Journal of Applied Polymer Science

# Influence of Filler Content on Physicomechanical and Bonding Properties of an Experimental Dental Resin Cement

**Jie Xiong,[1,2]* Xiang Sun,[1]* Jihua Chen,[1] Lihui Tang[3]**

[1]Department of Prosthodontics, School of Stomatology, Fourth Military Medical University, Xi'an, China
[2]Department of Stomatology, 307 Hospital, Military Medical Science Academy of the PLA, Beijing, China
[3]Department of dental materials, School of Stomatology, Fourth Military Medical University, Xi'an, China

*The authors contributed equally to this work

Correspondence to: J. Chen (E-mail: jhchen@fmmu.edu.cn)

**ABSTRACT:** To investigate the effects of filler contents on the bonding and physicomechanical properties of experimental dental resin cements and the correlation between them, four groups were formulated with silicon dioxide filler in the following weight percentages: A: 40%, B: 50%, C: 60%, and D: 70%. LuxaCore dental resin cement was used as group E for commercial reference. For testing bond strength, resin cements were applied to the prefabricated dental fiber posts in the artificial teeth canal and photo cured, and then the microtensile bonding strength (BS) between posts and resin cement was measured in sticks of $1 \times 1$ mm$^2$. For the mechanical properties, flexural strength (FS), diametral tensile strength (DTS), compressive strength (CS), and hardness (H) were tested according to the related standard. Water sorption and solubility were also determined. The results showed both bonding and physicomechanical strengths of the experimental resin cements varied to different extents with filler addition. Positive correlations existed respectively between the filler content and some mechanical properties ($r_{FS} = 0.964$, $r_{CS} = 0.967$, and $r_H = 0.959$), whereas no significant correlations were found between the filler content and the other strength values tested in this study ($r_{DTS} = 0.321$, $r_{BS} = 0.014$), neither were between bond strength and mechanical properties. The effect of filler content on mechanical properties was more influential and prominent compared to that on bond strength. It is partial to compare properties and to predict clinical behaviors of resin materials based on a single *in vitro* test, and comprehensive evaluation is necessary. © 2012 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 000: 000–000, 2012

**KEYWORDS:** mechanical properties; bonding properties; dental polymer; inorganic filler

Received 28 November 2010; accepted 20 April 2012; published online
**DOI: 10.1002/app.37945**

## INTRODUCTION

For modern adhesive restoration, the superior bonding and physicomechanical strength of dental materials may contribute much to their long-term clinical life expectance. With the wide application and development of resin material in dentistry, it is accepted that the clinical performance of resin cement is prior to any other adhesive materials, having obvious advantages like higher bonding and mechanical strength and lower dissolution and microleakage. For instance, the use of fiber-reinforced posts in combination with resin composite luting materials has been reported to be effective in restoring endodontically treated teeth. In recent years, many resin luting materials for bonding fiber post as well as to be used as the resin composite core materials, have been available on the market, such as Clearfil DC Core and LuxaCore (Table I). They differ in their handling characteristics, compositions (such as matrix type, filler type, filler load), and properties (such as polymerization ability, flexural strength, hardness). However, all the materials must meet the basic requirements for properties of luting materials and core materials at the same time: On the one hand, firm bonding strength (BS) due to chemical affinity and mechanical interlocking in the bonding interface would afford retention of restorations; on the other hand, high physicomechanical strength is necessary to withstand mastication force for the post core. So, the resin material that could meet both requirements would simplify the procedure of fiber post restoration and enhance the clinic efficacy.

Resin luting cement is a kind of diluted resin composite with less filler, lower viscosity, and higher fluency, which is consistent with resin core materials in composition. Resin matrix, as the

**Table I.** Composition of Commercial Resin Material for Luting and Core

| Material | Composition | Manufacturer | Filler loading (wt %) |
|---|---|---|---|
| Clearfil DC core | Catalyst: Bis-GMA, TEGDMA, silanated colloidal silica, barium glass, Camphorquinone, benzoyl peroxide Universal: Bis-GMA, TEGDMA, silanated colloidal silica, barium glass, *N*,*N*-Diethanol p-toluidine. | Kuraray (Tokyo, Japan) | 72.4 |
| LuxaCore | Bis-GMA, barium glass and pyrog. silica, chemical/photo initiator | DMG (Hamburg, Germany) | 72 |

major part, combines all the components together and controls the fundamental properties of the composite as a whole. Most commercial resin composites are based on Bis-phenol A diglycidylmethacrylate (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA) with urethane dimethacrylate as the resin matrix[1] and filled with inorganic fillers like silicon dioxide, titanium dioxide, or quartz in a certain content ranging from 30 to 85%. The filler loading is often adjusted to aim at different applications. For example, flowable dental adhesives are lightly filled to ensure fluency and infiltration in the bonding interface, whereas composites for restoring posterior teeth are highly filled to withstand the greater forces of mastication and less polymerization shrinkage. This suggests that except for mechanical strength, the filler loading used to reinforce the resin composite affects the final properties in many aspects for a given resin system, such as degree of conversion,[2] polymerization shrinkage,[3] surface tension, viscoelastic and rheological properties,[4] and so on. It was perceived generally that mechanical strength was enhanced when filler loading increased, whereas the other properties like polymerization shrinkage naturally decreased in the same process.[3] However, relevant studies have reported discrepant results in many aspects and remain inconclusive, because those properties are linked with many factors that interact with each other and cannot be studied in isolation using commercial resin systems.[5]

