Stress/strain behavior of some dental luting cements

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Øilo, G. & Espevik, S. Stress/strain behavior of some dental luting cements. *Acta Odont. Scand.* 36, 45–49

The compressive strength, modulus of elasticity and the plastic strain at fracture have been studied for several dental luting cements. Stress/strain diagrams of cylindrical specimens using two different crosshead speeds (2 mm/min and 0.1 mm/min) at 23° and 37°C showed that large differences existed between various luting cements.
A zinc phosphate cement exhibited high strength, high modulus of elasticity and a small plastic strain at fracture. A resin cement also had high strength, but elastic and plastic strains were high. A polycarboxylate and an EBA-cement both showed low values of strength and modulus of elasticity combined with a high degree of plastic deformation at fracture. Testing with low strain rate at 37 °C accentuated the differences between these two materials and the zinc phosphate cement.

Key-words: Dental materials, mechanical properties

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The retention of cast restorations is dependent on many factors, including the mechanical properties of the luting agent. It has been shown that the compressive strength of the cement is an important factor where the retention is based upon mechanical interlocking (4). However, a restoration and its luting cement is subjected to dynamic loading in vivo, with forces lower than those causing fracture of the materials. An elastic as well as plastic deformation could possibly be of importance for the retentive ability of the luting layer. Large differences have been found in the elastic behavior of some cements (9) and a tendency to plastic deformation has been reported for one type of cement (8).

The purpose of the present investigation was to compare the stress/strain behavior for some dental luting cements under varying testing conditions.

Received for publication, September 26, 1977.

METHOD

The cements listed in Table 1 were mixed according to the manufacturers' instructions at 23 ± 1 °C. Cylindrical specimens (4 x 6 mm) were produced according to the method described in ISO/DIS 1566 (International Organization for Standardization/Draft International Standard, 1566–1976).

Before testing, the specimens were stored for 24 hours in distilled water at 37 ± 2 °C. The specimens were then compressed to fracture in a mechanical testing machine (Testatron, S 718, Otto Wolpert Werke GmbH, Ludwigshafen/Rhein, Germany). The stress/strain behavior of these specimens were followed on a X-Y recorder. An apparent modulus of elasticity was calculated from the stress/strain curves. Corrections for the deformation of the compression plates were made.

Five specimens of each cement were tested at 23 ± 1 °C with a crosshead speed of 2 mm/min. Five other specimens were tested at the same temperature with a crosshead speed of 0.1 mm/min, and three specimens of each cement with the same strain rate at 37 ± 2 °C.

RESULTS

The compressive strength, modulus of elasticity and the plastic strain at fracture for different cements under three different testing conditions are presented in Figs. 1, 2 and 3. Large differences were found for the mechanical properties as well as the influence of the testing conditions on the stress/strain behavior of the different cements (Figs. 4,5).

The highest strength values were recorded for resin cement. The values for zinc phosphate cement were about 50% lower and those of the polycarboxylate and EBA-cements about 75% lower (Fig. 1). A variation of the crosshead speed showed that the polycarboxylate and EBA-cements had a significantly ($P < 0.01$) higher strength at the high loading rate than at the low loading rate.

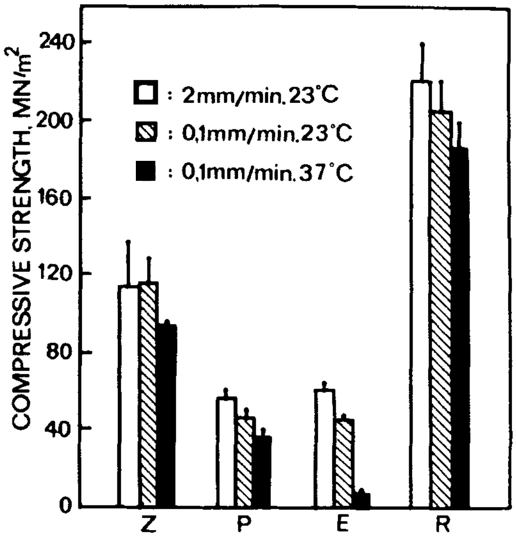

Fig. 1. Compressive strength as a function of crosshead speed and temperature (Z: Zinc phosphate cement, P: Polycarboxylate cement, E: EBA-cement and R: Composite resin cement).

