International Journal of Clinical Oral and Maxillofacial Surgery
2020; 6(2): 44-48
http://www.sciencepublishinggroup.com/j/ijcoms
doi: 10.11648/j.ijcoms.20200602.15
ISSN: 2472-1336 (Print); ISSN: 2472-1344 (Online)

Shear Bond Strength of Polymeric to Dentin

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To cite this article:
Linfu Han, Lijun Liu, Huanhuan Zhang. Shear Bond Strength of Polymeric to Dentin. *International Journal of Clinical Oral and Maxillofacial Surgery*. Vol. 6, No. 2, 2020, pp. 44-48. doi: 10.11648/j.ijcoms.20200602.15

Received: March 9, 2020; **Accepted**: March 23, 2020; **Published**: September 25, 2020

Abstract: The purpose of this study was to evaluate the dentin bond strength of restorations made of different polymeric materials with Single Bond Universal Adhensive and etch-and-bond resin cement. Ceromer (ceramage, Shofu), Polymethylmethacrylate (PMMA DISK, Yamahachi), resin nanoceramic (Lava Ultimate, 3M ESPE), and polymer-infiltrated-ceramic-network (Vita Enamic, Vita Zahnfabrik) specimens (n=15/group) were fabricated respectively. Dentin specimens were prepared from extracted third molars stored in distilled water in a refrigerator (4°C). Single Bond Universal Adhensive was applied to the prepared tooth and light cured. Then, specimens were cemented using 3M ESPE RelyX™ Uitimate Cliker™ adhesive resin cement. All cemented specimens were stored in distilled water for 24 h and subjected to shear forces by a universal testing machine. Vita Enamic was found to show the highest shear bond strength values. The shear bond strength of Lava Ultimate was weaker than that of Vita Enamic. But there was no statistical difference between Vita Enamic and Lava Ultimate. Both of them showed significantly higher shear bond strength than the Ceramage and PMMA groups. The lowest values were obtained for PMMA and there was a significant difference between the PMMA and Ceramage groups. The bond strength of the polymeric materials is material dependent. So doctors can use them for patients with different intent.

Keywords: Ceramage, Polymethylmethacrylate, Resin Nanoceramic, Polymer-infiltrated-ceramic-network, Shear Bond Strength

1. Introduction

In recent decades, metal-free, tooth-colored and high-performance restorations, such as ceramics or polymeric materials, have been used to replace missing tooth structures to rehabilitate the esthetics and functions of defected teeth. The advantage of ceramic restorations is that ceramics have superior esthetic appearance, good biocompatibility, durability, color stability [1], and can mimic the structural characteristics of natural teeth [2]. However, many studies have shown that ceramics are strong, rigid, brittle materials, with high susceptibility to fracture [3], and can induce damage to the natural surface of the tooth [4]. Recently, polymeric materials have been introduced for dental restorations [5], and with continuous evolution of polymeric materials have led to materials that have esthetic appearance, higher abrasion resistance and inferior discoloration [6], as well as less abrasive effect on the antagonist enamel [7-9].

It has been reported that one of the key advantages of polymeric restorations is the low abrasiveness of the enamel antagonists in comparison with ceramics [10-12]. Another advantage is the low elastic modulus, which allows better absorption of functional stresses by deformation [13]. Some studies have pointed out that ceramic restorations require certain thickness to acquire adequate fracture resistance, but for polymer restorations, even ultrathin polymeric materials can show higher fracture resistance than ceramics [14, 15]. Ender *et al.* [16] reported that, based on the findings of marginal adaptation, fracture load and macroscopic fracture mode, polymeric materials may be applicable as long-term restorations in some cases. In view of these advantages, polymeric materials have been considered as economic alternatives for ceramics with faster processing, higher performance, and lower costs [17, 18].

Despite the expanded application of polymeric materials, the clinical longevity of these restorations is still regulated by the strong and durable bonding to both materials and tooth with resin cement. Bonding properties of these polymeric materials still needs to be investigated, especially Ceramage and PMMA, as there is a lack of information on the shear bond strength of polymeric materials and dentin in the literatures. The objective of this study is to compare the shear bond strength between different polymeric materials and dentin.

