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RESEARCH ARTICLE

COMPARATIVE STUDY OF FLEXURAL STRENGTH AND FRACTURE RESISTANCE OF TWO DIFFERENT TYPES OF PROVISIONAL RESTORATIVE MATERIALS REINFORCED WITH TWO DIFFERENT FIBERS - AN INVITRO STUDY

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ABSTRACT

Aim of the study: The aim of this study is to compare and analyze the flexural strength and fracture resistance of two different provisional restorative materials reinforced with two different types of fibres.

Materials and Methods: Two commonly used resins, namely DPI (poly methyl methacrylate) and UNIFAST III (a mixture of poly methyl and poly ethyl methacrylates) were chosen in this study. These materials were reinforced with 5 wt% of nylon and 5 wt% of E-glass fibers forming a total of 12 groups with a total sample size of 120 (60 for flexural strength test and 60 for fracture resistance test). Both the tests were performed using 3- point bending tests and results were recorded. The results were then analyzed by using ANOVA and Scheffe's Post Hoc test.

Results: The mean flexural strengths of DPI control specimens, DPI specimens reinforced with 5 wt% nylon fibers and DPI specimens reinforced with 5 wt% E-Glass fibers were 3.07 MPa, 4.167 MPa and 5.280 MPa respectively, the mean flexural strengths of UNIFAST III control specimens, UNIFAST III specimens reinforced with 5 wt% nylon fibers and UNIFAST III specimens reinforced with 5 wt% E-Glass fibers were 3.948 MPa, 5.208 MPa and 5.886 MPa respectively. The mean fracture resistances of DPI control specimens, DPI specimens reinforced with 5 wt% nylon fibers and DPI specimens reinforced with 5 wt% E-Glass fibers were 2.08 MPa, 2.278 MPa and 2.989 MPa respectively. The mean fracture resistances of UNIFAST III control specimens, UNIFAST III specimens reinforced with 5 wt% nylon fibers and UNIFAST III specimens reinforced with 5 wt% E-Glass fibers were 2.654 MPa, 2.75 MPa and 3.535 MPa respectively.

Conclusion: Within the limitations of the study it was concluded that silanated E-Glass fibers exhibited superior flexural strength and fracture resistance for both DPI and UNIFAST III materials. It was also noticed that, between DPI and UNIFAST III materials UNIFAST III exhibited superior flexural strength and fracture resistance.

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INTRODUCTION

Loss of one or several teeth may present with problems such as reduced masticatory efficiency hence reduced intake of diet and related nutritional problems; impaired speech, deterioration of occlusion and loss of coordination in the stomatognathic system, aesthetic and psychosocial problems. Hence replacement of tooth/teeth is of very much importance. Treatment of completely or partially edentulous patients can be done by means of either removable or fixed prosthesis. Fixed prosthodontic treatment has several advantages over removable means of treatment which include durability, easy maintenance, patient's compliance etc. Hence fixed prosthodontic treatment is a preferable mode of treatment for edentulousness, particularly in case of partially edentulous patients. Fixed prosthodontic treatment can transform an unhealthy, unattractive dentition with poor function into a comfortable, healthy occlusion capable of years of further service while greatly enhancing aesthetics. Fixed prosthodontic treatment can range from the fairly straight forward restoration of a single tooth with a cast crown, replacement of one or more missing teeth with a fixed partial denture, to a highly complex restoration involving all the teeth in an entire arch or dentition. (Shillingburg, 3rd edition; Stephen F. Rosenstiel, 4th edition) It is important that the prepared tooth or teeth be protected and that

