

The thermomechanical properties of gutta-percha

I. The compressibility of gutta-percha

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Sample wafers of compounded dental gutta-percha and uncompounded dental-grade gutta-percha were compression tested to 20,000 pounds in uniaxial and triaxial systems. Unrestrained flow in the uniaxial series prevented development of stress levels sufficient to produce molecular compression. Negligible molecular compression did occur in the triaxial series but only above a stress level of approximately 2,000 p.s.i. Below this level there was a reduction in volume due to consolidation and collapse of voids. Compressibility values for compounded dental gutta-percha proved to be less than that of water, considered for all practical purposes to be incompressible. Gutta-percha material undergoes compaction and not true compression during its clinical application; therefore, no molecular "spring-back" can be expected to assist in the seal at the dentin-gutta-percha interface. Reduction in apparent volume is due to consolidation and collapse of voids.

During the past several years, a considerable amount of data has been collected at the Boston University School of Graduate Dentistry regarding fundamental physical and chemical properties of gutta-percha, both in the raw state and in its compounded forms for use in dentistry. While primarily motivated by interest in gutta-percha as a root canal filling material, the studies have developed considerable information regarding the basic characteristics of gutta-percha itself, as well as the physics and engineering of its use in endodontics. After more than 100 years of dental use, it is striking that so little work of this nature has been recorded in the dental literature. The ongoing work at

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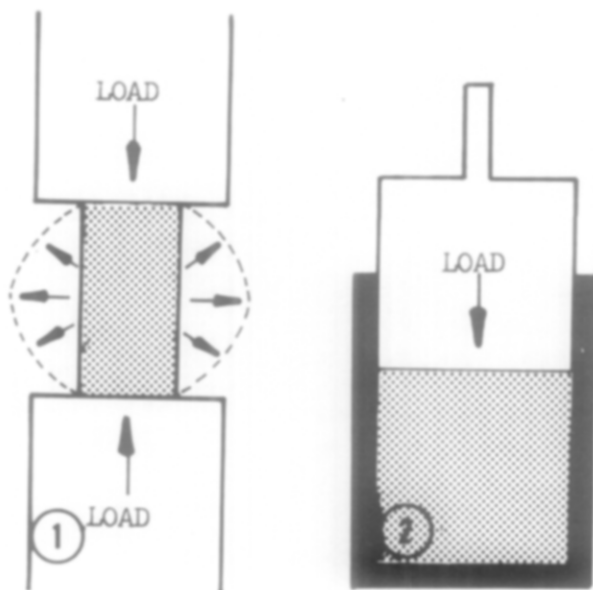


Fig. 1. Uniaxial system.

Fig. 2. Triaxial system.

Boston University is now being presented in serial form, the first section of which is recorded in this JOURNAL. Additional articles will cover further aspects of gutta-percha and will shed light, it is hoped, on the clinical use of this material.

There are dimensional changes in gutta-percha which result from the mechanical as well as the thermal manipulation to which it may be subjected during its various clinical applications in endodontics. The mechanism through which volume is presumed to be reduced with pressure has been a subject of current interest.

An earlier report¹ from our research program gave evidence of true compression of gutta-percha during endodontic manipulation, with volume reduction produced by the packing procedure and spring-back of the material released from restraining force. The data suggested the possibility of sealing canals at the dentin—gutta-percha interface without assistance from a cementing medium. Dye-immersion studies,² however, demonstrated dye penetration after condensation with all known root canal techniques unless some cementing agent was employed. It became evident that further refinement of experimental technique was necessary to clarify the question of the potential compressibility of gutta-percha.