On the other hand, all the physicomechanical properties mentioned above also had connections with the luting and bonding effect of resin cement to a certain degree. The question was: as filler content affected those properties greatly, how would the bond strength change with the variation of filler level and what's the connection between bond strength and mechanical strength? However, characterization of fillers in modern commercial resin composite was complicated because a wide range of different filler types, morphologies, and size distributions existed. It was not quite possible to gain a clear understanding of these results if the research was carried out with commercially available composites in which there were multiple differences between materials being compared.[6] Besides, until now, most of the researches on resin cement were to evaluate the dentinal bonding properties, and no special study was conducted on how the filler content affect the properties of resin cement that is used to bond fiber post and to build up the core. Hence, in order to eliminate the other relevant influential factors, the function of filler content on fiber postbonding and mechanical strength was evaluated separately in the same resin matrix in this research, which allows a meaningful comparison to be made.

The EAM resin used in this study (*cis*-butenedioic anhydride modified epoxy dimethacrylate resin) was a derivative of typical methacrylate monomer with greatly enhanced mechanical properties, lower water absorption and dissolution value, and excellent biocompatibility, which has been proved to be an ideal choice for dental material.[7] Moreover, the degree of conversion have been determined by Fourier transform infrared spectroscopy and proved to reach 62.8% in our test. When filled with a certain content of inorganic fillers, it would be endowed with better physical and mechanical properties because of chemical bonding between the resin matrix and fillers after polymerization. The aims of this study were:

1. To investigate the effect of filler addition on the bonding and physicomechanical properties of the EAM-based experimental resin composite and the correlation between them.
2. To evaluate this kind of resin composite as both luting and core material in comparison with the commercial product LuxaCore.

The null hypothesis tested was that the physicomechanical and bonding strength value of all the resin materials consistently enhanced with the addition of inorganic filler, and there were significant correlations between them.

## MATERIALS AND METHODS

The experimental resin composite was formulated by mixing the monomers Cis-butenedioic anhydride modified epoxy dimethacrylate resin (EAM, Department of Dental Materials, School of Stomatology, the Fourth Military Medical University) and TEGDMA, Esstech in a 70/30 wt % ratio. To make the materials dual curing, chemical and photo initiator systems constituted by 0.8% benzoyl peroxide (BPO, Liaoning Co.), 0.4% camphorquinone (CQ, Esstech), and accelerators were dissolved in the mixture. The reagents were used as received. The silanized silicon dioxide fillers (10 $\mu$m average particle) were provided by Huzhou Co. The commercial resin composite LuxaCore was used as reference. Fiber posts used in this study were prefabricated with EAM resin matrix and glass fibers (Department of Dental Materials, School of Stomatology, the Fourth Military Medical University), which had chemical affinity with the experimental resin cement due to having the same resin matrix.

### Composite preparation

The resin matrix (EAM: TEGDMA = 7: 3) was prepared with the initiator and accelerator added respectively in two equal portions which would initiate polymerization by mixing and photocuring when needed. Four groups of experimental resin composites were formulated according to the filler weight percentage (wt %), A: 40%, B: 50%, C: 60%, and D: 70%. The filler was added to the resin matrix prepared above and mechanically mixed with a motorized mixer. To ensure adequate dispersion of the filler, the

experimental resins were ultrasonicated for 30 min. The commercial product LuxaCore was used as group E for reference.

### Mechanical Strength Testing

Four groups of experimental resin composites were formed into standard specimens ($n = 8$) and then tested in a universal testing machine (AGS-10KNG, SHIMADZU, Japan) to evaluate the resulting mechanical strength.

**Flexural Strength.** The flexural strength of resin composites was determined by a three-point bending test. The $2 \times 2 \times 25$ mm$^3$ rectangular resin specimens were formed according to the standard YY1042-2003[1] and loaded until failure in a universal testing machine at a crosshead speed of 0.5 mm/min. The distance between the support beams of the three-point test jig was 20 mm. The flexural strength was calculated in megapascals by the formula

$$FS = 3FL/2B \cdot H^2$$

where $L$ is the distance between the supports in millimetres, $F$ is the failure load (N), $B$ is the width in millimetres, and $H$ is the height of the beam in millimetres.

**Compression Strength.** The specimens were formed into cylindrical resin (height 8 mm, diameter 4 mm) according to the standard YY1042-2003 and then loaded until failure in a universal testing machine at a crosshead speed of 0.5 mm/min. The compressive strength (CS) was calculated using the following formula:

$$CS = F/A$$

where $CS$ is the compressive strength, $F$ is the maximum failure load, and $A$ is the cross-sectional area of the specimen.

