Impact strength of denture polymethyl methacrylate reinforced with continuous glass fibers or metal wire

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The impact strength of heat-cured acrylic resin test specimens that had been reinforced in various ways was compared in this study. Ten rectangular test specimens were fabricated for each test group. The strengtheners included 1.0-mm-diameter steel wire and continuous E-glass fibers. Both notched and unnotched test specimens were tested in a Charpy-type impact test. In a further analysis the concentration of glass fibers in the test specimens was determined and plotted against the impact strength of the test specimens. The results showed that, compared with the unreinforced specimens, both types of reinforcement increased the impact strength of the test specimens considerably ($p < 0.001$). There was no clear difference between the mean impact strength value of the test specimens reinforced with metal wire and that of the specimens reinforced with glass fiber. The correlation coefficient between the fiber concentration of the test specimens and their impact strength was 0.818 ($p < 0.005$). Specimens with fiber concentrations greater than 25 wt% yielded to the higher impact strength more readily than those with metal wire reinforcement did. □ *Acrylic resins; dentures; reinforcement*

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The traditional techniques used to reinforce polymethyl methacrylate (PMMA) in dentures involve the use of metal wires, plates, or mesh as strengthener in the denture base (1–10). According to many studies, metal strengtheners increase the transverse strength of the denture PMMA considerably, but there is a lack of investigations concerning the fatigue or impact strength of dentures reinforced with metal wire (11).

Another way to reinforce denture PMMA is to use a PMMA fiber composite strengthener. Various types of fibers have been investigated for this purpose; among them glass, carbon/graphite, aramid, and polyethylene fibers (12–28). The impact strength of denture PMMA reinforced with aramid and polyethylene fiber has been reported previously (22–24). However, the effect of glass fiber reinforcement on impact strength has not been investigated.

The aim of this study was to determine the impact strength of unreinforced, metal-wire-reinforced, and glass-fiber-reinforced test specimens of heat-cured PMMA. The effect of the concentration of glass fiber on impact strength was also investigated.

Materials and methods

Heat-cured PMMA (Pro Base Hot, Ivoclar, Schaan, Liechtenstein) was used for fabricating the test specimens (the shape is shown in Fig. 1). To process the test specimens, a gypsum mold was used, and the acrylic resin was cured by placing the mold in boiling water for 40 min, as recommended by the manufacturer. The ratio of PMMA powder to MMA liquid was 22.5 g powder to 10 ml monomer. After they were taken out of the flask, the test specimens were ground to the dimensions of 4.0 × 6.0 × 50.0 mm with sand paper (grain size, 180).

The test specimens were either unreinforced (groups A1 and A2) or reinforced with 1.0-mm-diameter circular steel wire (Remanium Feder Hart, Dentaurum, Pforzheim, Germany) (groups B1 and B2) or with continuous E-glass fibers (Ahlstrom, Karhula, Finland) (groups C1 and C2) (Table 1). The surface of the metal wire was sandblasted with aluminum oxide that had a grain size of 250 μm, and the wires were then wetted with the monomer liquid for better penetration of PMMA into the microirregularities of the metal surface, as shown previously (8). The technique used to incorporate the glass fibers into the acrylic resin has also been reported in an earlier report (29). With this technique the silanized (A174 silane compound, Union Carbide Chemicals, Versoix, Switzerland) bundles of glass fiber were dipped in a mixture of PMMA powder and MMA liquid and then placed into the concavity that had been pressed into the acrylic resin dough. Placement of the fibers was followed by final pressing of the acrylic resin with a pressure of 100 bars. In each test group, which consisted of 10 specimens, there were both notched and unnotched test specimens (semicircular notch, 1.3 mm in diameter). The test specimens were stored in water at +22 °C for 1 week before they were tested.

The impact test was carried out on a Charpy-type pendulum impact tester (WPM Leipzig, Leipzig, Germany). By recording the reduced swing and hence the reduced kinetic energy of the pendulum, this instrument measures the energy required to fracture the specimens.