If volume is reduced with condensation, either lateral or vertical, the question arises as to whether intermolecular distances are significantly reduced. Mechanical reduction of intermolecular distances would result in volumetric "spring-back," thus facilitating the seal at the dentin—gutta-percha interface (true compression). If volume is reduced without some reduction in intermolecular

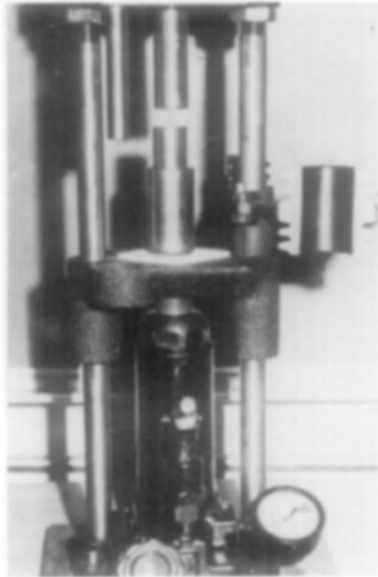


Fig. 3. Beuhler-Bakelite mounting press. (Piston-cylinder system in position.)

distance, another mechanism must account for the volume change. One must also consider the possibility that no volume changes occur during condensation and that any such changes may be illusory only. To examine this problem with precision, it was necessary to employ laboratory models and engineering procedures which would allow for reproducible quantitative determinations.

In making these determinations, the anatomy of the system into which the material is packed becomes an important consideration. Two types of system are recognized in the engineering literature for making the kinds of measurement required.³ A uniaxial or open stress system, comparable to a ram loading an unrestrained sample, is one in which the material has an opportunity to flow (Fig. 1). A triaxial system, on the other hand, is one in which the sample is completely restrained. This corresponds to a piston within a cylinder (Fig. 2).

It is difficult to monitor the actual stress levels achieved in partially restrained clinical systems with varying degrees of leakage. The clinical situation of condensing gutta-percha into a root canal system involves packing into a partially restrained uniaxial system and is capable of producing as many sets of data as there are teeth. Even in vertical condensation,⁴ one does not achieve a true triaxial system, since the plugger does not, and is not intended to, fit the canal like a piston. Some leakage of stressed material always takes place around the condensing instrument. Consequently, it became necessary to collect data for gutta-percha with uniaxial and triaxial systems of physically absolute design.

METHODS AND MATERIALS

Samples of both compounded and uncompounded gutta-percha were used in this phase of the study. The compounded dental gutta-percha was made available

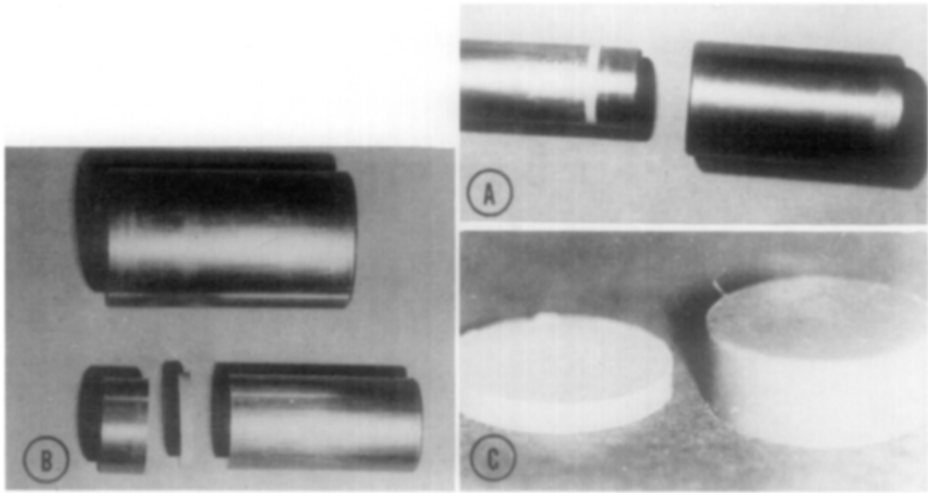


Fig. 4. Although both slugs are approximately the same weight in C, note thinner wafer of the compounded sample on the left, due to its greater density, as opposed to the uncompounded sample on the right.