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the patient is kept comfortable while a cast restoration is being fabricated. By successful management of this phase of the treatment, the dentist can gain patient's confidence and favourably influence the ultimate success of final restoration. During the time between the preparation of the tooth and the placement of the final restoration, the tooth is protected by a provisional restoration. (Stephen F. Rosenstiel, 4th edition; Naveen S Yadav and Hend Elkawash, 2011) An optimum interim fixed restoration must satisfy biologic, mechanical and aesthetic requirements. The biologic requirements include pulp protection, maintenance of periodontal health, provision of occlusal compatibility, maintenance of tooth position & protecting the tooth against fracture. Mechanical requirements include resistance to functional loads, resistance to removal forces and maintenance of interabutment alignment. Aesthetic requirements include easily contour able margins, colour compatibility translucency and colour stability. (Shillingburg, 3rdedition) For patients with bruxism or those whose treatment plans require long-term use of provisional restorations, provisional restorations with improved physical properties are required. (Hamza *et al*., 2004) Flexural strength, also known as transverse strength, is a measurement of the strength of a bar (supported at each end) under a static load. (Kenneth J. Anusavice, 11th edition) The flexural strength test is combination of tensile and compressive strength tests and includes elements of proportional limit and elastic modulus measurements. (Craig, 2001) Fracture toughness is the ability of a material to resist crack propagation and may more accurately determine the likelihood of fracture of provisional restoration in clinical practice, whereas fracture strength is the stress at which the material fractures. (Hamza *et al*., 2004; Craig, 2001) Both flexural strength and fracture resistance are the parameters based on which the clinical longevity of the provisional restoration can be predicted.

Various attempts have been made to reinforce provisional restorative materials. Modifications have been done by modifying the basic composition of the material itself or by the addition of various reinforcement elements to the resin material. These additional reinforcement materials include metal wire, (Geerts *et al*., 2008; Hamza *et al*., 2006) different types of fibers such as Carbon, Polyethylene, (Hamza *et al*., 2004; Geerts *et al*., 2008; Hamza *et al*., 2006) Glass, (Hamza *et al*., 2004; Geerts *et al*., 2008; Hamza *et al*., 2006) Aramid (Jacob John *et al*., 2001) and Nylon (Jacob John *et al*., 2001) fibers. Various studies have been conducted to determine the influence of the above mentioned materials on the flexural strength and fracture resistance of the acrylic resins used as provisional restorative material. Compared with conventional polymer materials, fiber reinforced polymers are successful in their application primarily because of their high specific modulus and specific strength. This study aims at evaluating the influence of two reinforcements in the form of short (2-3 mm) fibers on flexural strength and fracture resistance of two commonly used provisional restorative materials.

MATERIALS AND METHODS

In this study two commonly used polymer materials were used, PMMA based (D.P.I., Mumbai, India) and a mixture of PMMA and PEMA (UNIFAST III, GC, America). The reinforcement materials used were 5 wt % nylon and 5 wt% E-glass fibers. These fibers were mixed into these polymer materials and were tested for the flexural strength and fracture resistance. Three groups, first group comprising of non reinforced specimens, 2nd group comprising of specimens reinforced with 5 wt % nylon and 3rd group comprising of specimens reinforced with 5 wt% E- glass fibers were tested for each of the two parameters.

Fabrication of test specimens for flexural strength test

A specially designed split stainless steel die (Fig.1) was fabricated according to (American National Standards Institute/American Dental Association specification no. 27) (ANSI/ADA specification 27, 1993) to form rectangular specimens of dimensions 2.2 × 2.2 × 25.2 mm. The die comprised a base (75 × 85 × 3 mm), 2 rectangular metal plates (41 × 22.5 × 2.2 mm) and 5 identical rectangular bars that, when assembled over the base, formed 6 identical spaces with the required dimensions. Polymer and monomer were taken into a rubber container and mixed according to manufacturer's instructions. When the mix reached the dough stage, it was packed into the mold cavity of the die slowly to avoid entrapping of air; the mold was then covered with a clean glass slab to remove the excess resin and kept under a load of 500 grams (by using a custom made wooden jig) at room temperature for 30 minutes to allow for complete polymerization of the resin. After complete polymerization of the resin, the specimens were separated from the mold; flash was removed with the razor blade and the specimens were examined for voids by viewing against the intense light through the magnifying glass (5X). Using the caliper the specimens were finished to the desired dimensions with 400- and 600-grit sandpaper and stored in artificial saliva (wet mouth- ICPA, Ankleshwar, India) at 37^0 C for 1 week in a bacteriological incubator (Labline instruments, India). After 1 week the specimens were subjected to thermocycling in a customized thermocycling unit (Fig.2) between temperature ranges of 5^oC and 55^oC. The samples were exposed to each temperature for one minute with a dwell time of 30 seconds for a total of 500 cycles.

