International Journal of Life Sciences, Biotechnology and Pharma Research Vol. 14, No. 3, March 2025 Online ISSN: 2250-3137
Print ISSN: 2977-0122

DOI: 10.69605/ijlbpr_14.3.2025.152

ORIGINAL RESEARCH

Comparative Assessment of Compressive Strength and Fatigue in Short Fiber Composites, Glass Ionomer Cements, and Amalgam Restorative Materials: An In Vitro Study

Dr. Sonia Meshram[1], Dr. Sushmita Khatri[2], Dr. Rahul Ramteke[3], Dr. Aayush Dadwe[4]

[1,2]Assistant Professor, [4]Senior Resident, Department of Dentistry, Abhishek I Mishra Memorial Medical College and Research, Bhillai, Chhattisgarh, India
[3]Associate Professor, Department of Forensic Medicine, Shri Shankaracharya Institute of Medical Sciences, Junwani, Bhilai, Chhattisgarh, India

Corresponding author
Dr. Sonia Meshram
Assistant Professor, Department of Dentistry, Abhishek I Mishra Memorial Medical College and Research, Bhillai, Chhattisgarh, India
Email: drsoniameshram25@gmail.com

Received: 15 February, 2025 Accepted: 27 February, 2025 Published: 24 March, 2025

ABSTRACT

Background: The longevity of dental restorations depends on mechanical performance, yet cyclic fatigue—a key cause of failure—remains underexplored, particularly for new materials like Zirconomer and short fiber-reinforced composites.**Objective:** This study evaluates and compares the compressive fatigue limits of short fiber composite, resin-modified glass ionomer cement (RM GIC), Zirconomer, and Amalgam to assess their long-term durability.**Materials and Methods:** A total of 30 cylindrical specimens for each material were prepared. Compressive strength (n=10) and compressive fatigue limit (n=20) were assessed using a universal testing machine. The staircase method determined the compressive fatigue limit, with cyclic loading conducted at a frequency of 10 Hz for up to 5000 cycles.**Results:** Significant differences were observed in the compressive strength and fatigue limits among the materials ($p < 0.001$). Short fiber composite and Amalgam demonstrated the highest compressive strength and fatigue limits, while Zirconomer and RM GIC showed comparatively lower values. The compressive fatigue limit as a percentage of compressive strength was highest for RM GIC (69.81%) and lowest for Zirconomer (64.73%).**Conclusion:** Short fiber composite and Amalgam showed superior fatigue resistance, indicating greater clinical longevity, while Zirconomer exhibited lower resistance. All materials experienced reduced compressive strength after cyclic loading, emphasizing the need for fatigue evaluation to predict long-term success.

Keywords: Amalgam, fatigue, Zirconomer, compressive strength

INTRODUCTION

Mechanical performance of dental restorative materials has been a concern for dentists because the longevity of the material is essential for the long-term success of dental restoration.[1] Mechanical properties, such as compressive strength, tensile strength, flexural strength and fracture toughness have been evaluated for a large number of dental restorative materials.[2] Most of these studiesonly investigated the quasi-static mechanical properties of these materials.However, in clinical practice, restorations rarely fail immediately after placement. In fact, fatigue fracture after years of cyclic loading is one of the most common reasons for failure.[3]

Therefore, it is important to determine the fatigue limit of the restorative materials such as compressive fatigue limit since it can provide more reliable information about the longevity of a dental restoration.Fatigue limitcan be defined as number of stress cycles a material can withstand before it fails. It not only depends on nature of material but also on nature of the applied stress, the testing environment, and the frequency of cyclic loading [4]

DOI: 10.69605/ijlbpr_14.3.2025.152

The compressive strength of a material is defined as the maximum compressive load a material can withstand prior to failure. It is determined by dividing the maximum applied load by the original cross-sectional area.[5]

Since the 1890s, Amalgam was widely used restorative material by dental practitioners because of its high mechanical properties.However, due to increase in demand of esthetics, lack of adhesion to tooth surface, and the potential hazard of mercury toxicity considered by Food and Drug Administration (FDA), the pursuit for alternative materials fulfilling these shortcomings began. [6]

Glass Ionomer Cements were first introduced by Wilson and Kent in 1972.Main advantages of these material are adhesion to tooth structure and fluoride release which is of major cariostatic importance for patient groups with high caries incidence.[7]Compared to amalgam the low mechanical resistance of glass ionomer cements prevents their application in larger defects, particularly in Class I, II and IV cavities.[8]Since then, several modifications have been introduced to enhance their mechanical properties.

