Retentive strength of dental composite to metal surfaces

Lennart Wictorin, Gudbrand Øilo and Nils-Gunnar Ohlson
Department of Oral Prosthetics, Farsta, and Materials Research Center, Royal Institute of Technology, Stockholm, Sweden, and NIOM, Scandinavian Institute of Dental Materials, Oslo, Norway

Wictorin L, Øilo G, Ohlson N-G. Retentive strength of dental composite to metal surface. Acta Odontol Scand 1989;47:185–191. Oslo. ISSN 0001-6357.

Retentive strength of the metal–composite interface was studied with tensile tests for 10-mm and 4-mm diameter specimens. In both series nonperforated and perforated metal surfaces with various numbers of holes were used. The specimens were tested after 1 day of storage in air and after thermocycling in water at 7°C and 60°C, respectively. The nonperforated specimens had the highest retentive strength values for both small and large specimens. The retentive strength decreased with increasing number of perforations and for nonperforated specimens with large retentive area. Thermocycling reduced the tensile force required to break the specimens by 4% to 50%. The fracture surface was mostly located close to the metal surface, indicating that this is the zone of stress concentration. With increasing length of the bond edge a reduction of the retentive strength was observed. □ *Partial fixed bridge; tensile strength; thermocycling*

L. Wictorin, Department of Oral Prosthetics, Storforsplan 54, Farsta, S-123 47 Stockholm, Sweden

The replacement of a tooth by a semi-permanent bridge construction retained by a dental composite has been applied as an alternative treatment in young patients, especially in the anterior region (congenital anodontia or trauma). The replacement method implies an acid-etch technique to retain the composite to the enamel surface of the supporting teeth (1). Several methods have been suggested to enhance the retentive strength between metal and composite (2). A common method is to make penetrations of various sizes and numbers in the lingual framework. Clinical experience, however, has shown a risk of fracturing of the composite and dislodgement of the bridge (3).

The location of the fracture in a metal–composite–enamel bond has been studied (1). The authors stated that the fracture was due to a cohesive failure either in the composite material or the enamel, or both. However, other studies have reported three main fracture patterns, namely a cohesive fracture occurring in the composite resin, an adhesive failure along the interface, and a cohesive fracture in the enamel. Most fractures were found in the composite resin close to the enamel surface (3).

Other information has been obtained by testing bond strength of orthodontic brackets (4). The metal brackets failed at the bracket–cement interface. Three types of cement were tested. The two types of metal bracket used were of foil-mesh type, having different retentive surfaces. The bond strength varied with the type of retentive surface and with the type of bonding cement applied. A highly filled diacrylate cement gave the highest bond strength value for the metal brackets. Observations of clinically failed composite-retained bridges also demonstrate that the fracture is most often located close to or at the metal surface, which indicates that this is the most critical area of the bond.

The fracture toughness of dental composites has been studied (5, 6). The critical stress intensification factor (K_{IC}) and the fracture strength were determined for a range of composite products. Storage time and loss or gain of plasticizing molecules influenced the K_{IC} value. The introduction of filler into the polymer increased the critical

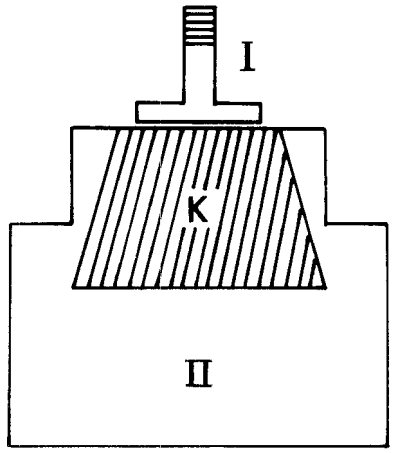

Fig. 1. Test specimen, parts I and II. K = composite material.

stress intensification factor. Experimental studies, evaluating the bond strength of the interface between various designs of metal retainers and a bonding composite have been performed. All designs were found retentive enough to withstand normal anterior forces of occlusion (7). However, most retainers failed at the retainer–composite interface. A pilot study indicated that sandblasting of the metal might significantly increase the bond between metal and a composite (8).

