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From:
The Department of Cariology,
Institute of Dentistry,
University of Turku, Finland

TRANSVERSE AND BOND STRENGTH OF RESTORATIVE RESINS

LENNART FORSTEN
MAIJA-LIISA VÄLIAHO

One silicate, one acrylic resin, and five manually and two mechanically mixed composite resins were studied. The strength was tested by three point loading on rectangular specimens ($2 \times 2 \times 12$ mm) 24 hours after storage in water. The lateral thirds of the bond strength specimens consisted of old and the central third of newly added material. The transverse strength of the strongest composite resin was five times higher than that of the silicate cement, two times higher than that of the acrylic resin and of the weakest composite, but one third of the average strength of amalgam. There were no differences in strength between manual and mechanical mixing of the silicate cement or between using flow and brush technique for the acrylic resin. Using the recommended ratio of the base to catalyst paste of a composite resulted in the highest strength value compared with the strength when the amount of either base or catalyst paste was doubled. Varying the time of the ultrahigh-speed mixer for one composite did not reveal significant differences in strength. Mixing in the high-speed amalgamator resulted in the same strength if the mixing time was increased by fifty per cent as mixing in the ultrahigh-speed mixer. The strength of the repaired acrylic resin specimens was a little less than that of unrepaired specimens. The strength of repaired composites was half or less, than that of unrepaired materials.

The reconstruction of a fractured incisal angle has always been a problem. The most common anterior filling material, silicate cement, is not suitable for this purpose due to its brittleness. Acrylic resin since it is a tougher material will last somewhat longer than silicate. Due to its low abrasion resistance, the acrylic filling is, however, considered a temporary one. It is also necessary to bear in mind the other negative properties of the acrylic resins, e.g. polymerization and thermal shrinkage and the irritating effect on the pulp. Attempts were made to eliminate these undesirable properties by the incorporation of inorganic filler particles in the resin (*Bowen*, 1962). A bond between the filler and the resin was established by coating the filler

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particles with a vinyl silane coupling agent. At the moment, there are many different brands of these materials which are called either composite, filled or reinforced resins. The reported advantages of these materials compared with conventional acrylics are, for example, greater strength, superior hardness and abrasion resistance, less polymerization shrinkage, lower coefficient of thermal expansion, and easy manipulation (*Phillips et al.*, 1969). The compressive strength of composite resins has been reported to be 2—3 times greater than that of acrylics, about the same as that of silicate cements and about half that of amalgam (*Skinner & Phillips*, 1967). Although the compressive strength of acrylic resin is much less than that of the composites, the tensile strength does not differ much between the two materials (*McLean & Short*, 1969).

In most studies the strengths of the different brands have been compared after storing the specimens for different periods of time both in water and air. The results have in many respects been quite controversial. The observed greater strengths of composite resins compared with other anterior filling materials indicate the possibility of these materials serving satisfactorily in incisal angles. This needs, however, more investigation, since some of the composites have been available only for a short period of time and because of the somewhat controversial results of earlier studies. Furthermore, the effect of manipulation on the properties of composites has been studied sparcely. The purpose of the present work was, therefore, to study the strength of various composites and the effect of manipulation variables on their strength. For purposes of comparison, the strength of a silicate cement also was studied.

An anterior resin filling may have defects. When using acrylic resin, one also has to take into consideration the loss of material due to its low abrasive resistance. In these cases it has to be decided whether to replace the whole filling or to repair the defect. When retention pins have been used, it is not always convenient to remove the whole filling. The result of repairing a defect depends, however, mainly on the ability of the new material to adhere to the old. The present authors have not found any paper dealing with this problem. Another purpose of the present investigation was, therefore, to study the bond strength of various repaired resins.

It has been observed (*Phillips et al.*, 1969) that the compressive strength is high for silicates, but low for acrylic resins. The tensile properties, however, show the opposite. Thus the clinical performance is correlated more with the tensile strength and not with the compressive strengths of these materials. When the restorative material in an incisal angle fractures, it is caused by a combination of forces. When performing a three point loading

transverse strength test, the specimen also is affected by a combination of forces, although the fracture propagates due to tensile stresses in the lower part of the specimen. Other advantages of the transverse strength test have been expressed earlier (*Forsten*, 1969). Therefore, the three point loading transverse strength test was used throughout this study.