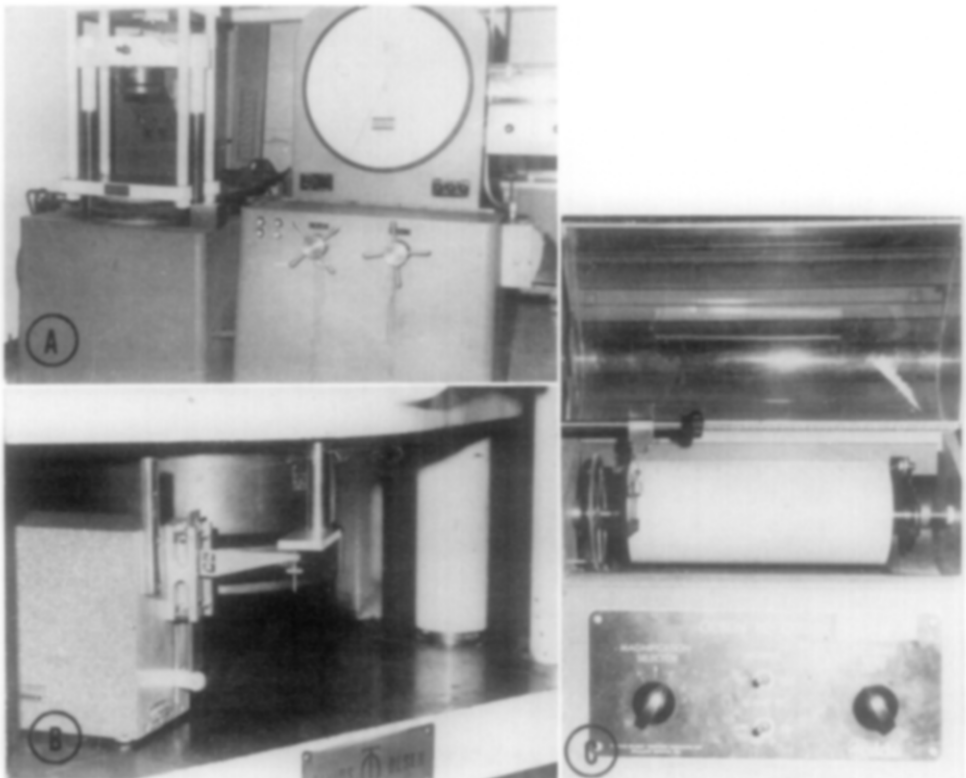


Fig. 5. A, Tinius-Olsen compression machine. B, Position transducer. C, Olsen recorder.

in the form of the usual rolled cones, and the uncompounded dental-grade material in the form of slabs $\frac{1}{2}$ inch thick furnished by the Mynol Company. To facilitate testing, portions of each were weighed to approximately 8 grams, placed into a steel piston—cylinder system, and molded into slugs with a Beuhler Bakelite mounting press (Figs. 3 and 4). Diameter and thickness were recorded for subsequent calculations.

The sample slugs were then compression tested to 20,000 pounds in a triaxial state of stress at room temperature (about 25° C.) and at 68° C., which was above the crystalline phase transformation temperatures of the polymer,⁵ but still low enough to prevent measurable leakage from the compression system. Uniaxial testing was performed at room temperature only, since uniaxial compressive stress of fluid material at low strain rates is essentially zero and gutta-percha at 68° C. attains semifluid consistency.

A Tinius-Olsen tension compression machine was used for the actual compression phase of the experiment (Fig. 5). This instrument incorporates a hydraulic loading device and load-measurement system with an electronic position transducer capable of measuring resultant displacement. Information from each system was received and charted by an Olsen recorder, with deformation of the specimen plotted as a function of applied load. From this it was possible to calculate the stress on the specimen (force per unit area) and the strain of the specimen (deformation per unit length). A graphic representation of stress versus strain was then plotted to evaluate the curves (Fig. 6).