The aim of this investigation was to study the retentive strength of the metal–composite interface with various types of retentive geometry of a sandblasted metal surface in dry condition and after thermocycling.

Materials and methods

Specimens

Circular plain brass plates (Fig. 1) were manufactured in two dimensions, 4 mm and 10 mm in diameter. To simulate various clinical methods, three different designs of metal plates with various numbers of retention holes were tested. The 4-mm plates were used with zero, two, and four holes, and the 10-mm plates with zero, one, and four holes, as shown in Fig. 2. All holes had an hourglass shape. The retentive metal surface of all

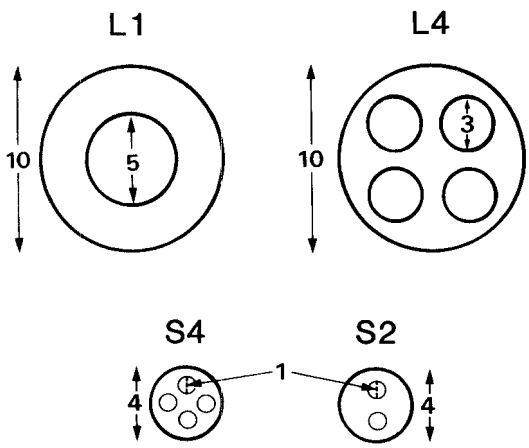

Fig. 2. Test specimen with retention holes. Measurements in mm. L and S denote large and small specimens.

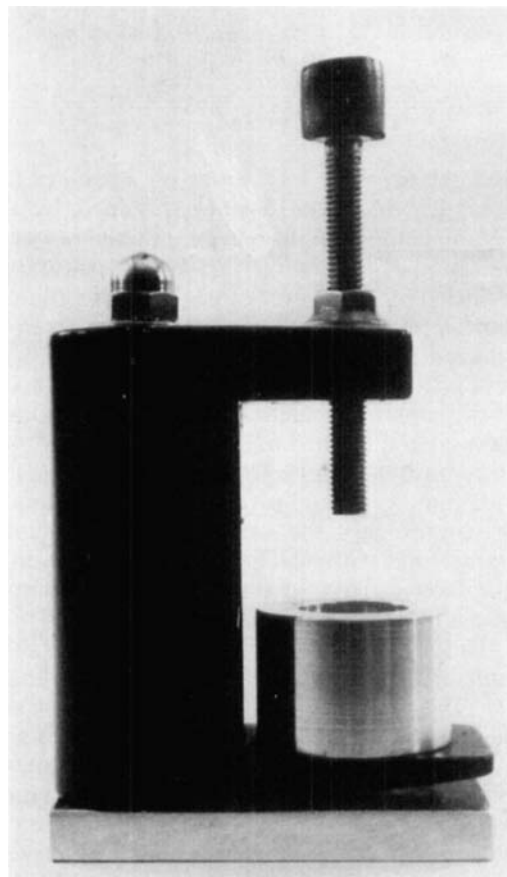

Fig. 3. Appliance for bonding procedure.

specimens was exposed to an air abrasive (aluminum oxide, 50-μm grain size) for 2 sec before bonding (Bego Ministar, 4 atm). The other side of the metal plate was equipped with a threaded rod, 3 mm in diameter, for the application of tensile force (Fig. 2) (8).

The second part of the specimen (Fig. 1), simulating the enamel surface, consisted of a circular plastic cylinder, whose center was filled with composite (Adaptic®, Johnson & Johnson, batch no. CH-B x027-26 for the dry-tested specimens and CH-B 5323 and 5319 for the thermocycled specimens).

The two parts, referred to as parts I and II, were bonded together in a special appliance (Fig. 3), using the same composite as mentioned above. No bonding agent was used. The material was mixed in accordance with the manufacturer's instructions. The surplus bonding material was carefully removed to reduce the risk of crack initiation in the groove surrounding the plate. The material was then stored for 24 h at 20°C in 100% relative humidity. Each series corresponds to seven repeated bonding and tensile tests.