Flexural strength testing

The flexural strength for all the specimens was determined by loading the specimens in the INSTRON universal testing machine (Fig.3). Each specimen was positioned on the bending fixture, consisting of 2 parallel, 2-mm–diameter supports, 20 mm apart. The load was applied with a crosshead speed of 0.75 mm/min, with a third 2-mm rod placed centrally between the supports. The maximum force [N] upon fracture was recorded. The flexural strength (σ) was calculated from the following equation

$$\sigma = \frac{3FI}{2bh^2}$$

Where, F is the maximal load (N) exerted on the specimen, I is the distance (mm) between the supports, b is the width (mm) of the specimen, and h is the height (mm) of the specimen.

Fracture toughness specimen preparation

A specially designed split stainless steel die (Fig.4) was fabricated according to British Standard 5477 (1977) (British Standards Institution. No 5477, 1977) to form rectangular specimens of dimensions 3. 2 × 6. 2 × 25. 2 mm. The mold was comprised of a base (70 × 74 × 12 mm) which was formed when the two identical halves (35 × 12 × 74mm) were joined,

2 rectangular metal blocks (35 × 6. 2 × 1. 2mm) and 3 identical rectangular bars. A razor blade was kept vertically between the two halves of the base with the cutting edge extending 3.1 mm upwards into the mold cavity to form a precrack in the specimen. All these parts when assembled formed 4 identical spaces with the required dimensions. Polymer and monomer were taken into a rubber container and mixed according to manufacturer's instructions. When the mix reached the dough stage, it was packed into the mold cavity slowly to avoid entrapping of air; the mold was then covered with a clean glass slab to remove the excess resin and kept under a load of 500 grams (by using a custom made wooden jig) (Fig.5) at room temperature for 30 minutes to allow for complete polymerization of the resin. After complete polymerization of the resin, the specimens were separated from the mold; flash was removed with the razor blade and the specimens were examined for voids as done in the case of specimens fabricated for flexural strength testing. The specimens were trimmed, polished, inspected, stored and were subjected to thermocycling similar to flexural strength test specimens before they were subjected to fracture resistance test.

Fracture toughness testing

Group of 60 samples were tested for the fracture resistance by using a three point bending test in an INSTRON universal testing machine (Fig.6). Each specimen was positioned on the bending fixture, consisting of 2 parallel, 2-mm–diameter supports, and 20 mm apart. The load was applied with a crosshead speed of 1 mm/min, with a third 2-mm rod placed centrally between the supports until the crack propagation initiated, which was indicated by a sudden drop in the load. The machine was attached to a computer with software to record these loads. The maximum loads (at which there was a sudden drop noticed, indicating crack propagation) were recorded in MPa.

The fracture toughness was then calculated using the following formula:

$$KIC = f(a/w)\, F/h\sqrt{w}$$

Where; KIC is the fracture toughness (MPa), f(a/w) is the fracture geometry factor, F is the force at begin of crack propagation (N), a is the length of the crack (mm), h is the specimen thickness (mm), w is the specimen width (mm) All the results (both flexural strength and fracture resistance) were recorded and were subjected to statistical analysis. Comparison of means of more than two groups was done using the Analysis of Variance (ANOVA). For multiple comparisons Scheffe's Post Hoc test was chosen.

RESULTS

The mean flexural strength of DPI control specimens was 3.07 MPa, the mean flexural strength of DPI specimens reinforced with 5 wt% nylon fibers was 4.167 MPa, the mean flexural strength of DPI specimens reinforced with 5 wt% E-Glass fibers was 5.280 MPa, the mean flexural strength of UNIFAST III control specimens was 3.948 MPa, the mean flexural strength of UNIFAST III specimens reinforced with 5 wt% nylon fibers was 5.208 Mpa and the mean flexural strength of UNIFAST III specimens reinforced with 5 wt% E-Glass fibers was 5.886 Mpa (Table.1) (Graph.2).

