Bending strength of intact and repaired denture base resins

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Berge, M. Bending strength of intact and repaired denture base resins. *Acta Odontol. Scand.* 1983, 41, 187–191. Oslo. ISSN 0001-6357.

Results of bending strength and deflection at fracture of intact and repaired denture base resin specimens were obtained. Both heat-cured and cold-cured resins of two different products were used. After storage in distilled water at 37°C for 1 month, some of the intact heat-cured specimens were dried in air at 21 ± 1°C for 24 h before testing. This induced a lowering of the bending strength. There was no difference in strength between the two products. However, the intact heat-cured specimens of SR 3/60 showed higher results of deflection at fracture than Vertex. Repaired specimens had a bending strength between 42.9% and 61.2% compared with the intact heat-cured specimens tested immediately after storage in water. The repair performed with the low-viscosity self-cured resin resulted in higher bending strength values than when using repair material with the higher initial viscosity. Drying the broken heat-cured specimens for 24 h at 21 ± 1 °C before the repair and painting with monomer liquid on the fractured surfaces of the heat-cured resin was without effect on the bending strength of the repaired specimens. □ *Mechanical properties; acrylic repairs; PMMA*

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Fracture of acrylic dentures is not an uncommon clinical finding in operative dentistry (5). The causes of such fractures have been analyzed by Beyli & von Fraunhofer (1). They suggested that poor fit and lack of balanced occlusion were the most frequent causes, but material breakdown and dropping of the dentures were also recognized as possible causes. The ratio of upper to lower denture fractures was found to be about 2:1. Deep notching at the midline labial frenulum and high local stress concentration at the incisal notch have been related to midline fractures of upper jaw dentures (5, 7, 15).

Several investigators have studied the strength of repair of denture base acrylic resin (2, 6, 8, 9, 13, 14, 16, 17). Bending strengths of repairs ranging between 35% and 75% compared with the intact heat-cured specimens have been presented (2, 9). It has been suggested that the junction between the heat-cured resin and the repair material was the weakest point of the repaired specimens (10). Somewhat different opinions about the appropriate shape of the joint surfaces have been presented. Some authors recommend rounded joints (6, 8, 9, 17), while others suggest the use of obliquely processed borders (2, 14, 16).

To obtain the formation of a strong bond between the heat-cured resin and the repair material, it has been suggested that an 'acrylic cement' should be applied to the surface of the heat-cured resin before packing the repair material (17). Even better results have been obtained when packing of the repair material was carried out at an early dough stage while the resin still had a sticky consistency (13, 17). The effect of painting the joint ends with acrylic monomer has been questioned (2, 17).

Repairs completed under pressure have shown higher bending strengths compared with curing the repair material at normal temperature and pressure (9). Other investigators have obtained results at variance with this finding (16).

The purpose of the present investigation was to examine the influence of storage of highly water-saturated intact heat-cured resin specimens in dry air for a short time on the bending strength. The relation between water content of the broken heat-cured specimens and the bending strength of the repaired specimens was also to be investigated. In addition, the aim was to study the effect of painting the fractured surfaces with monomer liquid. Furthermore, the strength of repaired specimens when using two different products of repair material with different initial viscosities was to be compared.

Materials and methods

The materials included in the investigation are listed in Table 1. Both the heat-cured and the cold-cured resins were processed in accordance with the manufacturer's instructions (Table 2). The specimens were 70 mm long, 15 mm wide, and 5 mm thick. They were prepared in gypsum molds. The various groups of specimens included in the test and their conditioning before testing or repairing are listed in Table 3.

The specimens were exposed to a three-point bending test performed in air at 21 ± 1 °C. The test jig (Fig. 1) had a piston with a tip radius of 1.25 mm and the distance between the supports was 25 mm. The testing was carried out in an Instron Universal testing machine operating at a cross-head speed of 1 mm/min. The bending strength was represented by the load at fracture. The deflection at fracture load was also measured.