MATERIALS AND METHODS

The materials, their manufacturers and the code letters used in this study are listed in Table I. Of the composite resins designed for manual mixing, resin D was of the same type as resins C I and C II in that a very small amount of catalyst liquid was added to the base paste before mixing. Resin F consisted of a base paste (universal paste) and a catalyst paste which were recommended to be mixed in equal parts. Composite G consisted of base powder and catalyst liquid and was to be mixed in the same way as silicate cement.

The above mentioned composites, the silicate cement and the acrylic resin were mixed according to the manufacturers' instructions. An exception was composite F which was mixed using three different ratios of base to catalyst paste. The silicate cement was dispensed both in bulk form for manual mixing and in capsules with premeasured powder and liquid designed for mechanical mixing. Two of the composites were also designed for me

Table I.
The tested anterior restorative materials

Code	Brand	Manufacturer	
	Silicate		
A I	Biotrey	Gebr. De Trey A.G.	Switzerland
A II	Biotrey capsule	Gebr. De Trey A.G.	Switzerland
	Acrylic resin		
B	Sevriton	Gebr. De Trey A.G.	Switzerland
	Composite resin		
C I	Addent 35	Minnesota Mining and Manufact. Co.	U.S.A.
C II	Addent 12	Minnesota Mining and Manufact. Co.	U.S.A.
C III	Addent XV	Minnesota Mining and Manufact. Co.	U.S.A.
D	Blendant	Kerr Manufact. Co.	U.S.A.
E	TD 71	Dental Fillings Ltd.	England
F	Adaptic	Johnson & Johnson	U.S.A.
G	D F R	Surgident Ltd.	U.S.A.

chanical mixing. The capsule dispensed materials were all mixed in an ultra-high-speed mixer (Silamat,® Ivoclar A.G.). Additional samples of composite E were mixed using a high-speed amalgamator (Dentomat,® Dr. Walter U. Schmitt, GMBH). When the Dentomat was used, a fork was fastened to the apparatus instead of the amalgam trituration capsule.

The test pieces were prepared using the same steel mold as in earlier studies (*Forsten*, 1969, 1970) when the transverse strength of amalgams were measured. The inside of the molds was covered with a thin insulation film (Wilde Folie, Zahnfabrik L. Wilde RHG, Niederwallud) to prevent the resin from sticking to the metal. The silicate cement and the composite resins were inserted into the cavity with a silicate instrument (Ash No. 1). Care was taken not to introduce air bubbles in the filling. The surface of the filling was pressed flat and flush with the upper plane of the mold using an acrylate strip (Directa Dental, Sweden). The strip was held in position for five minutes. After that it was removed and any excess was carved away with a sharp knife.

When the acrylic resin was manipulated according to the brush technique, monomer liquid and polymer powder were alternately transferred to the cavity with a small brush. The mix in the cavity was saturated with liquid until the cavity was overfilled. After that only powder was transferred to the filling to remove excess monomer. When this was done, the surface of the filling was covered with vaseline. After five minutes the excess was trimmed flush with the upper plane of the mold using a sharp knife. When the flow technique was used, the mixed material was flowed into the cavity with the silicate instrument. The mold was overfilled and the surface covered with vaseline. After that, the procedure was the same as above.

To study the bond strength of repaired acrylic and composite resins, test specimens that had been used for transverse strength tests and stored in water at $37\pm2°C$ for 6—12 weeks were used as old material. Before making the repaired specimen, the two pieces of the broken old test piece were ground to a length of 4 mm, in the same way as in a previous amalgam study (*Forsten*, 1970). As in that study, the two 4 mm pieces were placed in the steel mold, where the original test piece had been made, leaving a 4 mm long cavity open in the middle of the mold. Prior to this, the walls of the whole cavity in the steel mold had been covered with a thin film of varnish. The cavity between the two old pieces of material was then filled with the same material using the same method of manipulation as when the original test specimen had been made. Another series was done, where the cavity between two composite resin pieces was filled with acrylic resin using the brush technique. The repaired test specimen is shown in Fig. 1.