RESULTS

There was a marked difference between uniaxial and triaxial behavior. Because of the unrestrained flow in the uniaxial series, it was not possible to achieve stress levels sufficient to produce actual compression. In the triaxial series, however, molecular compression did occur, but only at stress levels above approximately 2,000 p.s.i. Calculated from the linear region of the curves and expressed in terms of inverse pounds per square inch, the compressibility values for compounded dental gutta-percha were 1.32×10^{-6} at room temperature and 9.54×10^{-7} at 68° C. The lower compressibility value at the higher temperature was attributed to molecular thermal excitation.

DISCUSSION

Only in the triaxial series did any molecular compression actually take place; however, this did not occur until after a stress level of approximately 2,000 p.s.i. was achieved. Below this level there was some recordable volume reduction due simply to consolidation and collapse of internal voids (Fig. 6). The compression of compounded dental gutta-percha which occurred at room temperature amounted to only 1.32 millionths of a cubic inch per cubic inch of material for every pound per square inch increase in pressure above 2,000 p.s.i. This was even less (0.954 millionths) at 68° C. For the uncompounded material, the compression curves were essentially the same. This negligible degree of compressibility can be demonstrated only within a system of true triaxial design, where the material is completely restrained and cannot flow in a superior, inferior, or lateral

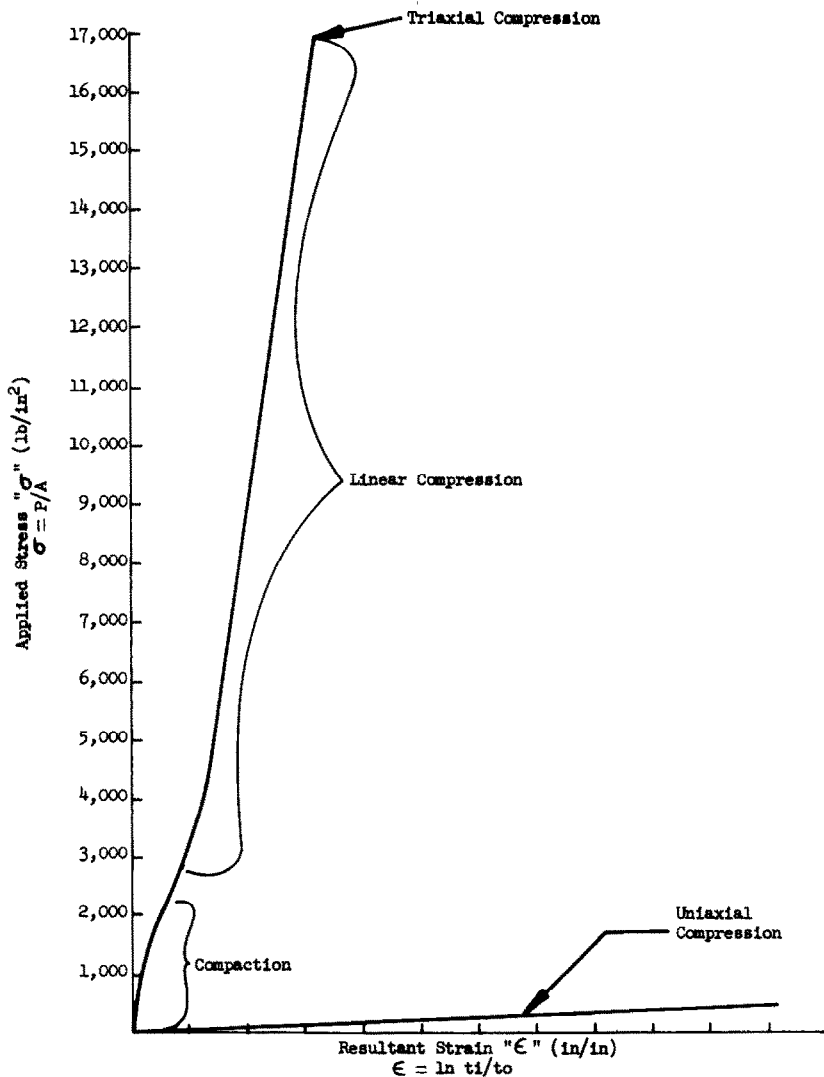


Fig. 6. Schematic representation of experimental stress-strain results illustrating the difference in behavior between triaxial and uniaxial compression of dental gutta-percha at room temperature.

