PHYSICAL PROPERTIES OF DENTIN

F. A. PEYTON, D.Sc., D. B. MAHLER, M.S., AND B. HERSHENOV, M.S.

School of Dentistry, University of Michigan, Ann Arbor, Mich.

FOR some time there has been considerable interest directed toward the evaluation of dental restorations from the physical property standpoint. The dental profession has long recognized that the success of a restorative appliance is dependent not only on the satisfaction of biologic criteria but, in addition, on the capabilities of the restorative materials as well as the tooth structure to resist external displacements and internal deformations. For purposes of clarity, *external displacement* is defined as a relative movement of the restoration with respect to the tooth, while *internal deformation* is defined as the dimensional change of the restoration or tooth with respect to itself. These effects are governed by the laws of mechanics and the inherent physical properties of the materials involved; either of them can result in the failure of the restorative attempt.

These movements are caused by forces applied to the tooth and restoration which, in turn, may be manifestations of mastication, thermal effects within the mouth, setting change of the restorative materials, and insertion of the restoration.

Present-day restorative preparations are results of years of practical experience and investigation, and have been qualitatively designed for retention or for resistance to external displacement, as well as to restore functon to the member involved. The quantitative analysis of external displacement and internal deformation, however, has not been investigated to any great extent, largely due to a lack of knowledge of the physical properties of tooth structure and restorative materials under the conditions which exist in the mouth.

As an aid in solving the over-all problem of the effects of these dimensional changes, this study was directed toward the determination of the physical properties of dentin. G. V. Black[1] (1895) determined the crushing strength of .080 inch cubes of dentin, but because of his equipment limitations, was unable to determine the proportional limit or the modulus of elasticity. Subsequent to this date, no substantial work has been done on these properties.

The difficulties connected with this investigation were quite extensive due to the many existing variables and will be borne out by the ensuing discussion. In general, the preparation of test specimens and the testing of them were further complicated by the small sizes involved and the absence of engineering testing procedures for these sizes, in addition to the heterogeneity of the tooth structure itself. As a result of these difficulties, the initial work, which is reported in this paper, was the determination of the existence of all the variables involved, so that further investigation on the singular effect of these variables could be expedited. In addition, working values of the physical properties of dentin were desired in order to establish a basis for analyzing the movements as described previously.

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SPECIMEN PREPARATION

First and second molar teeth were used for this study since they usually have relatively large amounts of dentin. These teeth were freshly extracted and were stored in water until time of test. The enamel was removed from the occlusal surface by grinding until the dentin was exposed. During this operation, the teeth were constantly dipped in water to prevent drying out and also to offset adverse temperature effects. They were then mounted in a steel ring filled with dental stone and the ring was placed in a lathe. Hollow drills were specially designed to be used for drilling out test samples. The design was such that water was in continual contact with the tooth. After this operation, the cylindrical specimens were placed in a special jig and the ends were finished to insure parallelism and flatness. They were then stored in water until time of test. The average size of these specimens was approximately 4.5 mm. long and 1.8 mm. in diameter.

TESTING PROCEDURE

The physical properties of dentin studied were the modulus of elasticity, proportional limit, and compressive strength, all of which can be determined from an applied stress and subsequent strain relationship for the material. By definition, stress is load or force per unit area and strain is deformation per unit length. As a consequence, the terms stress and load, strain and deformation, are often used synonymously since they are related simply by the geometry of the specimen.

The determination of strain presented a problem due to the small specimen size. A special loading device was made to allow for this measurement. Fig. 1 shows this device with a mounted specimen and the position of two Tuckerman Optical Strain Gauges. Eccentricity effects, which might enter into the strain measurements, were offset by the mounting of two gauges instead of one. The device consists of a rigid frame in which is mounted a stationary steel rod and a moveable one. The specimen was placed between the steel rods and load was applied through the upper moveable rod. By straddling the specimen, the strain gauges measured the deformation in both the specimen and that portion of the steel rods which lay within the gauge length. However, the deformation in the steel was negligible, for the loads applied. Therefore, the readings taken reflected only deformation in the dentin.