2. Methods

2.1. Preparation of Dentin Specimens

60 human third permanent molars from 16-year-old to 40-year-old individuals were extracted. The criteria for tooth selection included intact enamel with no cracks caused by extraction, the absence of caries, and an adequate dimension of the crown [17]. Before extraction, patients have been informed about the use of the teeth for research purposes, and verbal consent have been obtained. The teeth were thoroughly washed in running water and all blood and adherent tissue were removed by the clinician with periodontal curettes and stored in distilled water in a refrigerator (4°C) according to the ISO 11405:2015 (Dentistry-Testing of adhesion to tooth structure) until needed. The occlusal surface of each tooth was wet ground in an automatic grinding machine with rotating abrasive discs to remove enamel and to expose a 5mm area of dentin, and the roots of the teeth were mounted in a holder with self-curing acrylic resin. In order to ensure correct alignment in the test fixtures, the ground surface of each tooth was parallel to the shearing force. The exposed dentin surfaces were prepared by planning against silicon carbide abrasive paper with a grit size of P120 and P400 by a two-step sequential planning process under running water to obtain an even and uniform dentin surface and reduce any micromechanical interlocking that could affect the real bonding influence of the tested adhesive cements (ISO 29022:2013 Dentistry-Adhesion-Notched-edge shear bond strength test). Before cementation, to remove any foreign matter, the dentin surface was cleaned for 1min with a cotton pellet impregnated with alcohol and ultrasonically cleaned in distilled water for 5min. The mounted tooth was then placed in water at room temperature and use for the bonding procedure within 4 h. The surface was then rinsed and dried with an oil-free air stream before cementation. The teeth were randomly divided into 4 groups. One operator carried out all procedures to maximize standardization.

2.2. Preparation of Polymeric Specimens

Groups 1:15 Ceramage specimens were fabricated by placing the Ceramage inside a mold made of a Teflon material with an inner diameter of 4mm and a height of 2mm, and then light-polymerised with Solidilight (Shofu Inc., Kyoto, Japan) according to the manufacturer's recommendations. A glass microscope slide was used to compress the last increment to obtain a flat surface. After polymerization, specimens were removed from the mold.

Groups 2: PMMA specimens were milled from PMMA DISK (Yamahachi Dental, Aichi, Japan) using CAD/CAM machine (Imes-icore 250i, Germany).

Groups 3, 4: Vita Enamic and Lava Ultimate specimens (4mm diameter, 2mm height) were designed with CEREC software 4.2 platforms (Sirona Dental GmbH, Salzburg, Austria) and obtained by milling from their respective blocks for CAD/CAM with CEREC MC XL (Sirona Dental Gmbh, Salzburg, Austria).

The materials'names, manufactures, and chemical composition used in this study are listed in Table 1. The specimens were wet ground manually on only one surface using 600-grit silicon carbide paper and then ultrasonically cleaned in distilled water for 5 min.

Table 1. *Information regarding the materials used in the study.*

Product name	manufacturer	composition
Ceramage	Shofu, Kyoto, Japan	Zirconium Silicate featuring a progressively fine structural filling of more than 73% by weight of micro-fine ceramic particles in an organic polymer matrix
Yamahachi PMMA	Yamahachi Dental, Aichi, Japan	PMMA
Vita Enamic	Vita Zahnfabrik, Bad Säckingen, Germany	86wt% feldspar ceramic, 14wt% polymer
Lava Ultimate	3M ESPE, Seefeld, Germany	80wt% nanoceramic, 20wt% resin
RelyX Ultimate Clicker	3M ESPE, St. Paul, MN, USA	Base paste: methacrylate monomers, Radiopaque, silanated fillers, initiator, stabilizers, rheological additives; Catalyst paste: Methacrylate monomers, radiopaque alkaline fillers, initiators, stabilizers, pigments, rheological additives, fluorescence dye, dual-cure activator for single bond universal adhesive
Single Bond Universal Adhesive	3M ESPE, St. Paul, MN, USA	MDP phosphate-monomer dimethacrylate resins, HEMA, vitrbond Copolymer, filler, ethanol, water, initiators and silane.

PMMA: Polymethylmethacrylate; MDP: 10-methacryloyloxydecyl dihydrogen phosphate; HEMA: 2-hydroxyetheyl methacrylate.

2.3. Bonding Procedures

Before cementation, a small piece of insulating tape with a central hole was placed on the dentin surface. The tape was perforated with a punching machine to create 4mm holes. Then, Single Bond Universal Adhesive was applied to the prepared tooth with a microbrush and rubbed in for 20 s. The adhesive was gently air dried for approximately 5 s to evaporate the solvent, and then light-cured for 10 s, and a thin layer of RelyX^{TM} Ultimate Clicker^{TM} adhesive resin cement was applied and placed over the dentin substrates. Subsequently, the specimens were bonded on and excess cement was removed with a microbrush. The adhesive interface was light cured under a load of 10N from 4 directions for 40 s. The bonded specimens were stored in distilled water for 24 h at (37±2)°C prior to shear bond strength testing.

2.4. Shear Bond Strength Test

The shear bond strength was measured using a universal testing machine (MTS, Eden Prairie, USA) at a cross-head speed of 1mm/min. The force was measured in newtons divided by the cross-sectional area and is reported as megapascals.