direction, even under loads of up to 20,000 pounds. It is interesting to convert the compressibility values for gutta-percha into units more commonly used in reporting (bars), in order that they may be compared to those of other materials, such as water (Fig. 7).

Compounded dental gutta-percha was found to be less compressible than water, and, for all practical purposes, water is considered incompressible by the engineering community. Considering the triaxial load required to produce even negligible compression of the gutta-percha polymer, it becomes apparent that this material does not undergo true compression during its clinical application.

COMPRESSIBILITY VALUES FOR DENTAL GUTTA-PERCHA AND WATER			
TEMPERATURE	DENTAL GUTTA-PERCHA		WATER
	K (lb/in ²) ⁻¹	K BARS ⁻¹	K BARS ⁻¹
ROOM TEMPERATURE	1.32×10^{-6}	1.915×10^{-5}	4.52×10^{-5}
68° c	9.54×10^{-7}	1.380×10^{-5}	4.50×10^{-5}

Fig. 7. Compressibility values for dental gutta-percha and water expressed in bars⁻¹.

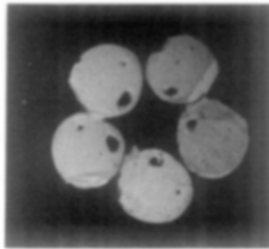


Fig. 8. Internal voids in a commercial gutta-percha cone chosen at random from a previously unopened package and sliced with a biopsy knife.

If volume reduction due to reduction of intermolecular distance is virtually nil under this type of powerful stressing, how, one might ask, can volume reduction due to compression be obtained under clinical conditions? It seems most probable that clinically available gutta-percha cones, which are easily demonstrated to contain significant voids (Fig. 8), are not compressed at all. However, the material is capable of compaction during endodontic condensation procedures. Compaction is not without merit in solidifying the gutta-percha mass in a root canal filling.

SUMMARY

Sample wafers of compounded dental gutta-percha and uncompounded dental-grade gutta-percha were compression tested to 20,000 pounds in uniaxial and triaxial systems. Unrestrained flow in the uniaxial series prevented stress levels sufficient to produce molecular compression. Negligible molecular compression occurred in the triaxial series, but only above a stress level of approximately 2,000 p.s.i. Below this level there was a reduction in volume due to consolidation and collapse of voids.

CONCLUSIONS

1. Compounded dental gutta-percha is less compressible than water.
2. *Compaction*, not compression, is what is obtained under clinical conditions.

3. The reduction in apparent volume which takes place as a result of mechanical manipulation is due to consolidation and collapse of internal voids and occurs well within compaction forces.

4. No molecular "spring-back" can be expected to assist in the seal at the gutta-percha-dentin interface.

REFERENCES

1. Marlin, J., and Schilder, H.: Physical Properties of Gutta-Percha When Subjected to Heat and Condensation, *ORAL SURG.* **36**: 872-879, 1973.
2. Schilder, H.: Student Laboratory Demonstrations at the Boston University School of Graduate Dentistry. Unpublished data.
3. Hayden, H. W., Moffatt, W. G., and Wolff, J.: The Structure and Properties of Materials, New York, 1965, John Wiley & Sons, Inc., vol. III, chap. 2.
4. Schilder, H.: Filling Root Canals in Three Dimensions, *Dent. Clin. North Am.*, pp. 723-744, November 1967.
5. Goodman, A., Schilder, H., and Aldrich, W.: The Determination of Phase Transition Temperatures for Gutta-Percha. (In press.)

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