The entire assembly was then placed in a Tinius Olsen Universal Testing Machine and load was applied to the moveable steel rod. Strain readings were taken simultaneously. A stress-strain curve was plotted for each specimen, a sample of which is shown in Fig. 2. The points at which the three physical properties and their average values were determined by the tests conducted are also shown in this graph. By definition, the modulus of elasticity is the slope of the stress-strain curve within the elastic limit; the proportional limit is the stress beyond which stress is no longer proportional to strain; the compressive strength is the highest stress the material will withstand.

These properties define the inherent strength of the dentin and can be used quantitatively to predict its behavior under applied stress.

VARIABLES INVOLVED AND THEIR DETERMINATION

The main variables involved in this problem are indicated as follows and are accompanied by the measures employed to determine them:

1. Physiological differences in the teeth tested—
   Knoop Hardness Tests (500 Gm. load) used as control tests, as well as a stress-strain relationship, were made on each specimen.
2. Directional effects in the tooth structure—
   After the test, specimens were decalcified and the direction of the tubules relative to the axis of the cylindrical specimens was determined.
3. Rate of stress application—
   An attempt was made to keep this variable constant with the equipment available; however, variations did occur and the different rates of loading were calculated.
4. Length to diameter ratio of the specimens—
   This variable was kept fairly constant, except where it proved desirable to determine its effects on the physical property measurement.
5. Soundness of specimen—
   Specimens were checked visibly for defects or the presence of decay and the type of fracture was recorded.

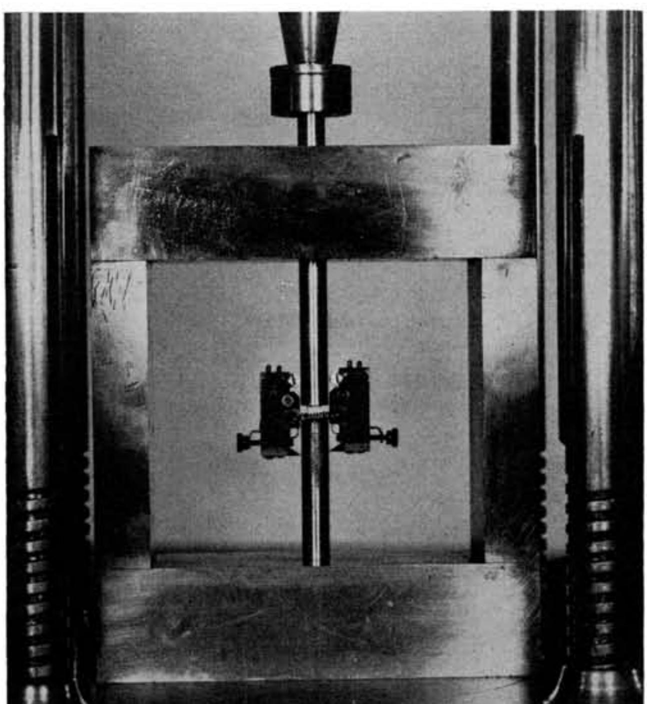

Fig. 1.—Dentin specimen mounted in a loading device showing the position of Tuckerman Strain Measuring Gauges. Entire assembly is shown between the loading platens of a Tinius Olsen Universal Testing Machine.

RESULTS

In Table I are shown the tabulated data for ten tests. The physical properties are recorded as well as the pertinent variables. As was mentioned, it

TABLE I
PHYSICAL PROPERTIES OF DENTIN AND INFLUENCING VARIABLES

SPECIMEN NUMBER	MODULUS OF ELASTICITY PSI	PROPORTIONAL LIMIT PSI	COMPRESSIVE STRENGTH PSI	KNOOP HARDNESS	TUBULE DIRECTION DEGREES	LOADING RATE PSI/MIN.	LENGTH TO DIAMETER RATIO
1	1,700,000	15,900	38,700	46	23	233,000	2.49
2	1,710,000	20,000	33,700	49	78	199,000	2.47
3	1,470,000	22.600	34,900	58	83	171,000	2.76
4	1,670,000	24,600	34,600	63	—	197,000	2.30
5	1 560,000	22,000	37,600	64	31	258 000	1.76
6	1,920,000	26.200	34,000	66	8	227,000	2.81
7	1,430,000	25,300	32,700	67	33	167,000	2.53
8	1,980,000	27,800	44,400	70	53	230,000	2.94
9	1,650,000	27.300	34,100	74	70	225,000	2.29
10	1.580,000	22,700	36,100	75	48	182,000	2.86
Average	1.670,000	23.400	36,100	63	47	209,000	2.52