Resin-modified glass ionomer restorative materials have been introduced to the market to overcome the disadvantage of conventional GIC. Resin-modified glass ionomer cements show considerably higher bond strengths to tooth structure than the conventional glass ionomer cements even after thermocycling.[9]

Recently, zirconia-reinforced GIC (Zirconomer, Shofu), a novel material, was introduced. It comprises zirconium oxide, glass powder, tartaric acid (1–10%), polyacrylic acid (20–50%), and deionized water as its liquid component. Zirconium oxide, the primary powder component of Zirconomer, is derived from Baddeleyite ($ZrO2$), which contains high levels of zirconia ranging from 96.5% to 98.5%.[10]

A new short fiber reinforced composite (everX Posterior) was introduced as a posterior restorative material. Due to presence of E glass fiber in short fibercomposite resins this enables the formation of semi-interpenetrating polymer network (semi-IPN) during the polymerization of the material, Enhancing the Bonding Properties and Toughness of Composite Resin.[11]The short, randomly oriented fibers provide an isotropic reinforcing effect, ensuring that the material's strength remains uniform and independent of the fracture load direction.[12]

Although thereare a plethora of studies on the physico-mechanical properties of different restorative materials, only a few studies have cited the importance of compressive fatigue limit. Alsothere is lack of thorough investigation about newly introduced restorative materials like zirconomer and short fiber reinforced composite. So present study compared the compressive fatigue, of different restorative materials.

The null hypothesis tested was that no difference will be present in the compressive fatigue limit of the different restorative materials used in this study.

MATERIALS AND METHODS

Table 1: Represents the materials that were used in the study, with lot numbers and manufacturers' information.

Material	Composition	Lot number	Manufacture	Brand name
Short fiber composite	It consists of a combination of a resin matrix, discontinuous E (electrical) glass fibers, and inorganic particulate fillers. The resin matrix comprises crosslinked monomers, bisphenol-A-glycidyl dimethacrylate (bis-GMA), and triethylene glycol dimethacrylate (TEGDMA), accompanied by linear polymethylmethacrylate (PMMA	1703291 1703271	GC Corp, Tokyo, Japan	Ever x posterior
Zirconomer	It contains zirconium oxide, glass powder, tartaric acid (1–10%), polyacrylic acid (20–50%) and deionized water as its liquid.	12152286 07172082	Sofu Inc	Zirconomer improved
Resin modified GIC	RMGIs are formulated from fluoroaluminosilicate glasses, photo-initiators, polyacrylic acid, water, and a water soluble methacrylate monomer, such as hydroxyethyl methacrylate (HEMA)	1710131 17082313	GC Corp, Tokyo, Japan	FUJI II
Amalgam	It consists of 40-60% silver, 27-30% tin and 13-30% copper and 0.1% zinc set with mercury.	1171 9161	DPI	Amalgam capsule

30 Cylindrical specimens (4 mm in diameter and 6 mm in height) were prepared for each group for the evaluation of compressive strength (n=10) and compressive fatigue limit (n=20). All materials were manipulated according to the manufacturer's instructions. Each material except Short Fibre

DOI: 10.69605/ijlbpr_14.3.2025.152

Composite was packed in bulk into the silicone rubber mold. A Mylar strip was then placed over the material and pressed with a glass plate to obtain a flat surface. Short fiber composite was packed into the mold in increments of 2 mm. Each increment was light cured for 20s. For short fiber composite and resin modified GIC the specimens were light cured with a LED curing device for 20 s through the exposed end of mold. The specimens were then removed from the mold and light cured from both sides and other end (opposite to exposed end) for 20 sec each. The specimens were polished using 800 grit silicon carbide papers to obtain a smooth surface.