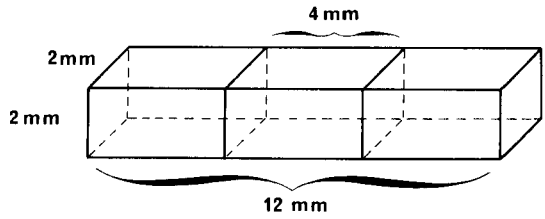

Fig. 1. The repaired transverse strength test specimen.

Ten minutes after inserting the material into the mold cavity, the test pieces, measuring $2\times2\times12$ mm were carefully removed from the mold and transferred into water. Prior to the insertion in water, the silicate test pieces were covered with vaseline. The test pieces were stored in water at 37 ± 2°C for 24 hours before testing the transverse strength. Prior to the testing, the specimens were wiped dry. The testing procedure has been described earlier (*Forsten*, 1969). The loading rate in this study was 5.5 mm/min. The preparation of the test pieces and all testing was performed at room temperature 23 ± 2°C). Six samples and test runs were made for each condition.

RESULTS

1. Transverse Strength

In Tables II—V the mean transverse strengths of the materials are shown. The scatter of data is expressed as standard deviation. An analysis of variance and Duncan's multiple range test were performed. The solid lines indicate that there was not a significant difference between mean values at the 95 % confidence level.

Table II shows the strengths of manually mixed resins. The strength of the unfilled resin was significantly lower than that of the composites mixed from pastes, but not lower than that of the composite mixed from powder and liquid. The large variance of data for composites C I and G can also be observed. The strength of the manually mixed silicate used in this study was 195 kg/cm² (S.D. = 13). The strength for the capsule dispensed form of this silicate was 163 kg/cm² (S.D. = 26) when mixed in the Silamat device. The strength of the silicate was thus only about one-fifth that of the composite resins. Furthermore, the results indicated that there was no significant difference in strength between the two methods of manipulating acrylic resin B.

Table II.

Transverse strengths (kg/cm²) of one acrylic resin and five manually mixed (30 sec.) composite resins

Resins	Strength Mean	SD
C I	1051	253
C II	932	57
F	947	95
G	694	206
B*	669	67
B**	585	37

* brush technique
** flow technique

NOTE: Solid lines indicate no significant differences between mean values at the 95 % confidence level.

Table III.

Transverse strength (kg/cm²) of the composite resin F using three different universal paste — catalyst paste ratios

Univ.	Catal.	Strength Mean	SD
1	1	947	95
1	2	864	64
2	1	669	54

NOTE: For solid lines, see Table II.

Table IV.

Transverse strength (kg/cm²) of composite resin C III mixed in ultrahigh-speed mixer Silamat using three different mixing times*

Mixing Time (s)	Strength Mean	SD
20	992	60
25	991	148
15	910	181

* Ivoclar

NOTE: For solid lines, see Table II.

Table V

Transverse strength (kg/cm²) of composite resin E using two different mixers

Mixer	Mixing Time (s)	Strength Mean	SD
Silamat	10	625	22
Dentomat*	15	592	50
Dentomat	10	542	54

* Dr. Walter U. Schmitt, GMBH

NOTE: For solid lines, see Table II.

From Table III it can be seen that altering the ratio of universal paste to catalyst paste of composite F resulted in the highest strength when the recommended ratio was used, and the lowest when an excess of universal paste was used. The difference between the highest and lowest values was statistically significant.

When composite C III was mixed mechanically using three different mixing times (Table IV), no significant differences in strength could be detected. From the results it can, however, be observed that the intermediate time (20 sec.) gave a variance of data, which was significantly smaller than the highest variance of data using 15 sec.

Table V shows the strength of composite E, using one mixing time with an ultrahigh-speed and two different mixing times with a high-speed mixer. The results show that to get the same strength with both mixers, it was necessary to increase the mixing time of the high-speed mixer by fifty per cent.