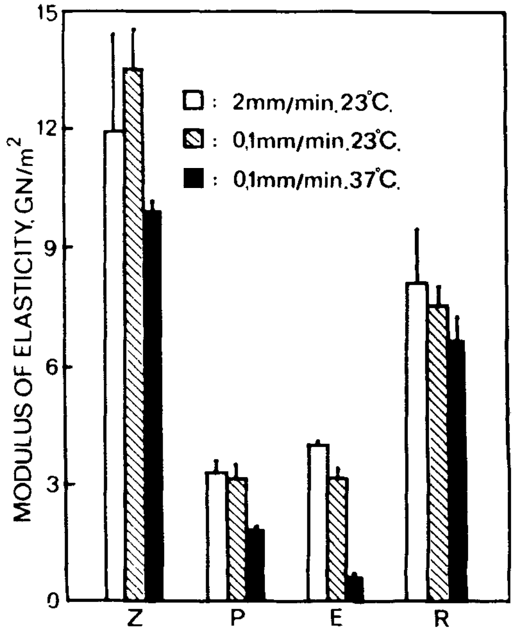

Fig. 2. Modulus of elasticity as a function of crosshead speed and temperature (Z: Zinc phosphate cement, P: Polycarboxylate cement, E: EBA-cement and R: Composite resin cement).

Table 1. *Cements used in the present study*

Type	Name	Manufacturer	Batch no.	Powder/liquidratio
Zinc phosphate	De Treys Zinc Cement Improved	De Trey Freres S.A. Zürich, Switzerland	Powder TD2TMK Liquid TD2TMK	3 g/ml
Polycarboxylate	Durelon	ESPE GmbH Seefeld/Oberbay, Germ.	Powder P7623818 Liquid LD 09018	1,5 g/g
Reinforced zinc oxide eugenol	Opotow Alumina EBA, Crown & Bridge cement	Teledyne Dental Getz-Opotow Div., Elk Grove Village, Illinois, USA	112175	7 g/ml
Composite Resin	Epoxylite CBA 9080	Lee Pharmaceuticals South El Monte, California, USA	1074BP – 2	2 g/g

A difference in the temperature during compression showed a significant effect on the strength of the polycarboxylate cement and the EBA-cement in particular, the latter showing a strength at 37 °C only 20% of that found at 23 °C.

Large differences were also observed between the values for modulus of elasticity (Fig. 2). The highest values were observed for zinc phosphate cement. The resin cement had a modulus about 30% lower and the two other cements approximately 75% lower. Variations of the crosshead speed had a significant effect on the elastic modulus of the EBA-cement only. However, an increase of the temperature was followed by a small but significant ($P < 0.01$) decrease of the modulus for polycarboxylate cement and a marked fall for that of the EBA-cement.

Striking differences were also found in the plastic strain at fracture for the different types of cements (Fig. 3). Low values were found for the zinc phosphate cement (0.1–0.2%). The plastic deformation of the other cements were about 10–150 times larger. At the high loading rate (2 mm/min) the resin cement showed a significantly higher plastic strain (5%) than the polycarboxylate- and EBA-cements (2%). However, at the lower loading rate an increase from 2 to more than 10% plastic deformation was found for the EBA-cement. The other cements showed no significant change of the deformation when the crosshead speed was varied. A change of the temperature from 23° to 37 °C was followed by a further increase of the plastic

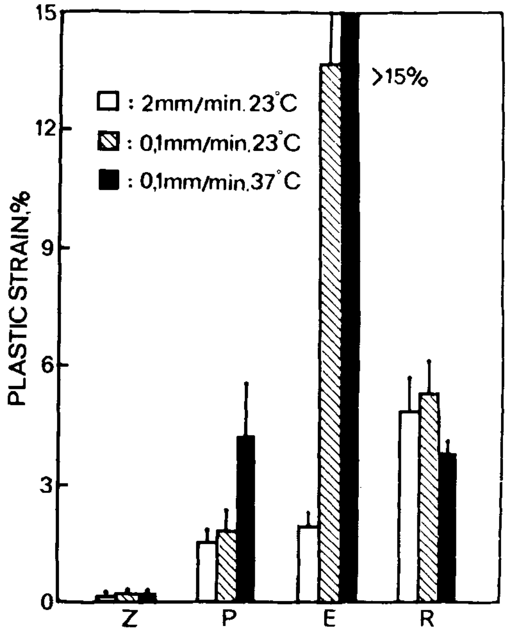

Fig. 3. Plastic strain at fracture as a function of crosshead speed and temperature (Z: Zinc phosphate cement, P: Polycarboxylate cement, E: EBA-cement and R: Composite resin cement).