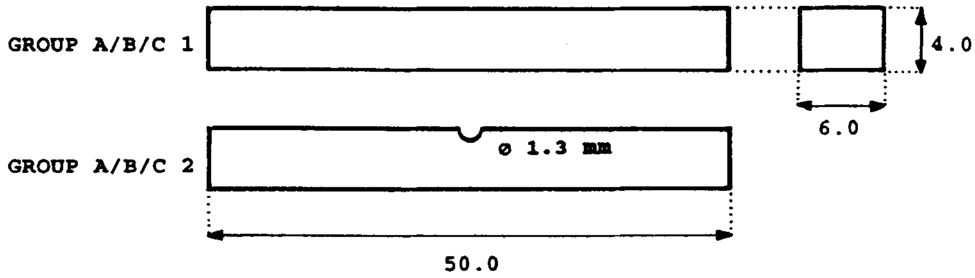

Fig. 1. Shape and dimensions (in mm) of the test specimens.

The tests were carried out with a pendulum rated at 0.5 J for unreinforced test specimens and a pendulum rated at 4.0 J for reinforced test specimens.

The distribution of fibers in the PMMA matrix and the impregnation of the fiber bundle with PMMA was examined visually from the polished transverse sections of the test specimens under a light microscope (magnification, 30×). To find the unimpregnated areas, polished transverse sections of the glass-fiber-reinforced specimens were treated with a coloring agent, as described in an earlier report (30). The coloring agent was a blunt-pointed waterproof marking pen. The colored transverse section was then ground with a rotating grinding surface so that the color just disappeared from the colored surface. The grinding surface was wet 500-grade sandpaper.

The glass fiber concentration of test specimens in group C1 was determined by ashing the PMMA matrix at 750°C for 30 min. The fiber concentration was calculated from the original weights of each test specimen and from the weights of the glass fibers remaining after the polymer matrix had been ashed.

For statistical analysis the means and standard deviations were calculated for the impact strength values and were then compared by ANOVA. Regression analysis was used to show the linear regression and correlation between the glass fiber concentration and the impact strength of the test specimens.

Results

The mean impact strength in the reinforced test groups was considerably higher than that in the unreinforced test group ($p < 0.001$) (Table 2). A similar tendency was noted when the notched test specimens were compared. There was only a slight difference between the impact strength of the test specimens reinforced with metal wire and those reinforced with glass fiber (groups B1 and B2 and groups C1 and C2, respectively).

Examination of the fiber distribution showed that in some of the test specimens the fibers were positioned on the surface of the specimens. Only small unimpregnated areas were detected inside the fiber bundles (Fig. 2). The mean fiber concentration in the test specimens of group C1 was 23.8 wt% (SD, 5.8 wt%). The correlation coefficient between the fiber concentration and the impact strength of the test specimens was 0.818 ($p < 0.005$) (Fig. 3). Metal wire reinforcement held the fractured pieces of the test specimens together, whereas unreinforced specimens and test specimens reinforced with glass fiber broke into two pieces (Fig. 4).

Discussion

This study examines the problem of denture fracture caused by an impact force. The impact forces can be caused by an accident or during chewing (31). However, normal impact tests are carried out with higher hitting speed than found for chewing speed. Almost all impact tests carried out on denture material have been with a Charpy or Izod type of test with high hitting speed. The Charpy type of impact test was chosen for this study, to obtain impact strength values comparable to those reported in previous studies.

Table 1. Classification of the test specimens on the basis of type of reinforcement and notching

Group	Type of reinforcement	Notching
A1	Unreinforced	No
A2	Unreinforced	Yes
B1	1.0-mm-diameter steel wire	No
B2	1.0-mm-diameter steel wire	Yes
C1	Continuous glass fibers	No
C2	Continuous glass fibers	Yes

Table 2. Impact strength (kJ/m^2 (± SD)) of unnotched and notched test specimens. Means compared by ANOVA. Symbols for the groups same as in Table 1

Group	M ± SD	*n*	df	*F*	*p*
A1	8.3 ± 0.7	10			
B1	59.1 ± 11.5	10			
C1	53.1 ± 23.2	10	2/27	34.41	0.000
A2	3.3 ± 2.5	10			
B2	64.5 ± 11.9	10			
C2	44.3 ± 22.2	10	2/27	45.47	0.000