Thermal cycling

One series of each type of the specimens described above was exposed to thermal cycling. The specimens were exposed to one water bath at 7°C for 20 sec and a second water bath at 60°C for an additional 20 sec. The automatic transmission required 2 sec and was performed by the apparatus shown in Fig. 4. The temperature within the specimen—that is, at the interface—was controlled by a copper-constantan thermocouple connected to a digital thermometer. A time temperature diagram was made (Fig. 5), showing the temperature at the interface to be 12.9°C and 56.2°C, respectively.

The specimens were stored for 1 h in air at room temperature before exposure to the cycling procedure comprising 5000 cycles—that is, 2500 in each bath.

Tensile strength test

A tensile testing machine was specially designed and constructed to supply the low loads encountered in testing dental composite material (Fig. 6).

The specimens were fixed to the clamps of the testing machine by two threaded rods. An inserted ball joint reduced the transversal force in the loading so that the bending moment of the specimen was reduced to a minimum. The specimen was loaded with a speed of 0.2 mm/sec. The load signals were

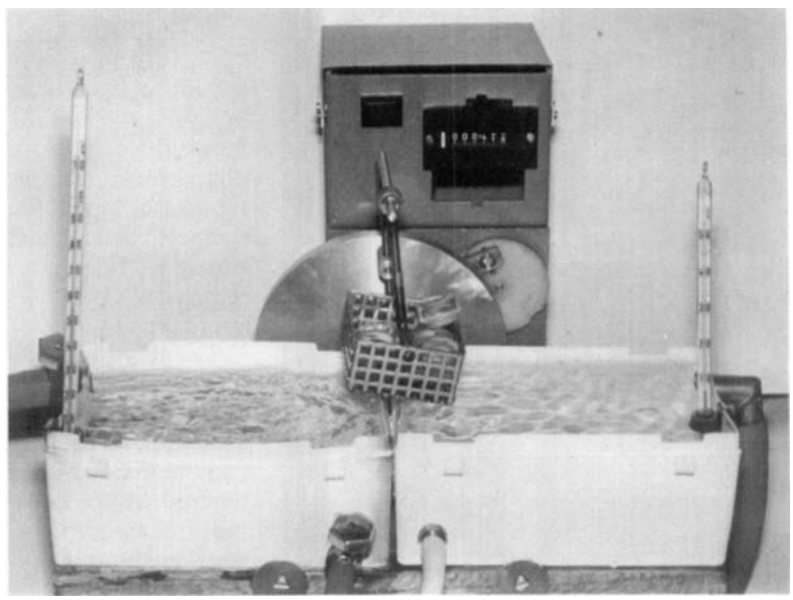

Fig. 4. Thermal cycling apparatus.

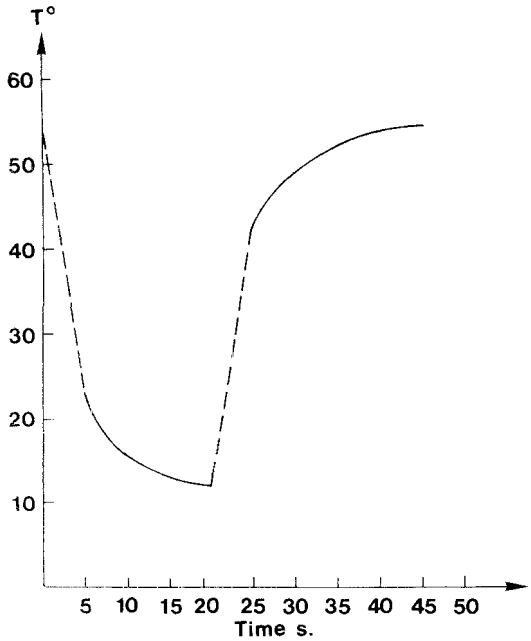

Fig. 5. Time/temperature diagram for thermal cycling of large specimens. Unbroken line = specimens in water; broken line = specimens in air.