2. Bond Strength of Repaired Resins

Table VI shows the transverse strengths of repaired and unrepaired resins. All the values except one are based on six experiments, in this case ten test specimens were made. The scatter of data is given as standard deviation. The results were statistically analyzed using a two-sided t-test at a 95 per cent confidence level. In Fig. 2 the results are shown graphically.

The values show that the transverse strengths of the repaired specimens were lower than the strength of the unrepaired resins. The difference was statistically significant in all cases. The smallest difference was shown by the acrylic resin. The strengths of the repaired specimens of the composite resins were about half the strengths of the unrepaired specimens. There was

Table VI.

Transverse strengths (kg/cm^2) of unrepaired and repaired acrylic and composite resins

Resin	B		C II		C III		D		E	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Unrepaired	669	67	1051	253	992	60	688	39	625	22
Repaired[1]	476	75	206	23	524	49	296	125	217	70
Repaired[2]	476	75	534	67	399	76	341	97	192*	77

[1]) Repaired with the same brand of material
[2]) Repaired with acrylic resin B
* Number of experiments, n = 10
NOTE: For solid lines, see Table II.

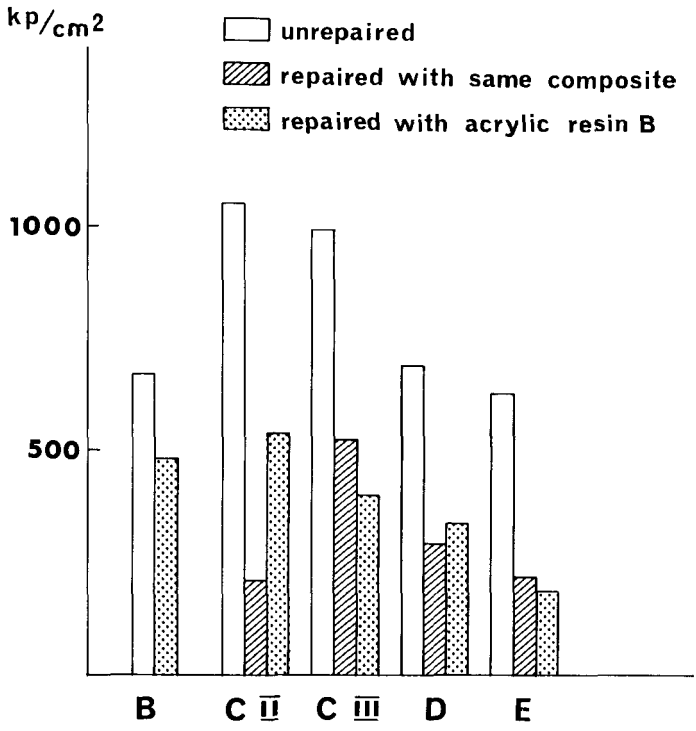

Fig. 2. Transverse strengths of unrepaired and repaired acrylic and composite resins.

no difference in strength when the specimens were repaired with the same composite or with the acrylic resin. The only exception was composite C II which showed very low strength when it was repaired with the same material.

DISCUSSION

Although the compressive strength of silicate cements has been shown to be of about the same as for composite resins (*Phillips & Skinner*, 1967), the transverse strength measured in the present study was much lower than that of the composite resins. As has been pointed out earlier (*Forsten*, 1969) and in this paper, the transverse strength test may be considered more relevant to clinical conditions than the compressive strength test. The measured low transverse strength of silicate confirms thus »theoretically» the general opinion that silicate cement is not a suitable material for restoring incisal angles.

The results show also that the acrylic resin has a greater transverse strength and thus may be more suitable for restoring incisal angles than silicate cement. However, the strength of acrylic resin was generally lower than the strength of the composite resins. Also, one must consider the known negative properties of acrylic resin, which makes its use for this purpose open to question.

Skinner and *Phillips* (1967) had observed the compressive strengths of composite resins to be about half that of amalgams. When the transverse strength values obtained for the composites in the present study were compared with the average transverse strength for amalgams obtained in an earlier study (*Forsten*, 1969), it was found that the transverse strengths of three of the composites were half that of amalgams and of the remaining four composites about two-thirds the transverse strength of amalgams.