was not found desirable, at this time, to isolate any of the variables to determine their singular effects on the physical properties. Instead, working values of modulus of elasticity, proportional limit, and compressive strength were initially deemed more important, and the averages of these ten tests were considered sufficient. A previous series of fourteen unpublished tests yielded an average modulus of elasticity of 1.66×10^6 psi. as compared to 1.67×10^6 psi. for

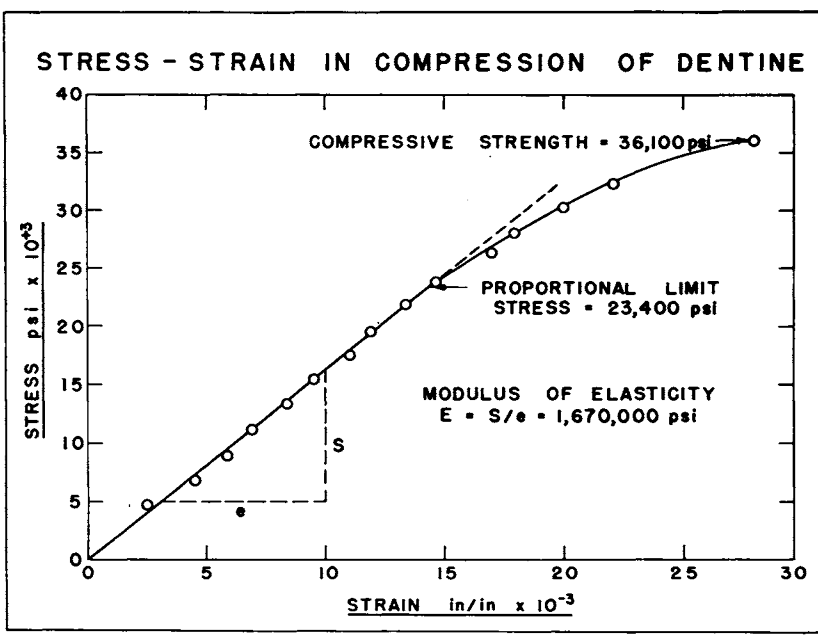

Fig. 2.—Stress-strain curve for dentin in compression indicating average useable values for the physical properties of this material.

these tests, and the work of G. V. Black[1] indicated an average compressive strength of 37,200 psi., compared to 36,100 psi. for these tests, thereby substantiating their validity. Inspection of the data indicates that all the variables mentioned are influential to some degree. Although the deviations of the physical property values from their averages may be as high as 20 per cent, it is important to realize that these are not random or experimental errors. These deviations can be correlated to a deviation of one or more variables from their average values, such that over-average, average, or under-average physical properties can be attributed to one or more over-average, average, or under-average variables. Specimens 3 and 8 were taken from the same tooth and, upon consideration of their Knoop hardness values, the results indicate that the physical properties of dentin may vary depending on the place from which the specimen was removed. This factor further validates the usage of an average physical property value since it would be most difficult to get a true value for any one tooth.

CONCLUSIONS

The following conclusions were drawn from this study:

1. The physical properties of dentin are influenced by the following variables:
   a. Physiological differences in teeth.
   b. Directional effects in the tooth structure.
   c. Rate of stress application.
   d. Length to diameter ratio of the test specimen.
   e. Soundness of test specimen.
2. The averages of the physical properties of dentin are as follows, and represent usable values for the analysis of stresses and subsequent movements in restorations and teeth:
   a. Modulus of elasticity—1.67×10^6 psi.
   b. Proportional Limit—23,400 psi.
   c. Compressive Strength—36,100 psi.
3. On the basis of Knoop hardness tests, the physical properties of dentin may vary within the same tooth, indicating the difficulty in obtaining true values for these properties.

REFERENCE

1. Black, G. V.: Physical Characters of the Human Teeth, *D. Cosmos* 37: May, 1895.