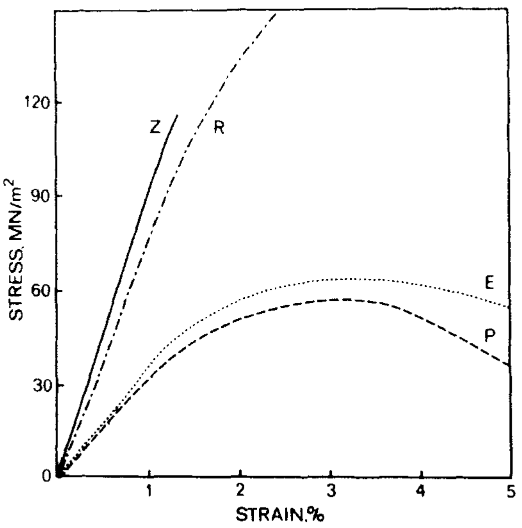

Fig. 4. Stress/strain behaviour of different luting cements compressed with a crosshead speed of 2 mm/min at 23 °C (Z: Zinc phosphate cement, P: Polycarboxylate cement, E: EBA-cement and R: Composite resin cement).

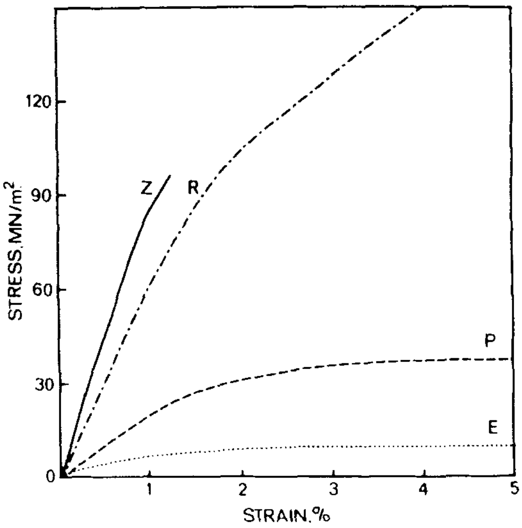

Fig. 5. Stress/strain behaviour of different luting cements compressed with a crosshead speed of 0.1 mm/min at 37°C, Z: Zinc phosphate cement, P: Polycarboxylate cement, E: EBA-cement and R: Composite resin cement.

deformation for EBA-cement to more than 15%, and an increase from 2 to 5% for the polycarboxylate cement (Fig. 3).

DISCUSSION

A comparison of compressive strength, modulus of elasticity and plastic strain at fracture for several dental luting cements showed that large differences existed between different materials. In addition, the present study showed that strain rate and temperature may be important factors when mechanical properties of dental cements are studied.

The values of strength and elastic modulus for zinc phosphate and EBA-cements are similar to those reported previously (9). The strength values found for the polycarboxylate cement and composite resin cement were also comparable to those reported (7, 12, 13). The influence of the crosshead speed on the recorded strength values for polycarboxylate cement is in agreement with that reported by Lawrence and Smith (5) who found 30% increase of the strength for polycarboxylate cement by variation of the strain rate from 0.5 mm/min to 20 mm/min.

Studies on biting forces in man have shown marked variations in the results. In the molar region, forces from 300 N (1) to 600 N (3) are reported. When an artificial crown is loaded, the main stresses will be distributed to the dentin cone along the axial walls due to the larger stiffness of the crown materials than the dentine (14). On the assumption that the load is axial and the stress evenly distributed at the axial walls, the stress in the cement film under the above mentioned load can be calculated. On a prepared molar of 8 mm diameter, 5 mm height and a convergence angle of 10°, the stress at the axial walls will be in the range of 2.5–5 MN/m². However, an even distribution of stresses will not occur. A stress concentration at localized parts of the cone might be expected dependent on the preparation form, crown design, direction and placement of the load (14). A stress concentration will also occur in the cement tags and around the large number of pores (11) present throughout the cement film. Thus stresses in the range of 5–10 MN/m^2 can be expected during mastication. The stress/strain behavior of the different cements (Fig. 5) indicate that repeated loading at 37 °C with forces giving a compressive stress up to 10 MN/m^2 would possibly have no effect on a layer of zinc phosphate cement, whereas polycarboxylate and EBA-cements in particular may be permanently deformed.

The clinical significance of a plastic deformation for the retentive ability of cements has not been tested. However, the interlocking effect is dependent on the amount and area of cement in undercuts (15), and it might be speculated that a slow deformation of cement tags in interlocking positions could reduce the retentive ability of a luting layer. This could possibly explain why the retentive ability of polycarboxylate cement is more dependent on the convergence angle than that of zinc phosphate cement, as indicated by McLean (6), i.e. high convergence angle requires less plastic deformation of tags prior to loss of retention. A plastic deformation of the cement followed by a loss of retention could also be an explanation for the clinical observations of a shorter lifetime for restorations cemented with polycarboxylate cement (2).

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