The transverse strength test in this study gave almost the same value for acrylic resin B as for composite E. *McLean* and *Short* (1969) came to the same conclusion when they tested these materials using a tensile strength test. Among the compressive strength values of composites reported by *Phillips et al.* (1969) composites F and G had higher values than composite C I. In the present study composite G showed a comparatively low transverse strength value. It has not been clarified if this was due to differences in test systems or only to differences in batches and/or handling of composite G. It has to be noted that the manipulation of composite G was more difficult than for the other composites, which also was reflected in the large scatter of data.

In *Godfredsen's* opinion (1969), composite C II is not usable for restorations which are exposed to biting forces. With this he probably means that the material is not suitable as a posterior filling material replacing amalgam. It is the opinion of the present authors that the strength of the strongest composites would be enough in many posterior cases. Other factors make, however, the use of composites in posterior teeth hazardous compared with the use of amalgam. It has not yet been proved beyond doubt that the effect of composites on the pulp is as mild as for amalgams. Although attempts have been made to develop X-ray-opaque composite resins (*Bowen & Cleek*, 1969 and *Chandler et al.*, 1970) and although these attempts have been partly successful, these experimental composites seemed still to be much more radiolucent than amalgam. Judging from the clinical experience of the authors the insertion and carving and finishing seems also to be more difficult with composites than with amalgam.

The different manipulation techniques used in this study showed that manual mixing often resulted in a large scatter of data. This was very apparent

in connection with the fast setting composite C II and the slab mixed composite G. The scatter of data was small after mechanical mixing when an ultrahigh-speed (Silmat) apparatus and a convenient mixing time were used. The use of three different times in mixing composite C III showed the great influence of the mixing time on the scatter of data. Mixing of composite E in two apparatuses showed that the ultrahigh-speed mixer was preferred since the same mixing time resulted in higher strength and smaller scatter of data than mixing in the high-speed mixer. It is, therefore, important to find, by experimenting, the best mixing apparatus and mixing time for each material. The importance of this in mixing silicate cement has earlier been pointed out by *Sorensen et al.* (1970).

The manufacturers' statement that the fifty-fifty ratio of universal to catalyst paste of the composite F does not need to be very exact is supported by the findings in this study. The deviation from the recommended ratio influenced the transverse strength, but the effect was not very great inspite of the big deviation from the fifty-fifty ratio. In *Phillips et al.* (1969) opinion, composite resins are easier to manipulate than acrylic resins. The acrylics can be manipulated according to the brush technique which is very simple and which in this study resulted in comparatively high transverse strength and small scatter of results. When mixing composite resins it is not easy to manually incorporate evenly the catalyst drops in the base paste. This was reflected in some instances by the large scatter of data after manual mixing. The results of manipulation of composites in this investigation and in clinical work indicate that mechanical mixing is the easiest and most reliable way to handle composite resins.

The results obtained in this study indicate further that repair of acrylic resin fillings with the same acrylic may be recommended. The repair of composite fillings has, however, to be considered more carefully. The strength of composite C II repaired with the same material was extremely low, which may partly be due to the fast setting of this material. As, however, the bond strength of composite C III repaired with the same brand was nearly as high as the transverse strengths of unrepaired composites D and E, and as the scatter of results in this case was relatively low, the opinion of the present authors is that repaired defects of this composite have good chances to be clinically acceptable. It is even likely that a partial replacement with this material will be successful clinically. In such cases some mechanical retentions will, however, be needed if the replaced part of the restoration will be exposed to biting forces.

The convenience of using acrylic resin as a repair material when it is manipulated according to the brush technique makes it an easy material for

larger defects in acrylic resin fillings, and for minor defects, e.g. air bubbles, in composite resin restorations. Minor defects in composites can be difficult to fill with a thick composite, but it will be easy and economical to »brush in» acrylic into such small cavities.

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Address:
Institute of Dentistry,
University of Turku,
Lemminkäisenk. 2,
SF-20520 Turku 52, Finland