After testing of the intact specimens, the fractured surfaces were made parallel to each other and perpendicular to the long axis of the specimens by grinding under water on silicone carbide papers no. 200 and 320. The specimens were stored for another week in distilled water at 37 °C before the repair was performed. This was done by placing the broken heat-cured specimens in the gypsum mold used previously and filling the gap, at a constant width of 2 mm, between the ground surfaces with the cold-cured resin. An excess of autopolymerized resin was

Table 1. The products included in the investigation

Product	Batch no. Powder	Liquid	Manufacturer
Vertex, rapid simplified	80093.03	80093.01	Dentimex, Zeist, Holland
Vertex, self-curing	800134	7912102	Dentimex, Zeist, Holland
Ivoclar, SR 3/60	25399	1802.CT.8538	Ivoclar AG, Liechtenstein
Ivoclar, SR 3/60 Quick '20'	25776	2804.CT.8640	Ivoclar AG, Leichtenstein

Table 2. Polymerization and processing conditions used

	Powder/liquid ratio (volume)	Curing temperature (°C)	Curing pressure (kPa)	Time under pressure (min)
Vertex, rapid simplified	3:1	*	*	–
Vertex, self-curing	5:2	22	200	10
Ivoclar, SR 3/60	3:1			
Ivoclar, SR 3/60 Quick '20'	3:1	22	200	25

* Vertex, rapid simplified, was cured in the following manner: The clamped flask was immersed in boiling water, the heat was turned off for 15 min, the water was then reheated to boil and boiled for 20 min. The clamped flask was bench-cooled before deflasking.

† Ivoclar SR 3/60 was stored in water at 70 °C for 90 min, followed by 30 min in boiling water. The clamped flask was bench-cooled before deflasking.

Table 3. Conditioning of the different groups of specimens

Specimen	Resin	Conditioning of specimen before testing/repairing	Treatment of fractured ends	Group
Intact	Heat-cured	1 month in distilled water at 37 °C, then for 24 h in air at 21 °C	—	A
Intact	Heat-cured	1 month in distilled water at 37 °C	—	B
Intact	Cold-cured	1 week in distilled water at 37 °C	—	C
Broken	Heat-cured	In distilled water at 37 °C	Painting with monomer liquid	D
Broken	Heat-cured	In distilled water at 37 °C	No painting	E
Broken	Heat-cured	1 month in distilled water at 37 °C, then for 24 hours in air at 21 °C	Painting with monomer liquid	F
Broken	Heat-cured	1 month in distilled water at 37 °C, then for 24 h in air at 21 °C	No painting	G

used, and this was removed after completion of the polymerization process. The thickness at the repair site was checked to be deviating no more than ±0.2 mm from the thickness of the heat-cured specimen. The testing of the repaired specimens was carried out after storage for 1 week in distilled water at 37 °C. The piston was placed at the repaired areas. After the testing, the fractured surfaces were inspected visually.

Statistical evaluation between the groups was performed by use of Student's *t* test at the 1% level of significance.

Results

Intact specimens

Both products studied showed lower values of bending strength for the specimens stored wet and kept dry 24 h before testing (Group A) than for those stored in distilled water until tested (Group B) ($p < 0.01$) (Table 4). The cold-cured intact specimens (Group C) showed bending strengths similar to those of the heat-cured specimens tested immediately after storage in distilled water (Group B). There was no statistically significant difference between the intact heat-cured specimens of Vertex and SR 3/60 ($p > 0.01$). All specimens fractured at the site of the piston. The recorded deflections showed intergroup distributions similar to the bending strength; however, the heat-cured SR 3/60 specimens showed larger values than Vertex ($p < 0.01$).

Repaired specimens

A comparison between the two products consisting of the pooled repairs showed that Vertex obtained higher bending strength values than SR 3/60 ($p < 0.01$) (Table 5). The pooled repairs of Vertex obtained 61.2% and of SR 3/60 42.8% of the bending strength of the intact-cured specimens stored in water until tested. All repairs obtained lower bending strength results than the corresponding

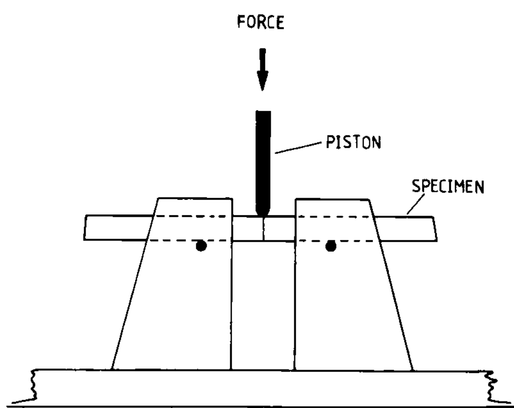

Fig. 1. The apparatus used in the three-point bending test.

Table 4. Bending strengths (in N) and deflection (in mm) for the different groups (A–C) of intact specimens. Testing performed in air at 21 ± 1 °C. x̄ = mean values, sd = standard deviation

		Bending strength (N)			Deflection (mm)		
		A	B	C	A	B	C
Vertex	x̄	516	680	682	0.70	0.90	1.06
	sd	100	102	66	0.14	0.12	0.09
SR 3/60	x̄	638	717	649	0.88	1.03	1.03
	sd	102	126	113	0.13	0.17	0.14
	No.	30	30	12	30	30	12

intact specimens of both heat-cured and cold-cured resins.