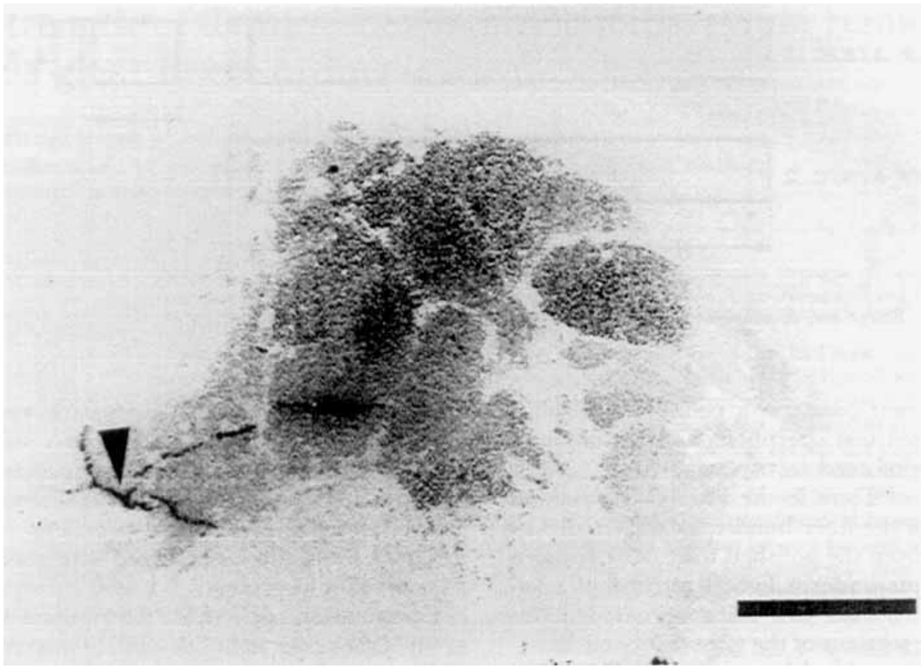

Fig. 2. Photomicrograph of the transverse section of a glass-fiber-reinforced test specimen. The grey areas show the fibers; the arrowhead indicates the unimpregnated areas. (Original magnification, 30×; bar = 1 mm.)

Even though Oku (31) has reported that there is no recognizable difference in the impact strength of PMMA specimens stored in water and those stored in air, the test specimens in this study were stored in water for 7 days before being tested. On the other hand, there are reports that the water absorption of PMMA decreases its transverse strength by plasticizing polymer structure (32, 33). Obviously, the composite materials based on