Fig.1. Master die for fabrication of flexural strength test specimens

Fig.2. Thermocycling machine

Fig.3. Flexural strength specimen under load in UTM

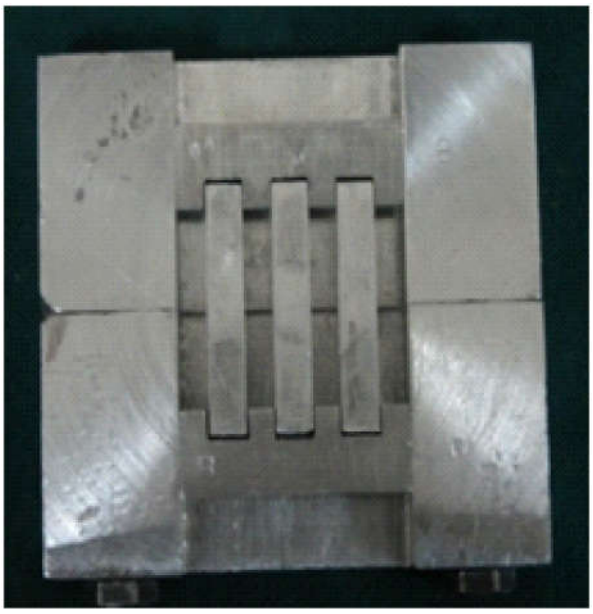


Fig.4. Master die for fabrication of flexural strength test specimens

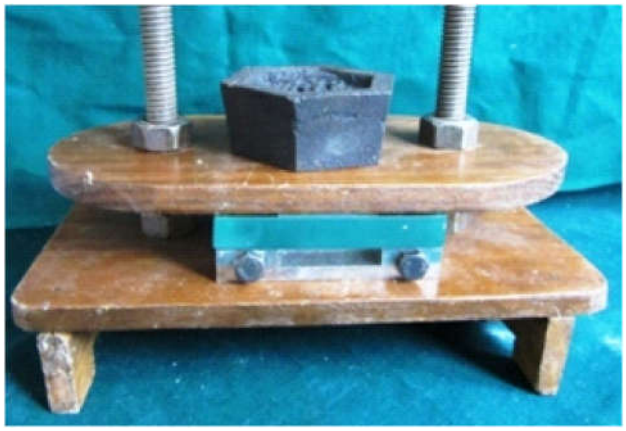


Fig.5. Load application during setting of fracture resistance test specimens

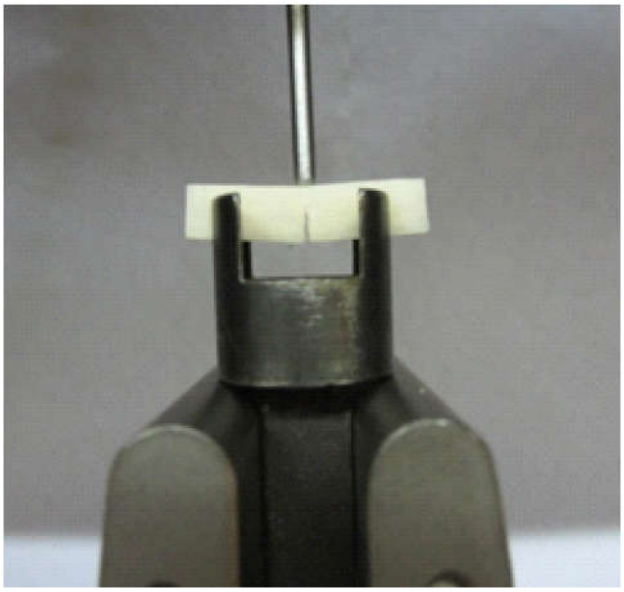
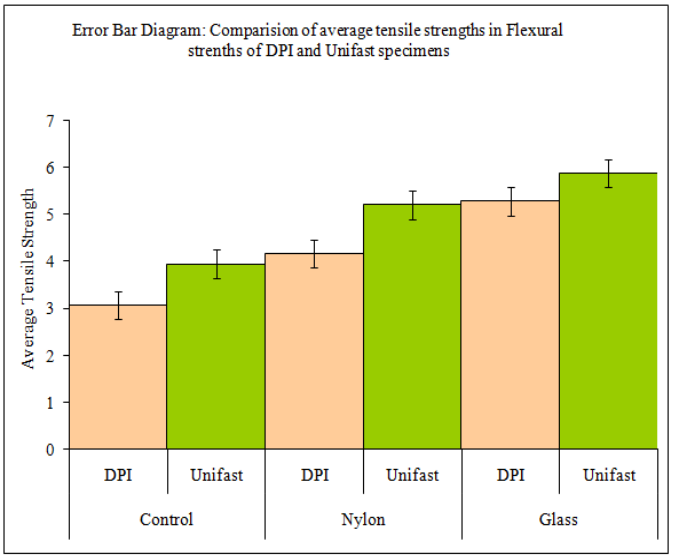