To evaluate the compressive strength, 10 specimens from each group were subjected to a compressive loading at a crosshead speed of 10 mm/min. Each specimen was placed with the flat end between the platens of apparatus so that load will be applied along the long axis of the specimen. The maximum load applied to fracture the specimen was recorded and compressive strength (CS) was calculated using following formula.

Compressive strength (CS) = $4P / \Pi d^2$

Where P is the maximum applied load in Newton (N) and d is the measured diameter of sample (mm^2).

Compressive fatigue test was conducted using universal testing machine programmed in compression-compression loading mode at a frequency of 10 Heartz. The staircase (or the up-and-down) method was used to in this study to determine the compressive fatigue limit using 20 specimens used for a test lasting up to 5000 cycles. The initial stress was 60% of the static compression strength mean, calculated for each material.

The specimens were loaded to 5000 cycles or until specimen fracture. When the specimen resisted fracture to 5000 cycles, it was tested with a fixed load increase of 8MPa of the initial load. If the specimen failed before reaching 5000 cycles, subsequent specimen was tested with a load reduction of 8MPa of the initial load. Thus, the strength values varied (higher or lower), depending on the event of failure or non-failure**.** The lowest stress level at which failure occurs is denoted as i=0, followed by i=1, and so on. The mean fatigue limit, X, and its standard deviation, S are given by formulae (1) and (2)**.** In the formulae, X0 is the lowest stress level considered in the analysis, and d is the stress increment (8MPa) employed in the sequential tests. The other constants are defined in Table 2.

$X = X_{0=d\,(A/N\pm1/2)}$ ………[1]

$S=1.62\, d\, (NB-A^2/ N^2+0.029)$…………[2]

Table 2: Method for analysing staircase test procedure data

stress (MPa)	i	ni(failure)	in i	i2ni

$N=\sum ni$

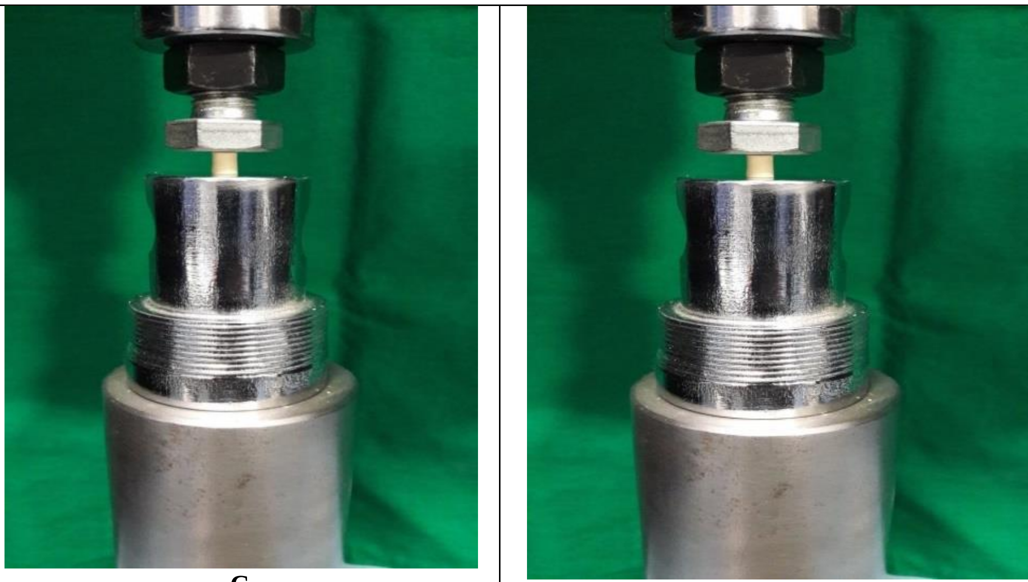
$A=\sum ini$

$B=\sum in2i$

A B

Online ISSN: 2250-3137
Print ISSN: 2977-0122

DOI: 10.69605/ijlbpr_14.3.2025.152



C D

Fig 11 – Apparatus for testing compressive fatigue strength of each cylindrical materials using universal testing machine A) Short fiber reinforced composite B) Amalgam C) Resin modified GICD) zirconomer