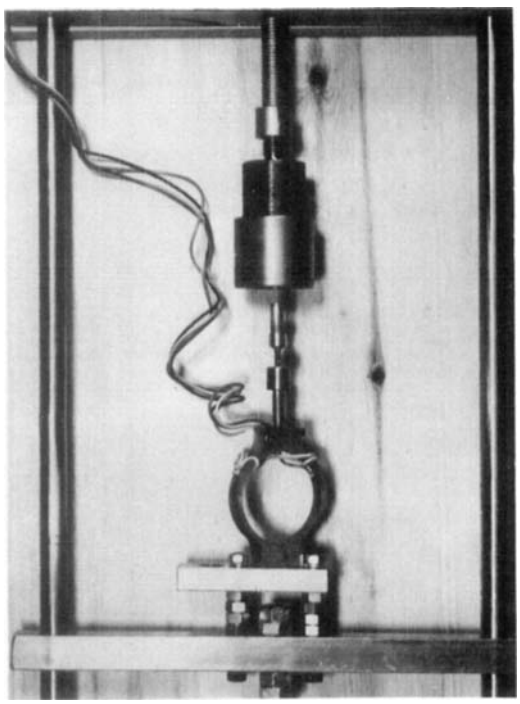

Fig. 6. Tensile testing machine.

transmitted from a dynamometer equipped with strain gauges to an xy-recorder, which thus registered the load along the vertical axis. The equipment was calibrated on several occasions.

Average values of the tensile stress necessary to separate the various types of specimens were calculated from the curves recorded. Each specimen was examined in a microscope at 10 times magnification after the tensile test to identify the fracture surface and its locations.

Differences in bond strength were tested for significance by Student's *t* test.

Results

The results of the tensile strength tests are shown in Fig. 7 as the load necessary to break the bond in relation to the size of the metal surface—that is, total area minus hole area. All differences between the three types of large specimens tested either in dry or in thermocycled condition were significant at the 99% level with the exception of the difference between L4 in dry and thermocycled condition. All differences between the three types of small specimens tested either in dry or in thermocycled condition were also significant at the 99% level.

For both the large and the small specimens the nonperforated type required the highest tensile load to break the bond. The thermocycling reduced the load necessary to break the bond to various extents. For the nonperforated large specimens (L0) the reduction was 40%, whereas for the small nonperforated specimens (S0) the reduction was 13%. For the specimens of type L4 the reduction was 3.5%, whereas for the type S4 specimens the reduction was 50%.

The retentive strength (Table 1) is lower for both small and large perforated specimens when calculated on the basis of the total area of the specimen, and it decreases with increasing number of holes. No systematic difference was seen between the two types of large or between the two types of small perforated specimens when the retentive strength was calculated on the basis of

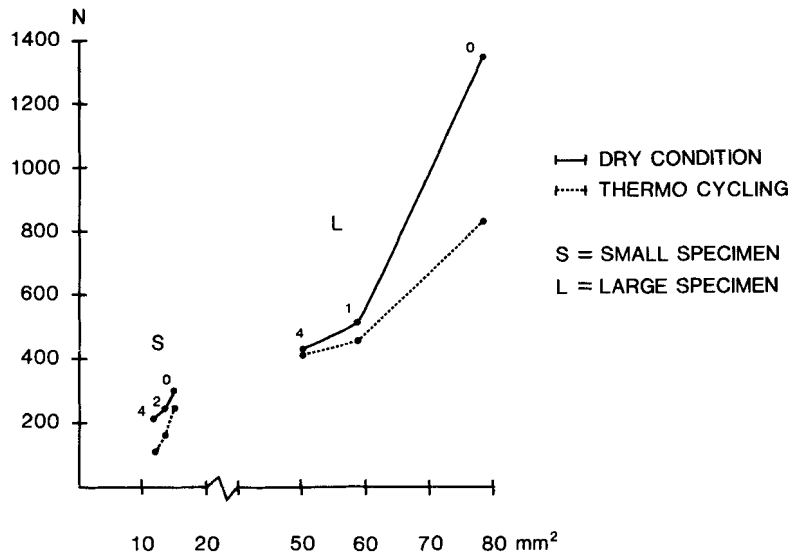

Fig. 7. Load necessary to break the bond as a function of the metal area. 0, 1, 2, and 4 denote number of holes.

the metal surface—that is, minus the area represented by holes.

