of materials subjected to significantly different environments while in clinical use.

Conclusions

The transverse strength of commercially available feldspathic and aluminous porcelains was compared. The effects of surface roughness and environmental moisture were investigated. Mean surface roughness values ranged from 21.1 microinches for smooth aluminous porcelain to 40.8 microinches for ground aluminous porcelain; the values ranged from 9.5 microinches for smooth feldspathic porcelain to 44.0 microinches for ground feldspathic porcelain.

Mean transverse strength values obtained for aluminous porcelain were 14.0 kg/mm^2 (19,000 psi) for ground-dry, 11.2 kg/mm^2

(16,200 psi) for ground-wet, 11.0 kg/mm² (15,600 psi) for smooth-dry, and 8.77 kg/mm² (12,600 psi) for smooth-wet combinations.

Mean transverse strength values obtained for feldspathic porcelain were 9.0 kg/mm² (13,000 psi) for ground-dry, 9.0 kg/mm² (13,000 psi) for smooth-dry, 7.3 kg/mm² (10,000 psi) for smooth-wet, and 6.6 kg/mm² (9,400 psi) for ground-wet combinations.

Analyses of variance with a confidence level of 99% indicated that aluminous porcelain was approximately 40% stronger than feldspathic porcelain; specimens that were tested dry were approximately 27% stronger than those that were tested while submerged in distilled water, (the effect was about the same with both types of porcelain); and that aluminous porcelain was approximately 27% stronger when ground than when a surface glaze was applied to the core material. No statistically significant difference was demonstrated between the transverse strength of ground and the transverse strength of glazed feldspathic porcelain.

References

1. McLean, J.W.: The Alumina Reinforced Porcelain Jacket Crown, *JADA* 75: 621-628, 1967.
2. McLean, J.W., and Hughes, T.H.: The Reinforcement of Dental Porcelain with Ceramic Oxides, *Br Dent J* 119: 251-272, 1965.
3. Binns, D.B.: Some Physical Properties of Two-Phase Crystal-Glass Solids, in Stewart, G.H., (ed): *Science of Ceramics*, 1st ed, New York: Academic Press, 1962, pp 315-334.
4. Hasselman, D.P.H., and Fulrath, R.M.: Proposed Fracture Theory of a Dispersion Strengthened Glass Matrix, *Am Ceram Soc J* 49: 68-72, 1966.
5. Mould, R.E.: The Strength and Static Fatigue of Glass, *Glasstechnic Berichte (Eng)* 32K: 18-28, 1959.
6. Bascom, W.D.: Water at the Interface, *J Adhesion*, 2: 161-183, 1970.
7. Wiederhoen, S.: Effects of Environment on the Fracture of Glass, in Westwood, A.R.C. and Stoloff. (eds): *Environment-Sensitive Mechanical Behavior*, New York: Gordon and Beach, 1966, pp 293-315.