Fig.6. Fracture resistance specimen under load in UTM

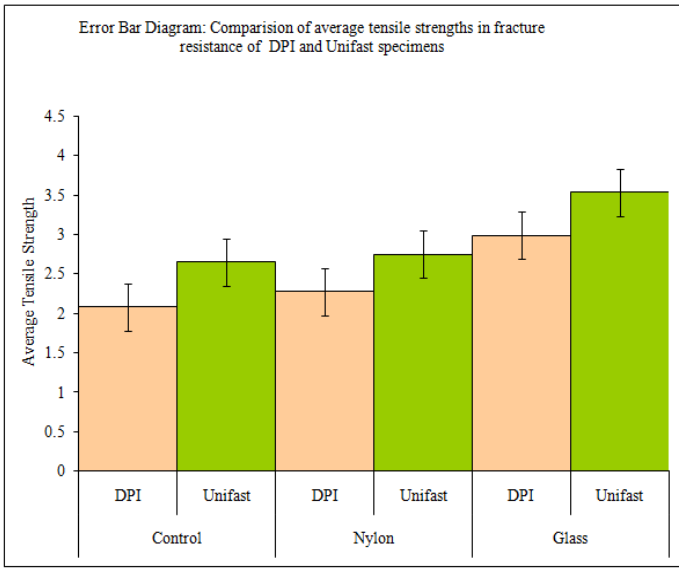
The mean fracture resistance of DPI control specimens was 2.08 MPa, the mean fracture resistance of DPI specimens reinforced with 5 wt% nylon fibers was 2.278 MPa, the mean fracture resistance of DPI specimens reinforced with 5 wt% E-Glass fibers was 2.989 MPa, the mean fracture resistance of UNIFAST III control specimens was 2.654 MPa, the mean fracture resistance of UNIFAST III specimens reinforced with 5 wt% nylon fibers was 2.75 Mpa and the mean fracture resistance of UNIFAST III specimens reinforced with 5 wt% E-Glass fibers was 3.535 Mpa. (Table.2) (Graph.2).

Table 1. Comparison between flexural strengths of all the subgroups of DPI and UNIFAST III

Flexural Strengths	Type	n	Mean	S.D	T-value	P-value	Decision
Control	DPI	10	3.0710	.65329	-	0.009	Significant
	UNIFAST III	10	3.9480	.69520	2.907		
5 wt% nylon	DPI	10	4.1670	.67910	-	0.000	Significant
	UNIFAST III	10	5.2080	.23088	4.589		
5 wt% Glass	DPI	10	5.2800	.35512	-	0.018	Significant
	UNIFAST III	10	5.8860	.64773	2.594		



Graph 1. Bar diagram showing comparison between flexural strengths of all the subgroups of DPI and UNIFAST III



Graph 2. Bar diagram showing comparison between fracture resistances of all the subgroups of DPI and UNIFAST III

Table 2. Comparison between fracture resistances of all the subgroups of DPI and UNIFAST III

Fracture Resistance	Type	n	Mean	S.D	T-value	P-value	Decision
Control	DPI	10	2.0800	.31703	-2.824	0.011	Significant
	UNIFAST III	10	2.6540	.55915			
5 wt% nylon	DPI	10	2.2780	.37190	-2.271	0.036	Significant
	UNIFAST III	10	2.7500	.54193			
5 wt% Glass	DPI	10	2.9890	.31796	-2.413	0.027	Significant
	UNIFAST III	10	3.5350	.64117			