Whereas the repaired specimens of SR 3/60 seemed to fracture at the junction between the heat-cured resin and the repair material, this was not the case for the repairs performed on the Vertex specimens. These seemed to fracture mostly through the cold-cured resin (Fig. 2). Even though inter-group differences of the repairs were recorded, neither drying of the broken specimens before the repair was performed nor painting with monomer liquid was shown to have any systematic influence on the obtained bending strengths.

Discussion

It is generally known that denture base resins with a high water content have poorer mechanical properties than resins that contain small amounts of water (11, 12). However, the present results, perhaps somewhat unexpectedly, indicate that the heat-cured resins, highly saturated with water (approximately 90%) (3), stored in a dry atmosphere at 21 ± 1 °C for 24 h before testing, showed lower values of bending strength than the specimens remaining in water until tested. However, this might be due to evaporation of water from the superficial part, while the central core might be little affected, thus producing an inhomogeneous distribution of water throughout the specimen. The result of this phenomenon might be internal stresses that could weaken the specimen.

Since the bending strengths of the two products were not statistically discernible, the higher deflection values obtained for SR 3/60 might indicate a higher toughness of this product than of Vertex. This might be due to differences in degree of cross-linking between the two products. Ruyter & Svendsen (12) found a very high degree of cross-linking of SR 3/60, but no such analyses have yet been published for Vertex.

Table 5. Bending strengths (in N) for the different groups of repaired specimens and the pooled repairs

		Group				
		D	E	F	G	Pooled repairs
Vertex	x̄	374	439	477	374	416
	sd	84	98	61	76	90
SR 3/60	x̄	380	250	292	309	307
	sd	117	88	46	61	93
	No.	12	12	12	12	48

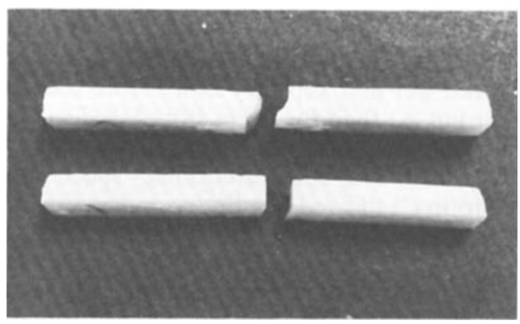

Fig. 2. Fractures of *repaired* specimens. The upper specimen is showing evidence of fracture mostly through the repair material (Vertex); the lower one has fractured at the junction between the heat-cured resin and the repair material (SR 3/60).

The bending strengths obtained in this investigation for the cold-cured resins are somewhat higher compared with the heat-cured ones than other investigators have found (4, 11–13). This might be caused by the lower water content of the autopolymerized resin during testing compared with the heat-cured ones owing to the shorter storage period in distilled water.

Vertex showed the highest bending strength values for the repaired specimens. This fact seems to be related to a stronger bond formation between the heat-cured resin and the repair material for this product. The cause of this might be the lower viscosity of the Vertex cold-cured resin, which may possibly lead to a stronger and more prolonged softening effect of the adjacent heat-cured resin surfaces. Ware & Docking suggested a similar theory (17). In addition, it might be more difficult to achieve a softening effect on the heat-cured surfaces of SR 3/60 owing to the high degree of cross-linking of this product (12).

The lack of effect from painting with monomer liquid could be related to the volatility of the pure monomer. Much of the liquid probably evaporated before any softening effect on the heat-cured surfaces was achieved (17). In addition, the water solubility of the pure monomer might partly explain why the drying procedure performed before the repair was without effect on the bending strength values obtained for the repaired specimens.

This study has demonstrated that a heat-cured denture base resin with a high content of water may be weakened by dry storage even for a short time, and this should therefore be avoided. Furthermore, it is suggested that repairs should be performed using a low-viscosity cold-cured resin. On the other hand, neither the recommended painting with monomer liquid on the heat-cured surfaces nor a careful drying procedure of the broken heat-cured specimen before applying the repair material seems to be of any importance for the final strength of the repair.

Received for publication 19 February 1982

Acknowledgement.—The kind guidance of Dr. I. E. Ruyter, NIOM, Scandinavian Institute of Dental Materials, and Drs. Trond Hegdahl and Nils Roar Gjerdet, Department of Dental Materials, University of Bergen, is acknowledged.

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