Microscopic inspection showed the fracture surface to be located at the interface or in the composite close to the metal.

Discussion

Bonding of metal structures to etched enamel by composite materials is a complex procedure. In addition to factors like the geometry of the total assembly and the type and duration of the load, the resultant strength and clinical lifetime of this bond is dependent on various factors like the pretreatment and structure of the enamel, the strength of the composite, and the pretreatment, geometry, and surface structure of the metal counterpart.

Tensile tests have previously been used to investigate the bond between the composites and enamel, and a linear relationship was shown between the tensile strength of the composite and the bond strength (9). The bond between the composite and the metal surface has previously been tested, and results indicate that sandblasting or etching the surface may give the best bond (2, 8).

Tensile tests are commonly used to meas-

Table 1. Retentive strength values (MPa) calculated on the basis of the total area or the metal surface only

	Dry/d. storage				Thermocycled			
	Total area		Metal surface		Total area		Metal surface	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
L0	17.1	0.39	17.1	0.39	10.6	1.51	10.6	1.51
L1	6.5	0.14	8.7	0.18	6.0	0.40	8.0	0.54
L4	5.5	0.09	8.6	0.14	5.3	0.32	8.3	0.50
S0	19.3	0.55	19.3	0.55	16.9	1.64	16.9	1.64
S2	15.8	0.47	17.7	0.52	10.5	1.99	11.8	2.22
S4	14.5	0.36	18.4	0.45	7.1	2.45	9.1	3.11

ure bond strength values. The difficulties with such tests are largely related to the problem of a correct alignment of the two test pieces bonded together (10). Precautions were taken in the present experimental arrangement to ensure that the tensile force acted normally to the bond plane.

The results of the present study support our previous findings that retention holes do not contribute to the strength of a bond between composites and metal (8). On the contrary, a considerable reduction was observed for both large and small specimens on introduction of holes in the metal plate. This is contrast to clinical application, where perforated metal frames are used frequently (11).

The reduced strength was observed in spite of a circular shape, well-rounded edges, and an hourglass shape of the holes, as previously suggested (8). The new retention on the outside of the plate could obviously not compensate for the loss of interfacial area.

The largest reduction in bond strength occurred with 0 to 1 hole (large specimens) or with 0 to 2 holes (small specimens). An increase in the number and area of holes was followed by a further decrease of bond strength, but to a somewhat smaller extent (Fig. 7).

Introducing holes in the metal plate not only reduces the bond area but also establishes new edges in the interfacial bond plane. An extended bond edge is followed by an increased risk for flaws acting as initiators of crack growth. This explains the dramatic reduction of the force necessary to break the bond and the calculated bond strength per unit metal surface, especially for large specimens. In addition, the holes result in a very complex stress distribution and a possibility for crack growth more centrally in the bond plane. The last factor may be more important for diameter to thickness ratios of the adhesive layer greater than 10, and might probably explain some of the differences found in strength reduction between large and small specimens (12).

The thermal cycling procedure reduced the bond strength of the assembly. This can be explained mostly as a result of the stresses introduced during the cycling procedure due to the difference in thermal expansion between the two materials. The coefficient of expansion for the composite is five times that of the metal. An increase in size and number of flaws during the thermal cycling period can be anticipated as a result of the thermal stress. Another factor might be absorption of water by the composite, followed by a reduction of the physical properties of the material (13). A third factor might be penetration of water in slits and flaws along the bond edge, reducing the eventual adhesive forces. However, the influence of water sorption might be limited, as penetration and complete saturation of such layers have been found to require as much as 3 months (14). Two different batches were used for the dry and the thermocycling precedure, which may have influenced the differences in the tensile strength between the two series.

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Received for publication 11 March 1988