DISCUSSION

Biologically acceptable fixed prosthodontic treatment demands that prepared teeth be protected and stabilized with provisional restorations that resemble the form and function of the planned definitive treatment. They can assist in the maintenance of periodontal health and act as a healing matrix. Besides the immediate protective, functional, and stabilizing value, interim restorations are useful for diagnostic purposes where the functional, occlusal, and esthetic parameters are developed to identify an optimum treatment outcome before the completion of definitive procedures. A provisional fixed restoration will provide a template for defining tooth contour, esthetics, proximal contacts and occlusion, and for evaluating the potential consequences from an alteration in the vertical dimension of occlusion. Provisional treatment can also provide an important tool for the psychological management of patients where a mutual understanding of treatment outcome and limitations of treatment can be identified. Though methacrylate resins are the materials of choice for the fabrication of provisional restorations, fracture of the restoration may occur during function because of the poor transverse and flexural strengths of methacrylate resins. Hence various reinforcement materials have been used to strengthen the provisional restorative materials. Compared with conventional polymer materials, fiber reinforced polymers are successful in their application primarily because of their high specific modulus and specific strength. Glass is an inorganic substance that has been cooled to a rigid condition without crystallization. Because the modulus of elasticity of glass fibers is very high, most of the stresses are received by them without deformation. Untreated fibers act as inclusion bodies in the acrylic resin mixture and, instead of strengthening, actually weaken the resin. The fibers may break up the homogeneous matrix. Silane coupling agents, who chemically bond glass fibers to the resin matrix, may make the mixtures more homogeneous, resulting in stronger PMMA. (The effect of glass fiber reinforcement on the fracture resistance of a provisional fixed partial denture, 1998) Nylon fibers are polyamide fibers and are based primarily on aliphatic chains. The chief advantage of nylon lies in its resistance to shock and repeated stressing. However, water absorption affects the mechanical properties of nylon. (Jacob John *et al*., 2001)

Laboratory thermal cycling is a simulation of in vivo conditions in which the specimens or the materials are subjected to various temperatures similar to that of the oral conditions. There were various regimens of temperatures that were followed during thermal thermal cycling. (Gale and Darvell, 1999) The regimen followed in this study was 5˚c and 55˚c as these temperatures were proven to be the minimum and maximum temperatures which can be tolerated by the patient. In the present study reinforced DPI specimens exhibited more flexural strength than non reinforced DPI specimens. Mean flexural strength of non reinforced DPI specimens (control) was 3.071 MPa and mean flexural strength of 5 wt % nylon reinforced specimens was 4.167 MPa and mean flexural strength of 5 wt % E-Glass reinforced specimens was 5.280 MPa. In the present study reinforced UNIFAST III specimens exhibited more flexural strength than non reinforced specimens. Mean flexural strength of non reinforced UNIFAST III specimens (control) was 3.948 MPa and mean flexural strength of 5 wt % nylon reinforced specimens was 5.208 MPa and mean flexural strength of 5 wt % E-Glass reinforced specimens was 5.886 MPa. Increase in flexural strength in specimens reinforced with 5 wt % nylon when compared to non reinforced specimens can be explained due to transfer of stress from the weak polymer matrix to the fibers that have a higher tensile strength. (Jacob John *et al*., 2001) Increase in flexural strength of specimens reinforced with silanated 5 wt % E-Glass fibers when compared to non reinforced specimens can be explained due to transfer of stress from the weak polymer matrix to the fibers that have a higher tensile strength, and also due to formation of bond between polymer matrix and fiber. (The effect of glass fiber reinforcement on the fracture resistance of a provisional fixed partial denture, 1998; Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers, 1999) The increase in flexural strength of specimens reinforced with silanated 5 wt % E-Glass fibers compared to the specimens reinforced with 5 wt % nylon fibers can be explained by the fact that silanization increases bond between glass fiber (Gary and Solnit, 1991) and the polymer matrix and due to water sorption the nylon fiber is weakened. (Jacob John *et al*., 2001)