**Diametral Tensile Strength.** Cylindrical specimens (height 3 mm, diameter 6 mm) were made according to ANSI/ADA No.27-2005 and then loaded until failure in a universal machine at a crosshead speed of 0.5 mm/min. The diametral tensile strength (DTS) was calculated using the following formula:

$$DTS = 2F/\pi dh$$

where $DTS$ is diametral tensile strength, $F$ is maximum failure load, $h$ is height, and $d$ is cross-sectional diameter of the specimen.

**Surface Hardness.** The surfaces of specimens in all groups were polished using ascending grades of abrasive SiC papers under running water and tested on the microindentation tester (HXD-1000TM, Shanghai Optical Instrument Co., China) after storing in distilled water for 24 h (load = 50 N, dwell time = 25 s).

### Water Sorption and Solubility

Water sorption and solubility tests of experimental resin cement were conducted according to standard YY1042-2003. Specimen discs ($n = 8$) were prepared into 15 mm in diameter and 1 mm in height after irradiation in mould and placed in a desiccator with freshly dried silica gel at 37°C. After 24 h, they were fetched and stored in a desiccator at 23°C for 2 h and weighed at a precision of 0.01 mg. Repeat the cycle until get a constant mass ($m_1$). Then, they were immersed in distilled water at 37°C for 7 days and weighted again as $m_2$. Another constant mass ($m_3$) was obtained when the process above was repeated. The value of water sorption and solubility was calculated by the following formula

$$WS = m_2 - m3/V \qquad WL = m_1 - m_3/V$$

where $V$ is the precise volume of every specimen which is calculated by the average of thickness and diameter measured at five points.

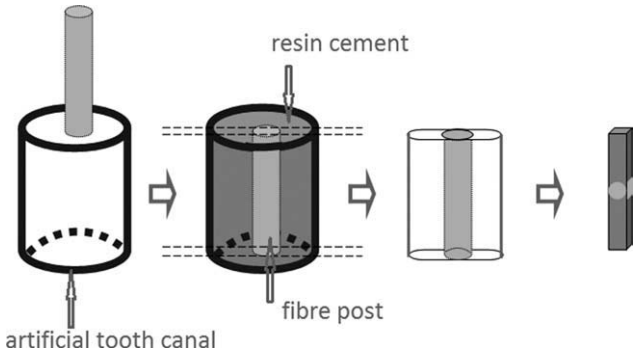


**Figure 1.** The fabrication of specimen in microtensile bonding test

### Bond Strength Testing

**Bonding Fiber Posts with Resin Cement.** The fiber posts were divided randomly into five groups, ultrasonicated for 30 s in the distilled water, and allowed to dry. Each group of experimental resin cement specimens was compacted into a custom-made hollow cylindrical mould (height 15 mm, inner diameter 10 mm), with the fiber posts sticking in the centre (Figure 1). The upper surface of the specimen was covered with a plastic film and pressed gently with a glass slide to squeeze out the excess resin. It was photo cured for 40 s from the top (QHL75, Dentsply, Germany), removed from the mould after curing completely, and stored in distilled water for 24 h before testing.

**Fabricating the Microtensile Sticks.** Five groups of cylindrical resin specimens with fiber posts in the centre were sectioned into sticks for microtensile testing with a low speed diamond saw (SYJ-150A, Kejing Co., China). As shown in Figure 1, the resin around the fiber post was cut off along axially to get resin slabs of 1 mm in thickness, which were then sectioned perpendicularly to obtain resin sticks of 1 mm in height. The precise thickness and height of each stick was measured with digital calipers and the bonding area was then calculated using a mathematical formula introduced by Bouillaguet et al.[8] and Goracci et al.[9]

$$L' = r \times 2\sin\theta^{-1} \times (L/2r)$$

where $L'$ is the length of the bonding interface arc, $L$ is the precisely measured chord, and θ is the angle corresponding to $L'$ (Figure 2).

**Microtensile Bonding Test.** Each stick was loaded until failure occurred at either side of the postcomposite interface under tension at a crosshead speed of 0.5 mm/min in the testing machine (EZ-TEST, SHIMADZU, Japan). The maximum failure loadings were recorded and the microtensile bond strength between fiber posts and experimental resin cement were expressed in megapascals according to the bonding area of each specimen. After testing, each fractured stick was examined in a stereomicroscope

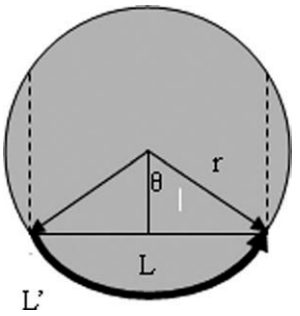


**Figure 2.** The exact bonding interface arc

(SMZ645, Nikon, Japan) at 30× magnification to investigate the fracture interface and failure modes, which were categorized into adhesive, cohesive, or mixed adhesive/cohesive failure separately (Figure 3). The representative specimens were observed and photographs were taken though a scanning electron microscope (Figure 4).