RESULTS

Materials	**Compressive strength (cs)**	**Compressive fatigue limit (CFL)**	**CFL/CS (%)**
Short fiber composite	334.40 (17.81)	216.8 (7.04)	64.83%
RM GIC	218.30 (15.04)	152.4 (5.45)	69.81%
Zirconomer	244.70 (15.13)	158.4 (12.96)	64.73%
Amalgam	319.40 (14.77)	213.4 (6.05)	66.81%
P-value	< 0.001*	< 0.001*	
Short fiber composite vs RM GIC	< 0.001*	< 0.001*	
Short fiber composite vs zirconomer	< 0.001*	< 0.001*	
Short fiber composite vs amalgam	0.456	0.918	
RM GIC vs zirconomer	0.074	0.679	
RM GIC vs amalgam	< 0.001*	< 0.001*	
Zirconomer vs amalgam	< 0.001*	< 0.001*	

One-way ANOVA test Post-hocbonferroni test * Significant difference

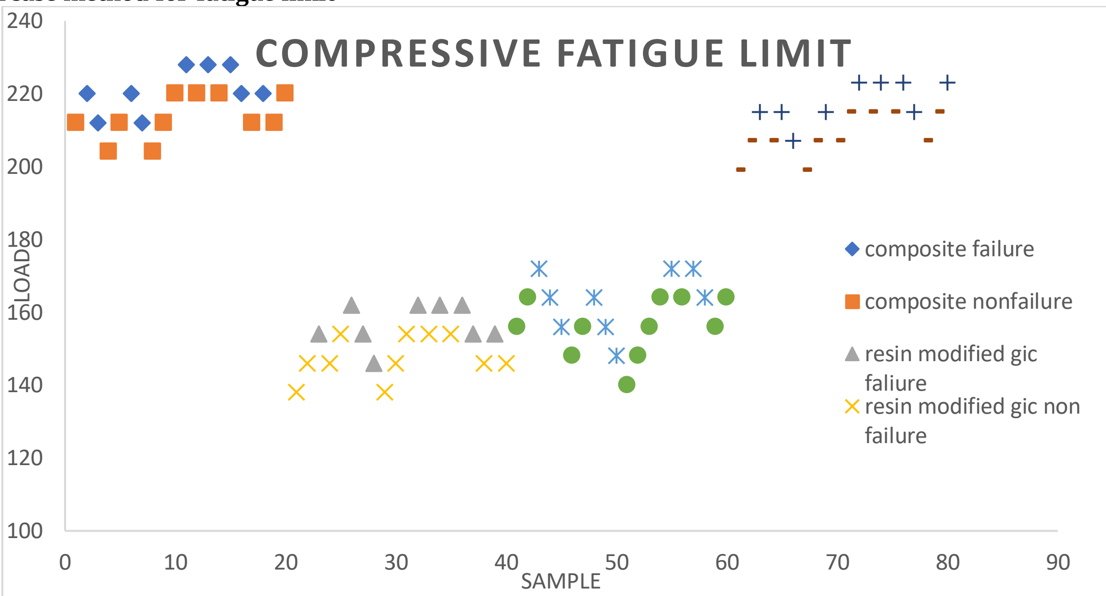
The comparison of mean Compressive strength (CS) and Compressive fatigue limit (CFL) was done between Shortfiber composite, Resin modified GIC, Zirconomer and Amalgam using the **One-way ANOVA test**. There was a significant difference in mean Compressive strength (CS) and Compressive fatigue limit (CFL) between Shortfiber composite, Resin modified GIC, Zirconomer and Amalgam.

The inter-group comparison of mean Compressive strength (CS) and Compressive fatigue limit (CFL) was using the **Post-hocbonferroni test**. The mean Compressive strength (CS) and Compressive fatigue limit (CFL) was significantly more among Shortfiber composite and Amalgam in comparison to Resin modified GIC and Zirconomer.