2.5. Statistical Analysis

SPSS 20 statistical analysis software (IBM, Chicago, USA) were used in this study. As the data was completely numerical, distribution characteristics and homogeneity of variance were checked with the Kolmogorov-Smirnov test and Levene's test, respectively. Descriptive statistics (mean and SD) were computed. Multi-group comparisons of the means were carried out by one-way analysis of variance (ANOVA) test with post hoc contrasts by Student–Newman–Keuls test and Kruska al-Wallis test. All results with *P*-values smaller than 5% were considered as statistically significant.

3. Results

The obtained mean for shear bond strength values and their respective standard deviations of the different polymeric materials are shown in Table 2. Among the tested polymers, the highest shear bond strength values were obtained with Vita Enamic group, which was followed by the Lava Ultimate group. Vita Enamic and Lava Ultimate were not statistically different, and both had significantly higher shear bond strength than the Ceramage and PMMA. The lowest values were obtained for PMMA with significant difference between group PMMA and Ceramage (Figure 1).

Table 2. *The shear bond strength (means and standard deviations) of 4 groups.*

Groups	Sample number	Mean (Mpa)	Standard deviation
PMMA	15	5.99	1.42
Ceramage	15	11.20	1.49
Lava Ultimate	15	14.66	2.10
Vita Enamic	15	15.43	2.69

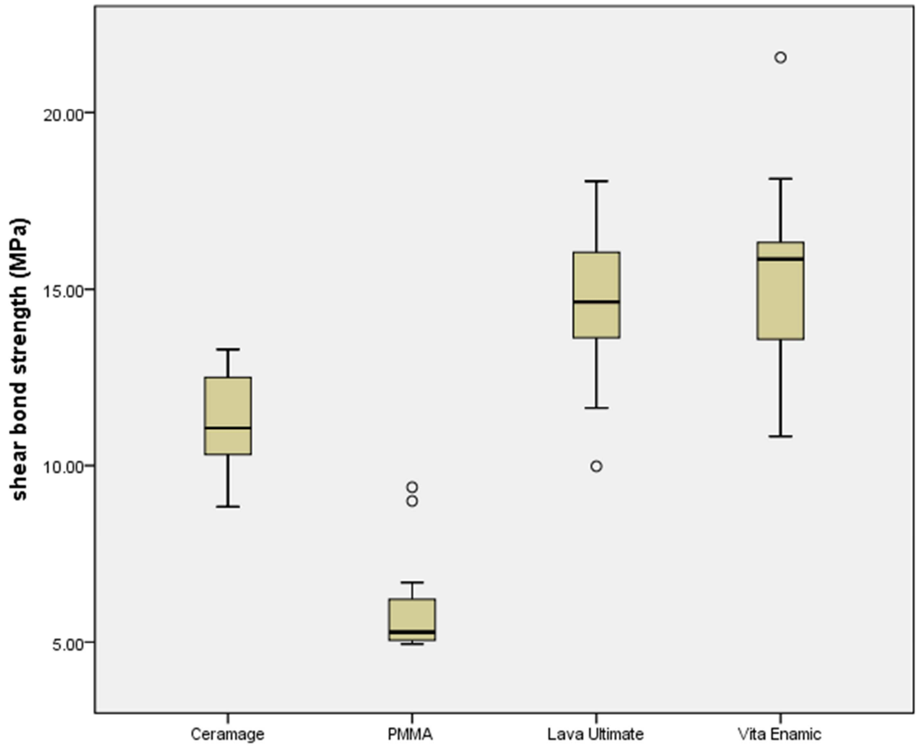

Figure 1. *Boxplots for shear bond strength values (MPa; medians, lower and upper quartiles as well as minima and maxima) of the four polymeric materials.*

4. Discussion

It is well known that different dental restoration materials are priced differently. The consumption ability of patients with tooth defects is widely ranged in China, the biggest developing country. Before different dental restoration materials were used for patients, it is necessary to tell them the merits and demerits of dental restoration materials which are related to factors including repaired dental life at a different prices. Polymeric materials are gaining popularity for hardness, high flexibility, color stability, and with low rigidity, and brittleness [18]. Durable and effective bond strength between the polymeric material and the tooth is fundamental for the clinical long-term survival of a restoration [19]. However, the bond strength of polymeric materials for restorations are not clear. At the same time, some patients need long-term temporaries treatment including changes of vertical dimensions, with considerations of aesthetic and phoneric properties. So it is important for doctors to known shear bond strength value of polymeric dental restoration. The aim of this study was to evaluate the shear bond strength between dentin and four kinds of polymeric materials, which are commonly used in clinic.