## RESULTS

As shown in Table II, four parameters of mechanical properties showed different reactions and tendencies with filler addition. As the filler content increased from 40 to 70%, the flexural strength ranged from 80.74 to 122.91 MPa, compression strength from 133.67 to 189.38 MPa, hardness from 32.22 to 48.90, and DTS from 38.00 to 41.83 MPa. Statistical analysis indicated that there were significant differences among experimental groups, in which flexural strength, hardness, and compression strength all continued to rise as the inorganic filler increased in the tested range ($P < 0.05$) and obtained the highest value in group D (70 wt %), whereas DTS reached the highest value in group B (50 wt %) and then decreased slightly and leveled off in the following groups instead of continuing to rise. Water sorption and solubility ranged from 20.16 to 18.58 $\mu g/mm^3$ and from 1.39 to 1.24 $\mu g/mm^3$ separately, which both had no significant differences among groups ($P > 0.05$) and changed little statistically with filler addition.

As for the bond strength between experimental resin and fiber posts, the results (Table III) showed that it increased till the highest value (12.03 MPa) in group C (60%) and then decreased with the filler addition. Statistical analysis indicated that there was no significant difference between groups B and C ($P > 0.05$), and both of the two groups had higher values than groups A, D, and E ($P < 0.05$). The interface investigation of the debonded specimens revealed that mixed cohesive/adhesive failure became the dominant failure mode in all experimental groups, although cohesive failure of resin composite (3%) was found in group A and cohesive failure of the fiber post (6%) in group C (Figure 3).

Pearson's correlation test showed that there were different correlation coefficients between the filler content and strength values tested in the study and between bond and mechanical strength (Figure 5). Positive correlations existed respectively between the filler content and some mechanical properties ($r_{FS} = 0.964$, $r_{CS} = 0.967$, and $r_H = 0.959$), whereas little correlations were found between the filler content and the others ($r_{DTS} = 0.321$, $r_{BS} = 0.014$). Also, there were no significant correlations between bond strength and mechanical properties ($r_{FS} = -0.234$, $r_{CS} = -0.300$, $r_{DTS} = 0.278$, and $r_H = -0.261$).

## DISCUSSION

As resin materials for both luting and core build-up, optimal mechanical and bond strength are important for an enduring fiber post restoration. The evaluation of mechanical properties should be considered overall because dental materials are subjected to all types of stress in the complex oral environment. However, the most appropriate kind of mechanical testing for evaluating dental materials has not been agreed so far amongst the international community responsible for developing standard tests for these products.[10] Hence, many parameters which are all mechanical indicators of different aspects of dental materials are designed to measure specific stress under different force application, and strength value is rather affected by several factors, including the specimen preparation and storage, the test method, and the failure mechanisms.[11–13] Based on respective testing methods, it turned out that of the four mechanical parameters, flexural strength, compression strength, and hardness continued to increase and proved a sensitive reaction and consistent trend to the filler addition ranging from 40 to 70 wt %, whereas the DTS did not respond accordingly, which increased till obtaining optimal value at 50 wt % first, and then decreased slightly and level off with the following addition. It suggested that the tensile strength was not sensitive to the filler addition as the other parameters and they were incomparable with each other. High CS, flexural strength, or hardness did not signify high tensile strength in a certain resin material.

The phenomenon of inconsistent mechanical behaviors in DTS compared to the other tested parameters proved that filler addition would not always strengthen the resin and was assumed for the reason that stress distribution and propagation of inside minicracks varied greatly with force exertion on samples in different geometry. Specifically, the DTS is used to measure the cohesive strength of the material exposed to tensile stress, which will influence the fracture load. Compression test is also for cohesion between the materials with difference is that for the CS test, the specimens were placed in a vertical position, with