Online ISSN: 2250-3137
Print ISSN: 2977-0122

DOI: 10.69605/ijlbpr_14.3.2025.152

Staircase method for fatigue limit



DISCUSSION

Stress applied to teeth and dental restorations is generally low and cyclic in nature. It is estimated that the intraoral stress received by dental restorations during mastication is repeated more than 3×10^5 times per year.[12] From this viewpoint, it might be more appropriateto estimate the load-bearing capacity of dental filling materialby dynamic type of mechanical test, rather than by static loadingtest. Therefore, it is important to determine the fatigue behaviour of the restorative materials since it can provide more reliable information about the longevity of the dental restorations. Studies investigating resistance to fatigue are unable to simulate the clinical situations but may provide an estimate of the clinical performance of a material in a short period of time and with lower costs. [13,14]

In the literature, two different approaches have been used to evaluate the fatigue performance of materials; one approach follows a defect-tolerant philosophy, assuming the presence of inherent flaws in the material, with fatigue performance dependent on the propagation of these initial defects. The other adopts a total-life philosophy, assuming a defect-free specimen, where material failure results from the initiation of a flaw and its subsequent propagation to a critical size. Under the latter assumption, both S–N plots (where S represents stress amplitude and N represents cycles to failure) and the staircase method (up and down method) can be used.[15] In this study staircase method has been applied due to its multiple advantages like convenience, requirement of fewer specimens and accurate results may be obtained.

In staircase method, the first specimen is subjected to a stress corresponding to the expected average fatigue strength. If the specimen fails prior to pre- determined cycle, the next specimen has to be tested at a lower stress level. If the specimen does not fail within this cycle of interest, the new test is run at a higher stress level. Therefore, each test is dependent on the previous test result, and the tests continue in this manner in sequence with the stress level being increased or decreased by selected stress increments. [16]

In the literature, the number of cycles defined as run-out for fatigue testing of dental restoratives has ranged from10^3 to 10^6. [17,18] A scarce number of cycles provide limited value in predicting long term performance of materials while an excessive number of cycles are energy and time consuming. The number of cycles used in this study (5,000 cycles) is in accordance with the number of cycles mentioned in a previous study. [19]

Compressive fatigue limit

In the present study, tests were conducted sequentially, with the maximum applied stress in each succeeding test being increased or decreased by a fixed increment of 8 Mpa, according to whether the previous test resulted is failure or not. The compressive fatigue limit of resin-based composites is around 60% of its static compressive strength. Thus 60% of the static compressive strength was chosen as the initial stress value. The chosen in vitro setup of the present study was shown to give reliable and reasonable results in several studies with different types of materials. [15, 20]

Present study evaluated the effect of cyclic loading on the compressive properties of different restorative materials. The data showed that when short fiber reinforced composite, Resin modified GIC,zirconomer and amalgam restorative materials were subjected to 5000 compressive load cycles, the load-bearing capacity decreased by a rates of 66 % , 63% 63% and 66 % respectively, compared to the their value found after static load cycle. It should be noted that the number of loading cycles used in this study is low compared to the total number of load

DOI: 10.69605/ijlbpr_14.3.2025.152

cycles that a restoration must withstand in oral cavity, also in oral environment they are subjected to thermal shocks and constant chemical corrosion. [15]

The high compressive strength and fatigue limit of recently introduced short fiber reinforced composite might be attributed to its millimeter-scale short fibers, which exceed the critical fiber length.[21] It has been measured using fiber fragmentation test that the critical fiber lengths of E-glass with bis-GMA polymer matrix vary between 0.5 and 1.6 mm.[22]

This enables the stress transfer from the matrix to the fibers. Furthermore, it was reported that the linear PMMA polymer chain and the cross-linked polymer matrix of BisGMA and TEGDMA might also contribute to the higher values. [11]

The random orientation of fibers in the matrix, has also been suggested to play a significant role in the mechanical properties of the composite. [23]For a fiber to serve as an effective reinforcement in polymers, it is essential to facilitate stress transfer from the polymer matrix to the fibers. This is achieved when the fiber length is equal to or greater than the critical fiber length. [24] The short fiber composite resins have fiber fillers equal to or greater than the critical fiber length and therefore it provides better mechanical properties of the composite.

In the present study, although no significant difference was found between the compressive strength and fatigue limit of amalgam and short fiber reinforced composite, the value was still lower for amalgam. But the value of amalgam was significantly higher than resin modified GIC and zirconomer. Hence amalgam is certainly to be preferred over resin modified GIC and zirconomer. This result is in accordance with the results of the study by Cho et al, [25] who also reported that the fatigue limit of amalgam was significantly higher than that of Resin modified GIC.