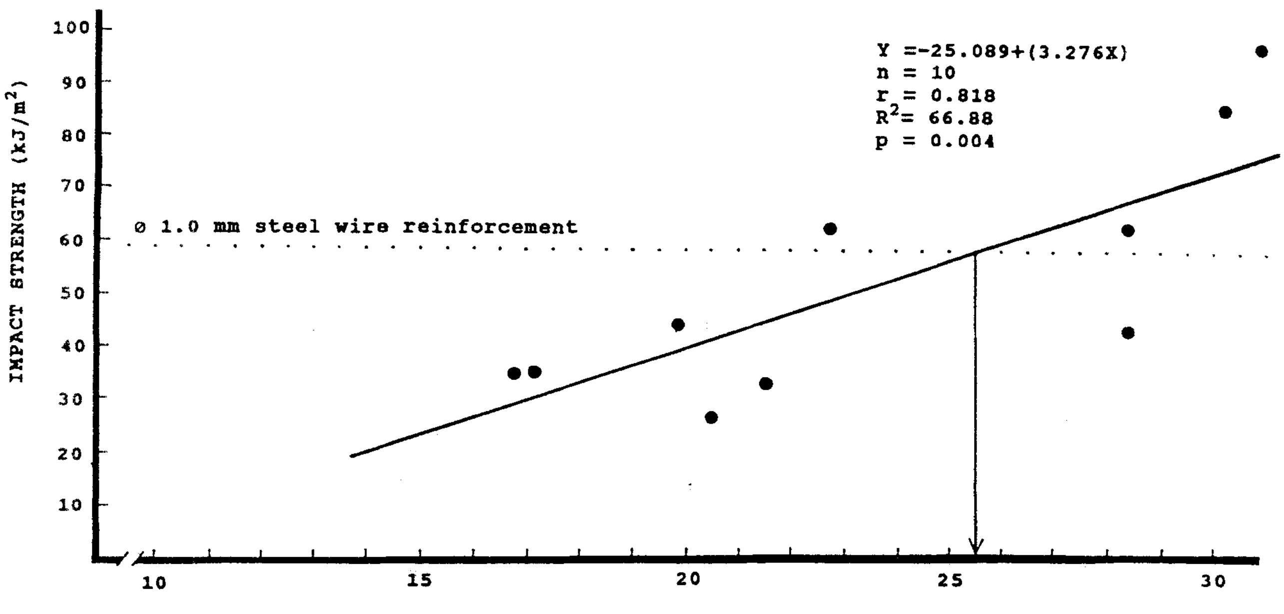

Fig. 3. Linear regression between concentration of glass fiber and impact strength of the test specimens. The arrow indicates the fiber concentration that yields to the same impact strength as the metal wire reinforcement did.

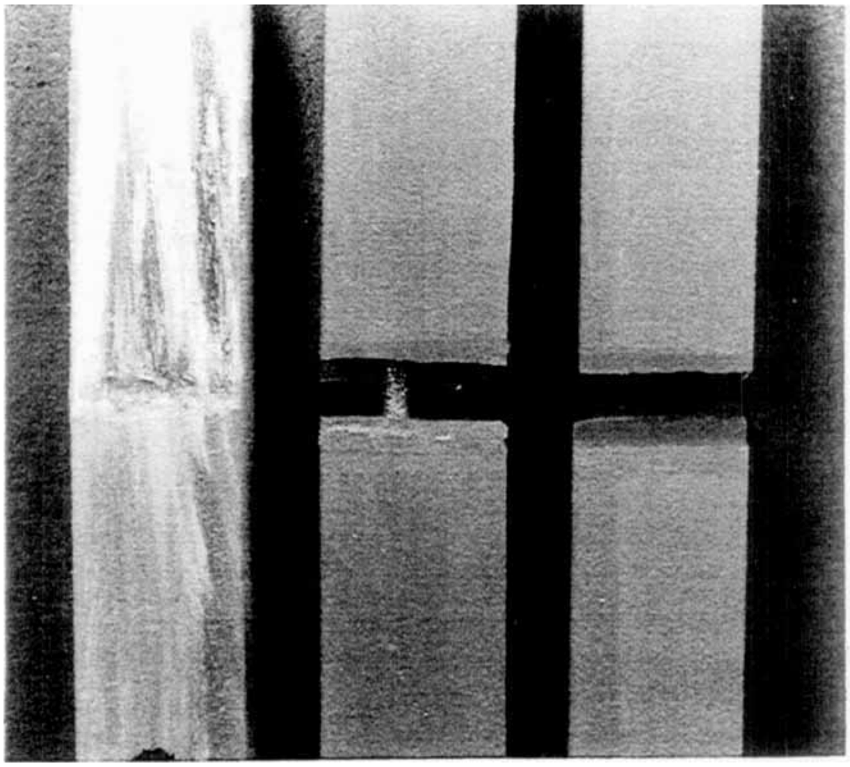

Fig. 4. Notched test specimens after impact test. From the left: unreinforced; steel-wire-reinforced; and glass-fiber-reinforced test specimen.

PMMA and glass fiber composites are prone to degradation by water. However, at present there is a lack of information about degradation of the PMMA–glass fiber composite used in dentures.

When testing the impact strength of a PMMA–fiber composite made of highly drawn linear polyethylene, Ladizesky et al. (34) found that with a 13.4 vol% concentration of woven polyethylene fiber, an impact strength of 44 kJ/m^2 can be obtained. According to the same study, the impact strength of unreinforced PMMA is 10 kJ/m^2, which agrees well with the results of the present study. In another study (27) Ladizesky et al. reported that if chopped polyethylene fibers are used, to reach the same impact strength as obtained with the 13.4 vol% woven fibers, the concentration of fibers must be 37 vol%. The glass fiber concentration used in the present study is presented as percentage weight, which can be converted to percentage volume when the weight and density of the polymer matrix and the fiber, as described in the literature (35), are known. According to the conversion formula, 25 wt% of glass fibers equals approximately 13 vol%. Consequently, the impact strength of both PMMA reinforced with glass fibers and that reinforced with steel wire seem to be higher than the impact strength of PMMA reinforced with polyethylene fiber. This finding, however, requires further verification.