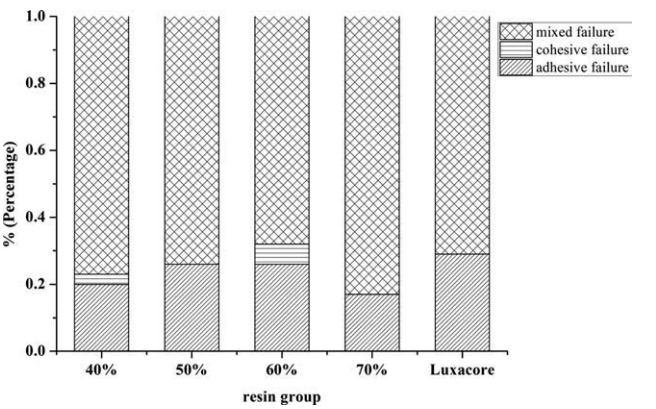


**Figure 3.** Failure mode distribution of experimental resin groups after microtensile test

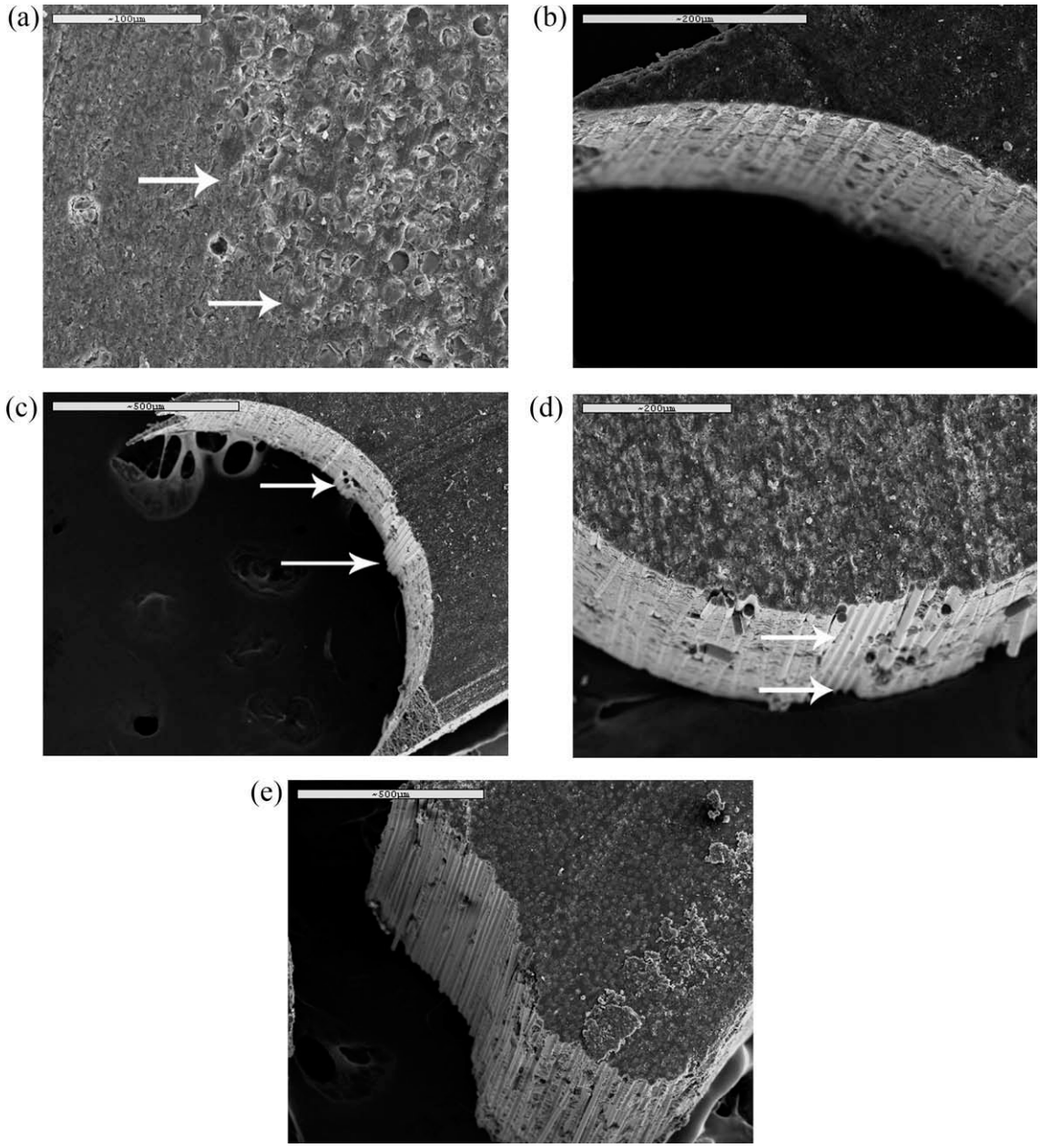


**Figure 4.** Representative SEM-images of typical failure modes of the microtensile sticks. (a) Intergrated bonding interface between fiber post and resin cement. The arrow indicated the bonding line (×400). (b) Fiber post end of microtensile stick in adhesive failure (×300). (c) Resin end of microtensile stick in mixed failure, with remnant glass fibers pointed by white arrow (×400). (d) Fiber post end of microtensile stick in mixed failure, with loss of glass fibers pointed by white arrow (×200). (e) Cohesive failure of fiber post in the C experimental resin group(60 wt %) (×100).

**Table II.** Physicomechanical Strength of All Experimental Resin Groups

| Filler loading | Flexual strength | Hardness | Diametral tensile strength | Compression strength | Water sorption | Water solubility |
|---|---|---|---|---|---|---|
| A 40% | $80.74^{a}$ (3.11) | $32.22^{a}$ (1.49) | $39.16^{a}$ (1.34) | $133.67^{a}$ (3.74) | $20.08^{a}$ (2.22) | $1.39^{a}$ (0.17) |
| B 50% | $92.42^{b}$ (4.13) | $37.74^{b}$ (1.07) | $41.83^{b}$ (1.90) | $142.82^{b}$ (3.43) | $20.16^{a}$ (1.48) | $1.37^{a}$ (0.15) |
| C 60% | $105.10^{c}$ (4.92) | $40.41^{c}$ (1.30) | $39.33^{a}$ (1.39) | $166.60^{c}$ (4.45) | $18.58^{a}$ (1.23) | $1.24^{a}$ (0.15) |
| D 70% | $122.91^{d}$ (4.63) | $48.90^{d}$ (1.38) | $38.00^{a}$ (1.89) | $189.38^{d}$ (5.67) | $18.66^{a}$ (1.47) | $1.27^{a}$ (0.13) |