According to a previous studies, both mechanical tests and finite element analyses have indicated that amalgam restorative material have superior performance in comparison to resin composite. In fatigue testing, amalgam has deformed less, produced smaller marginal gaps and applied lesser stresses to tooth structure than resin composite. [26, 27] This result is in contrast with our result due to different composite restorative material and different methodology used.

Resin-modified glass ionomer restorative materials have been introduced to the market to overcome the disadvantages of traditional glass ionomer cements. In the present study when Resin modified GIC was subjected to cyclic loading, compressive strength decreased by 63% of its original compressive strength. Chen et al, [15]had stated that compressive fatigue limits of resin-based composites and resin modified GIC were around 55% of the compressive strength after one day storage in distilled water. The result is in contrast with our study due to more number of loading cycles and different testing apparatusused.

According to a previous study done by Mohandesi et al [20]compressive fatigue limits of resin-based composites and resin modified GIC were determined to be around 55% of the compressive strength after one day storage in distilled water. The difference in the results might be due to the difference in methodology. In their study, Fatigue test was conducted using an Instron 8501 servo-hydraulic universal testing machine and testings were also carried out in distilled water accompanied by water spray at 37 degrees Celsius. A special chamber with a punch made of stainless steel was employed for applying the load

The addition of zirconia as fillers particle in the glass component of zirconomer increased the compressive strength when compared to that of traditional glass-ionomer cement. Still its compressive strength was lower than that of short fiber composites and amalgam while no significance difference was found between resin modified GIC and zirconomer.

Previous studies have reported compressive strength of zirconomer ranging from 195 up to 250 MPa. [28]In the present study compressive strength of zirconomer is 248mpa. When zirconomer was subjected to cyclic loading its compressive strength reduced by 63% of its static compressive strength. Unfortunately, no study has been reported about compressive fatigue behaviour of this material for comparison.

CONCLUSION

Considering the limitations and disadvantages of this in-vitro study, it was concluded that- In the present study, mean compressive strength and fatigue limit was found to be significantly higher in Shortfiber reinforced composite and Amalgam when compared to zirconomer and that of zirconomer was significantly higher than Resin modified GIC.

When all the restorative materials were subjected to cyclic loading, its compressive strength decreased by 60- 70 % of its initial compressive strength. Thus, all tested materials showed reduction in the compressivestrength after cyclic loading.

Ethical Clearance: Approved by the Institutional Ethical Committee

Contributor ship of Author: All authors contributed equally.

Conflict of interest: Nil.
Source of funding: Nil.

REFERENCE

1. Khan, A.S., Azam, M.T., Khan, M., Mian, S.A., Ur Rehman, I., 2015. An update on glass fiber dental restorative composites: a systematic review. Mater. Sci. Eng. C Mater. Biol. Appl. 47, 26–39.
2. Sayyedan, F.S., Fathi, M.H., Edris, H., Doostmohammadi, A., Mortazavi, V., Hanifi, A., 2014. Effect of forsterite nanoparticles on mechanical

DOI: 10.69605/ijlbpr_14.3.2025.152

properties of glass ionomer cements. Ceram. Int. 40, 10743–10748.