It has been shown that surface defects affect the impact strength of acrylic materials used to make the denture base (36). Even small defects on the surface reduce the strength significantly. In this study the notched and unnotched test specimens were tested, to simulate the effect of frenal notches of dentures on the impact strength. The results showed that when there was a semicircular notch on the surface of the test specimens, the impact strength was reduced. The reduction was clear in all groups expect in specimens reinforced with metal wire. The reason for this may be that the notch did not extend to the metal wire strengthener, and therefore its strengthening effect remained constant even though there was a notch on the specimen. In the test specimens reinforced with glass fiber the notch extended to the fiber bundle and, in some of the test specimens, cut the superficial fibers. Obviously, this reduced the impact strength of the specimens. Fig. 4 shows how the fracture started from a notch on the test specimens reinforced with glass fiber and continued in the direction of the fibers.

From a clinical perspective the impact failure of a denture is very unpleasant for the patient. To diminish the unpleasantness of denture fractures, it is important that the fractured pieces of the denture be held together. As can be seen in Fig. 4, the metal wire strengthener held the fractured pieces together, whereas glass-fiber-reinforced and unreinforced test specimens broke into two pieces. To avoid impact failures in denture PMMA when glass fiber reinforcement is used, the fiber concentration must be high enough. As the present study suggests, concentrations of glass fiber greater than 25 wt% yield better impact strength than steel wire 1.0 mm in diameter. However, the optimal fiber concentration is obviously higher, approximately 60 wt%, as is also the case when the transverse strength of the PMMA–glass fiber composite is optimized. The usefulness of PMMA–glass fiber composite strengtheners in such a high concentration should be investigated further, in particular taking into consideration clinical aspects.