Superscript letters indicate statistical differences among experimental groups

**Table III.** Bond Strength of All Experimental Resin Groups

| Filler loading | N | Bond strength |
|---|---|---|
| A (40%) | 35 | 10.15[a] (2.72) |
| B (50%) | 35 | 11.48[b] (2.81) |
| C (60%) | 35 | 12.03[b] (2.78) |
| D (70%) | 35 | 10.07[a] (2.06) |
| E (LuxaCore) | 35 | 10.88[a] (2.85) |

Superscript letters indicate statistical differences among experimental groups

two axial sets of force imposed on a sample in an opposite direction, whereas for the DTS test, the specimens were compressed diametrically, introducing tensile stress in the material in the plane of the force application.[14] Flexural strength combined tensile, compressive, and other form stresses which could be considered as a more general state of force and more functional. Filler addition made resin fragile and brittle in tensile force with the stiffness and solidness, and optimum performance may not be achieved by maximizing the filler fraction. A plateau was reached at a certain value of fraction at which further additions of filler had little or no beneficial effect on tensile

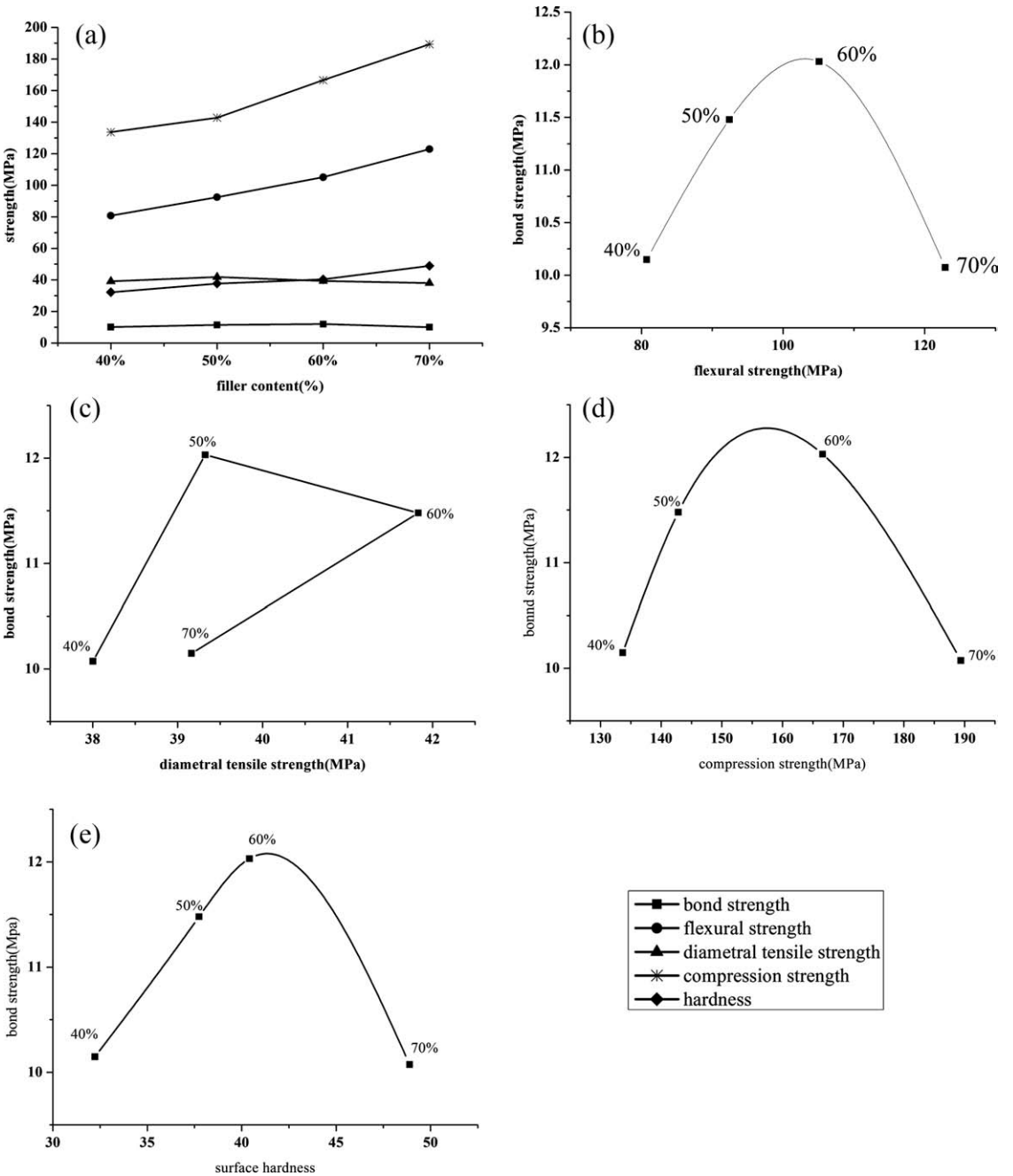


**Figure 5.** (a) Correlation between filler content and mechanical and bond strength. Correlation between bond strength and: (b) flexural strength; (c) diametral tensile strength; (d) compression strength; (e) hardness