In the present study, dentin bond strength of the polymeric materials was determined using the shear bond strength test. Shear bond strength test is defined as a test in which two materials are connected by an adhesive agent and loaded in shear until separation occurs [20]. In the shear bond strength test, the shear stress was considered to be more representative of a clinical situation, and the shear bond strength test was considered the most efficient method for reliable results [21].

The shear bond strength of four kinds of polymeric materials which widely used in our clinic were studied. These materials showed different shear bond strength which may depend on their chemical composition. Yamahachi PMMA DISK contains 100% polymethylmethacrylate without organic or inorganic filler. Ceramage is a kind of light-curing micro-fine resin, containing more than 73% by weight of micro-fine ceramic particles, which is mainly composed of Zirconium Silicate. Recently, an innovative polymeric CAD/CAM material has been introduced. It combines the positive aspects of both ceramics and composites with beneficial properties [22]. Vita Enamic, an innovative polymeric CAD/CAM material, is composed of a dominant feldspathic-based ceramic network (86wt%) integrated with an acrylate polymer network (14wt%) with both networks fully penetrating one another [23]. The main components of ceramic network are SiO_2 (58~63wt%), Al_2O_3 (20~23wt%), and ZrO_2 (<1wt%). Lava Ultimate, another innovative polymeric CAD/CAM material, which is 80wt% nanoceramic particles (silica- and zirconia filler/cluster filler) embedded in a highly cross-linked polymer network (20 wt%) [24].

In this study, all the specimens were cemented with Single Bond Universal Adhesive, which was advantageous because the Adhesive not only have silane coupling agent, but also have 10-MDP. Application of the adhesive to the Vita Enamic ceramic surfaces can provide a chemical covalent hydrogen bond, which is a major factor for a sufficient bond to ceramics [25]. Besides, Silanes are bifunctional molecules that bond silicon dioxide with OH groups on the ceramic surface and can increase the bond strength by improving the wettability of surface [26]. They also have a degradable functional group that copolymerizes with the resin's organic matrix [27]. 10-MDP has previously been shown to offer chemical bond-mediating capacity directly with zirconia and thus, to the zirconia clusters/fillers present in Vita Enamic [28, 29]. Therefore, Vita Enamic can have significantly higher bond strength values than other three groups. Compared with Ceramage and PMMA, Lava Ultimate showed higher bond strength values. In this study, although no statistically significant difference found between Lava Ultimate and Vita Enamic, Vita Enamic has shown higher bond strength than Lava Ultimate. This reliable bond between Lava Ultimate and dentin may have been explained through the nanoceramic particles present in Lava Ultimate, and Silanes, 10-MDP monomers present in Adhesive. Lava Ultimate is composed of resin matrix, silica, and zirconia nanomers, getting strong and durable bonding. The bond strength of Ceramage is weaker than that of the Vita Enamic and Lava Ultimate. It is because that, due to a highly uniform and quality ceramic content, the bond strength of Vita Enamic and Lave Ultimate have been increased. The polymerization mode of the Ceramage is greatly influenced by operator, resulting in the presence of flaws during incremental build up, but cannot eliminate during the curing process [30]. PMMA had the lowest shear bond strength values. Reason may be that the PMMA that has high polymethylmethacrylate content and is industrially polymerized at high temperature and pressure, has relatively high density with fewer flaws and pores, which decrease the penetration of adhesive resin cement into the PMMA [31]. In addition, the specific components of PMMA can decrease the possibility of additional chemical bonding, which in turn affect bonding performance. One study showed that most of the functional groups of PMMA did not exist in terms of double bindings, which leads to adhesive problems [32].

Although different polymeric materials showed different shear bond strength value, polymeric material with lower shear bond strength value can be used for long-term tempotizations. Ender and his colleagues have shown that some polymeric materials may be applicable as long-term restorations in some cases [16]. PMMA, the least expensive one in china, showed the lowest shear bond strength value in this study. It can be used for tempotizations more than 6 months [33]. However, It is found that the usage of temporary cements on polymeric materials led to frequent loss of retention through clinical observations. Therefore, doctors should think about repaired dental life which patients wanted before they choose materials.

5. Conclusions

Based on the results presented and within the limitations of this study, it can be concluded that four different kinds of polymeric materials showed different shear bond strength. The bond strength of polymeric materials is material dependent. Vita Enamic, Lava Ultimate and Ceramage revealed higher shear bond strength than PMMA. Despite the high cost of treatment, Vita Enamic, Lava Ultimate and Ceramage restorations should be advised if the retained tooth is expected to maintain functionality over the long time. PMMA, the least expensive one in china, showed the lowest shear bond strength value in this study. It can be used for long-term tempotizations more than 6 months. Since the shear bond strength differed, it is evident that appropriate polymeric materials selection should be based on considerations of specific clinical situations and economic levels. So doctors can use them for patients with different intent.

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