References

1. Siirilä H, Berg J. Tukirakenteista akryyliproteeseissa. Suom Hammlaak Toim 1958;54:31–47.
2. Jennings RE, Wuebbenhorst AM. The effect of metal reinforcements on the transverse strength of acrylic resin. J Dent Child 1960;27:162–8.
3. Schwickerath H. Zur Frage der Prothesenverstärkung. Dtsch Zahnaertzl Z 1966;21:491–4.
4. Carrol CE, von Fraunhofer JA. Wire reinforcement of acrylic resin prostheses. J Prosthet Dent 1984;52:639–41.
5. Ruffino AR. Effect of steel strengtheners on fracture resistance of the acrylic resin complete denture base. J Prosthet Dent 1985; 54:75–8.
6. Maeda Y, Nakahira Y, Okada M, Nokubi T, Okuno Y. Reinforcement of cold-cured acrylic resin denture base with 4-META adhesive resin and Co-Cr alloy wrought wires. J Osaka Univ Dent Sch 1987;27:235–41.
7. Kawano F, Miyamoto M, Tada N, Matsumoto N. Reinforcement of acrylic resin denture base with Ni-Cr alloy plate. Int J Prosthodont 1990;3:484–8.
8. Vallittu PK, Lassila VP. Effect of metal strengtheners surface roughness on fracture resistance of acrylic denture base material. J Oral Rehabil 1992;19:385–91.
9. Vallittu PK, Lassila VP. Reinforcement of acrylic resin denture base material with metal or fibre strengtheners. J Oral Rehabil 1992;19:225–30.
10. Vallittu PK. Effect of some properties of metal strengtheners on the fracture resistance of acrylic denture base material construction. J Oral Rehabil 1993;20:241–8.
11. Vallittu PK. Comparison of the in vitro fatigue resistance of an acrylic resin partial denture reinforced with continuous glass fibers or metal wires. J Prosthodont. In press.
12. Goldberg AJ, Burstone CJ. The use of continuous fiber reinforcement in dentistry. Dent Mater 1992;8:197–202.
13. Vallittu PK. Comparison of two different silane compounds used for improving adhesion between fibres and acrylic denture base material. J Oral Rehabil 1993;20:533–9.
14. Vallittu PK, Lassila VP, Lappalainen R. Acrylic resin fiber composite. I. The effect of fiber concentration on fracture resistance. J Prosthet Dent 1994;71:607–12.
15. Vallittu PK. Acrylic resin-fiber composite. II. The effect of polymerization shrinkage of polymethyl methacrylate applied to the fiber roving on transverse strength. J Prosthet Dent 1994;71: 613–7.
16. Solnit GS. The effect of methyl methacrylate reinforcement with silane-treated and untreated glass fibers. J Prosthet Dent 1991; 66:310–4.
17. Schreiber CK. Polymethylmethacrylate reinforced with carbon fibres. Br Dent J 1971;130:29–30.
18. DeBoer J, Vermilyea SG, Brady RE. The effect of carbon fiber orientation on the fatigue resistance and bending properties of two denture resins. J Prosthet Dent 1984;51:119–21.
19. Yazdanie N, Mahood M. Carbon fiber acrylic resin composite: an investigation of transverse strength. J Prosthet Dent 1985; 54:543–7.
20. Ekstrand K, Ruyter IE, Wellendorf H. Carbon/graphite fiber reinforced poly(methyl methacrylate): properties under dry and wet conditions. J Biomed Mater Res 1987;21:1065–80.
21. Mullarky RH. Aramid fiber reinforcement of acrylic appliances. J Clin Orthod 1985;19:655–8.
22. Berrong JM, Weed RW, Young JM. Fracture resistance of kevlar-reinforced poly (methyl methacrylate) resin: a preliminary study. Int J Prosthod 1990;3:391–5.
23. Gutteridge DL. The effect of including ultra-high-modulus polyethylene fibre in the impact strength of acrylic resin. Br Dent J 1988;164:177–80.
24. Gutteridge DL. Reinforcement of poly (methyl methacrylate) with ultra-high-modulus polyethylene fibre. J Dent 1992;20:50–4.
25. Ladizesky NH, Chow TW. The effect of highly drawn polyethylene fibres on the mechanical properties of denture base resins. Clin Mater 1990;6:209–25.
26. Ladizesky NH, Ho CF, Chow TW. Reinforcement of complete denture bases with continuous high performance polyethylene fibers. J Prosthet Dent 1992;62:934–9.
27. Ladizesky NH, Cheng YY, Chow TW, Ward IM. Acrylic resin reinforced with chopped high performance polyethylene fiber-properties and denture construction. Dent Mater 1993;9:128–35.
28. Dixon DL, Breeding LC. The transverse strengths of three denture base resins reinforced with polyethylene fibers. J Prosthet Dent 1992;67:417–9.
29. Vallittu PK, Lassila VP, Lappalainen R. Transverse strength and fatigue of denture acrylic-glass fiber composite. Dent Mater 1994; 10:116–21.
30. Peltonen P, Järvelä P. Methodology for determining the degree of impregnation from continuous glass fibre prepreg. Polymer Testing 1992;11:215–24.
31. Oku J. Impact properties of acrylic denture base resin. 3. Impact properties of cross-linked polymers. Dent Mater J 1989;8:215–22.
32. Gilbert AS, Pethrik RA, Phillps DW. Acoustic relaxation and infrared spectroscopic measurements of the plastization of poly (methylmethacrylate) by water. J Appl Polym Sci 1977;21:319–30.
33. Dixon DL, Ekstrand KG, Breeding LC. The transverse strengths of three different denture base resins. J Prosthet Dent 1991; 67:4178–9.
34. Ladizesky NH, Pang MKM, Chow TW, Ward IM. Acrylic resins reinforced with woven highly drawn liner polyethylene fibres. 3. Mechanical properties and further aspects of denture construction. Aust Dent J 1993;38:28–38.
35. Airasmaa I, Johansson C-J, Kokko J, Komppa V, Linkoaho P, Piltz A, et al. Lujitemuovitekniikka. Hämeenlinna: Karisto Oy, 1984:246–8.
36. Robinson JG, McCabe JF. Impact strength of acrylic resin denture base materials with surface defects. Dent Mater 1993;9:355–60.

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