strength. It was likely that these limiting plateau regions represented the point at which filler particle contacts with no binding matrix became prevalent and resin was becoming oversaturated with filler. However, Hara et al.[15] thought that strength was not expected to enhance continuously once the filler content was raised above a certain level due to the greater possibility of voids being incorporated. No matter what reason the negative effect was assumed to be related to, whether oversaturating filler or inherent flaws, especially air porosity, in the composite material, the complicated effect of filler in resin composite should be understood and studied further.

Hence, DTS, other than FS, CS, and Knoop Hardness, had no correlation with filler content in Pearson's correlation test, which could be attributed to the plateau region of DTS in the very filler loading range (40–70 wt %). Still, it should be pointed out that DTS, like the other mechanical parameters, was affected significantly by filler addition ($P < 0.05$). The reversed direction of forces caused the different mechanical behaviors of resin in the same filler loading, which indicated that evaluation of dental materials with any single parameter was partial and incomplete. Similarly, it was generally inappropriate to compare mechanical properties between commercial resin composites and to predict their clinical behaviors based on a single *in vitro* mechanical test.[16]

The corresponding properties of LuxaCore were according to technical data from the manufacturer, the DTS of LuxaCore could reach 50 MPa, which is slightly higher than that of the experimental resin in 50% filler loading (41 MPa). However, it must be pointed out that the DTS for dental material is required at least 34 MPa according to the American Dental Association, and even the lowest value of the experimental resin (70 wt %) reached 38 MPa, which assured its validity. Moreover, Yu et al.[17] reported that the flexural strength of LuxaCore reached 110.11 ± 10.03 MPa, which was lower than that of the experimental resin with 70 wt % filler loading.

Water sorption and solubility of experimental resin varied little among groups and showed insensitive reaction to filler content other than the mechanical properties. Yet, according to ISO 9000s standards for dental restorative resins [water sorption (WS) < 50 $\mu g/mm^3$, water solubility (WL) < 5 $\mu g/mm^3$],[18] they were far lower than limits and proved to be suitable for the dental application.

Furthermore, one of the reasons for failure of fiber posts was the lack of adhesion to the post or core materials.[19] In clinic, the post was bonded into teeth canal by resin cement with two bonding interfaces, the one was canal dentin-resin cement whose bonding strength was from dental adhesive, and the other was resin cement-fiber post which was bonded mainly by mechanical interlocking and affinity between them. Given the study was designed for the properties of resin cement, the experiment eliminated the other factors like dental adhesive and focused on the relevance of latter interface bonding with filler content. Generally, the resin composite should exhibit good adaptation and a reliable bond to the fiber post surface apart from mechanical properties, either for luting or core build-up. For restorations of fiber posts, especially prefabricated ones, it was observed that the polymer matrix used for embedding the fibers was highly crosslinked and did not possess functional groups that can react with the methacrylate groups of the resins usually used in dental resin cement.[19] Thus, it was speculated that the bonding of resin materials to fiber posts could be attributed mainly to micromechanical interlocking and sliding friction, although the coupling agent generally used could cause the chemical bonding between the organic resin and inorganic fibers. Besides, minimal voids should be present along the interface between the post and the resin cement as these voids may act as stress raisers and initiate bonding failure.[20] Resin materials with lower filler/resin ratios, which exhibited better adaptation/wettability, easier insertion at the post surface due to low viscosity, high flowability, and great elasticity, could best eliminate the voids and integrate with posts but would have less micromechanical retention to resist dislocation force due to insufficient strength. Furthermore, it was predictable that the high resinous content may also induce a significant contraction during polymerization, causing stress which might weaken the integrity of the interface and affect the bond strength. Based on the related factors, filler content would affect bonding performance of resin materials in a certain degree, which have been observed from the results in this study.

The bond strength between experimental resin cement and fiber posts increased and then decreased with the filler addition, and reached an optimal bonding strength at 60 wt %, which was even a little higher than that of the commercial product LuxaCore. The reason for this is that the homogeneity and integrity between the fiber posts and luting cement based on the same matrix were supposed to play an important role, which was emphasized in many studies.[21,22] Investigation of the debonding interface revealed that most specimens of all groups fractured in the mixed failure mode, which could reflect the true bonding strength between resin and post, although a small amount of cohesive failure was observed in groups A and C. The scanning electron microscope pictures (Figure 4) were representative of the microtensile sticks in typical failure modes. Integrated bonding interface [Figure 4(a)] without boundary exhibited good adaptation and affinity between fiber post and resin cement. Resin end [Figure 4(c)] of microtensile stick with remnant glass fiber and fiber post end [Figure 4(d)] with responding loss of glass fibers (pointed by white arrow) showed separately the mixed fracture which was the most failure mode. Fiber post end in adhesive failure [Figure 4(b)] and cohesive failure [Figure 4(e)] stood the rare situation of fracture in debonding process.