3. Baran, G., Boberick, K., McCool, J., 2001. Fatigue of restorative materials. Crit. Rev. Oral. Biol. Med. 12, 350–360
4. Drummond, J.L., 2008. Degradation, fatigue, and failure of resin dental composite materials. J Dent. Res. 87, 710–719
5. Knobloch LA, Kerby RE, Seghi R, Berlin JS, Clelland N. Fracture toughness of packable and conventional compositematerials. J Prosthet Dent 2002;88(3):307-13.
6. FDA. Dental devices: Classification of dental amalgam,reclassification of dental mercury, designation of specialcontrols for dental amalgam, mercury, and amalgam alloy.Final rule. Fed Regist 2009 Aug;74(148):38685-38714.
7. Sidhu SK Watson TF Resin-modified glass ionomer materials. A status report for the American Journal of Dentistry. 1995Am J Dent 8:59-67.
8. Goldman M Fracture properties of composite and glass ionomer dental restorative materials. J BiomedMater Res 1985 19:771-783.
9. Shigeru Uno Long-term mechanical characteristics of resin-modified glass ionomer restorative material Dent Mater 12:64-69, January, 1996
10. Volpato CM ; garbelottoLGD;fredelMC;BondioloF , Apliication of zirconia in dentistry : biological, mechanical and optical condideration In: sikalidiaC,editors . advances in ceramic – electric and magnetic ceramics ,bioceramics ,ceramic and environment . Rijeka: In Tech 2011 . P 397-404
11. Garoushi S, Säilynoja E, Vallittu PK, Lassila L. Physical properties and depth of cure of a new short fiber reinforced composite. Dent Mater 2013;29:835-41.
12. Kato H. Fatigue properties of dental alloys. 12% Au-Pd-Ag alloy and type III gold alloy. Aichi GakuinDaigakuShigakkai Shi. 1989 Dec;27(4):1017–27.
13. Summitt JB, Robbins JW, Schwartz R (2006). Fundamentals of operative dentistry. 3rd edition, USA, Quintessence books pp.560-1.
14. Saygili G, Mahmali SM. Comparative study of the physical properties of core materials. Int J Periodontics Restorative Dent. 2002 Aug;22(4):355–63.
15. Chen s, ohman c, Jefferies SR, Gray H, Xia w, Engqvist H. compressive fatigue limit of four type of dental restorative materials. Journal of mechanical behavior of biomedical material. 2016 Aug; 61:283-89
16. Collins JA. Failure of materials in mechanical design: analysis, prediction, prevention. Wiley; 1981. 668 p.
17. Htang A, Ohsawa M, Matsumoto H. Fatigue resistance of composite restorations: Effect of filler content. Dental Materials. 1995 Jan 1;11(1):7–13.
18. Drummond JL, Sakaguchi RL, Racean DC, Wonzy J, Steinberg AD, Testing mode and surface treatment effects on dentin bonding. J Biomed Mater Res. 1996 DEC;32(4):533-41
19. Draughn RA. Compressive fatigue limit of composite restorative material. J Dent Res. 1979 Mar;58(3):1093-6
20. Mohandesi JA, Rafiee MA, Barzegaran V, Shafiei F. Compressive fatigue behavior of dental restorative composites. Dental materials journal. 2007;26(6):827-37.
21. Vallittu PK. High-aspect ratio fillers: fiber-reinforced composites and their anisotropic properties. Dental materials. 2015 Jan 1;31(1):1-7.
22. Cheng TH, Jones FR, Wang D. Effect of fibre conditioning on the interfacial shear strength of glass-fibre composites. Composites Science and Technology. 1993 Jan 1;48(1-4):89-96.
23. Garoushi S, Tanner J, Vallittu PK, Lassila L. Preliminary clinical evaluation of short fiber-reinforced composite resin in posterior teeth: 12-months report. The open dentistry journals. 2012; 6:41.
24. Vallittu PK, Lassila VP, Lappalainen R. Transverse strength and fatigue of denture acrylic-glass fiber composite. Dental Materials. 1994 Mar 1;10(2):116-21.
25. Cho GC, Kaneko LM, Donovan TE, White SN. Diametral and compressive strength of dental core materials. The Journal of prosthetic dentistry. 1999 Sep 1;82(3):272-6.
26. Kovarik RE, Breeding LC, Caughman WF. Fatigue life of three core materials under simulated chewing conditions. The Journal of prosthetic dentistry. 1992 Oct 1;68(4):584-90.
27. Huysmans MC, van der Varst PG. Mechanical longevity estimation model for post-and-core restorations. Dental Materials. 1995 Jul 1;11(4):252-7.
28. Walia R, Jasuja P, Verma KG, Juneja S, Mathur A, Ahuja L. A comparative evaluation of microleakage and compressive strength of Ketac Molar, Giomer, Zirconomer, and Ceram-x: An: in vitro: study. Journal of Indian Society of Pedodontics and Preventive Dentistry. 2016 Jul 1;34(3):280-4.