Statistical analysis revealed that neither correlations were found between bond strength and the filler content nor between bond strength and mechanical properties, although there were significant correlations between filler content and mechanical parameters, with the exception of DTS. It was assumed that the bond strength was influenced by multiple factors such as bonding interface stress, chemical affinity of resin matrix, rheological, and other intrinsic properties, in which filler content and mechanical properties of resin materials were not the dominant and influential factors and played a limited role.

Within the limits of this study, the null hypothesis that the physicomechanical and bonding strength value of all the resin

materials consistently enhanced with the addition of inorganic filler, and there were significant correlations between them that could be partly rejected.

## CONCLUSION

From the research, we found that due to many complex forces which occurred and tended to deform the material (tensile, compressive, and shear forces), investigation of their behaviors under such forces was necessary. The different response to filler addition of each parameter, especially diametral tensile and bond strength, suggested that caution was required when optimizing the properties of dental materials. Further, the effect of filler content on mechanical properties was more influential and prominent compared to that on bond strength which was mainly from micromechanical interactions. In the comprehensive consideration of multiple properties, the EAM-based experimental resin cements in this study could attain superior performance when the inorganic filler loading was added to 60 wt %, which was comparable with a commercial product like Luxa-Core in both mechanical and bonding properties and adequate for use as a luting and core resin material.

The authors thank Esstech for generous support in supplying some test materials and Department of dental materials in Fourth Military Medical University for technical guidance.

## REFERENCES

1. Leinfelder, K. F. *J. Am. Dent. Assoc.* **1997,** *128*, 573.
2. Halvorson, R. H.; Erickson, R. L.; Davidson, C. L. *Dent. Mater.* **2003,** *19*, 327.
3. McCabe, J. F., Walls, A. W. G. Applied Dental Materials, 8th ed.; Blackwell Science: Oxford, **1998.** p 170.
4. Beun, S.; Bailly, C.; Dabin, A, Vreven, J, Devaux, J, Leloup, G. *Dent. Mater.* **2009,** *25*, 198.
5. Conde, M. C.; Zanchi, C. H.; Rodrigues-Junior, S. A.; Carreño, N. L.; Ogliari, F. A.; Piva, E. *J. Dent.* **2009,** *37*, 331.
6. Ikejima, I.; Nomoto, R.; McCabe, J. F. *Dent. Mater.* **2003,** *19*, 206.
7. Tang, L. H.; Chen, P.; Liu, F. *Chinese Med. Equip. J.* **2006,** *27*, 9.
8. Bouillaguet, S.; Troesch, S.; Wataha, J. C.; Krejci, I.; Meyer, J. M.; Pashley, D. H. *Dent. Mater.* **2003,** *19*, 199.
9. Goracci, C.; Raffaelli, O.; Monticelli, F.; Balleri, B.; Bertelli, E.; Ferrari, M. *Dent. Mater.* **2005,** *21*, 437.
10. Ikejima, I.; Nomoto, R.; McCabe, J. F. *Dent. Mater.* **2003,** *19*, 206.
11. St Germain, H.; Swartz, M. L.; Phillips, R. W.; Moore, B. K.; Roberts, T. A. *J. Dent. Res.* **1985,** *64*, 155.
12. Li, Y.; Swartz, M. L.; Phillips, R. W.; Moore, B. K.; Roberts, T. A. *J. Dent. Res.* **1985,** *64*, 1396.
13. McCabe, J. F.; Wassell, R. W. *J. Mater. Sci. Mater. Med.* **1999,** *10*, 291.
14. Yap, A. U.; Pek, Y. S.; Cheang, P. *J. Oral. Rehabil.* **2003,** *30*, 1.
15. Hara, R.; Nemoto, K. *Jpn. J. Dent. Mater.* **1986,** *5*, 1.
16. Craig, R. G. Mechanical Properties. Restorative Dental Materials, 10th ed.; Mosby: St. Louis, **1997,** p 56
17. Yu, C. L.; Luo, X. P. *J. Oral Sci. Res.* **2005,** *21*, 286.
18. Nie, J.; Lovell, L. G.; Bowman, C. N. *Biomaterials* **2001,** *22*, 535.
19. Purton, D. G.; Payne, J. A. *Quintessence Int.* **1996,** *27*, 93.
20. Lin, S.; Hills, D. *Int. J. Fract.* **1996,** *77*, 175.
21. Boschian Pest, L.; Cavalli, G.; Bertani, P. *Dent. Mater.* **2002,** *18*, 596.
22. Monticelli, F.; Goracci, C.; Ferrari, M. *Dent. Mater.* **2004,** *20*, 176.