On multiple comparisons between control, 5 wt % nylon reinforced and 5 wt % E-Glass fiber reinforced DPI specimens and between control, 5 wt % nylon reinforced and 5 wt % E-Glass fiber reinforced UNIFAST III specimens, Scheffe's Post Hoc test disclosed that the differences between flexural strengths among all the groups were not statistically significant as all the p-values were less than 0.05. On comparing both DPI and UNIFAST III specimens, flexural strength and fracture resistances were more for UNIFAST III specimens than that of DPI specimens. This can be attributed to the SURF Technology (Surface Uniformity Revolutionary Fixation Technology), a new and revolutionary polymer processing technology. The new technology developed a perfectly balanced composition that has unsurpassed adaptability, wear resistance, hardness and flexural strength. The good wettability of powder and liquid makes it easy to produce a homogeneous, bubble-free mix. In this technology polymer particles are coated with pigment and are responsible for bubble-free and long-lasting exceptionally even-coloured mixtures with high flexural strength and fracture resistance.

In the present study, reinforced DPI specimens exhibited more fracture resistance than non reinforced specimens. Mean fracture resistance of non reinforced specimens (control) was 2.08 MPa and mean fracture resistance of 5 wt % nylon reinforced specimens were 2.278 MPa and mean fracture resistance of 5 wt % E-Glass reinforced specimens was 2.989 MPa. In the present study, reinforced UNIFAST III specimens exhibited more fracture resistance than non reinforced specimens. Mean fracture resistance of non reinforced specimens (control) was 2.654 MPa and mean fracture resistance of 5 wt % nylon reinforced specimens was 2.75 MPa and mean fracture resistance of 5 wt % E-Glass reinforced

specimens was 3.535 MPa. Increase in fracture resistance in specimens reinforced with 5 wt % nylon when compared to non reinforced specimens can be explained due to transfer of stress from the weak polymer matrix to the fibers that have a higher tensile strength. Increase in fracture resistance in specimens reinforced with silanated 5 wt % E-Glass fibers when compared to non reinforced specimens can be explained due to transfer of stress from the weak polymer matrix to the fibers that have a higher tensile strength, and also due to formation of bond between polymer matrix and fiber. (The effect of glass fiber reinforcement on the fracture resistance of a provisional fixed partial denture, 1998; Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers, 1999) The increase in fracture resistance of specimens reinforced with silanated 5 wt % E-Glass fibers than the specimens reinforced with 5 wt % nylon fibers can be explained by the fact that silanization increases bond between glass fiber and the polymer matrix (Gary S. Solnit, 1991) and due to water sorption the nylon fiber is weakened. (Jacob John *et al*., 2001) On comparing both DPI and UNIFAST III specimens, flexural strength and fracture resistances were more for UNIFAST III specimens than that of DPI specimens. This can be attributed to the SURF Technology (Surface Uniformity Revolutionary Fixation Technology), a new and revolutionary polymer processing technology. The new technology developed a perfectly balanced composition that has unsurpassed adaptability, wear resistance, hardness and flexural strength. The good wettability of powder and liquid makes it easy to produce a homogeneous, bubble-free mix. In this technology polymer particles are coated with pigment and are responsible for bubble-free and long-lasting exceptionally even-coloured mixtures with high flexural strength and fracture resistance.

SUMMARY

In the present study two parameters were evaluated, flexural strength and fracture resistance of provisional restorative materials, reinforced with two different fibers. Two commercially available provisional restorative materials were used. They were DPI (PMMA) and UNIFAST III (PMMA+PEMA), two types of fibers were tested, Nylon fibers and silanated E- glass fibers. Specimens fabricated by using DPI and UNIFAST III materials were divided into 3 subgroups each for each of the two parameters. These groups included the; control group (non reinforced), 5 wt% nylon reinforced group and 5 wt% E-glass fiber reinforced group. Each subgroup was having 10 specimens in it with a total of 120 specimens. All the specimens were stored in artificial saliva for 1 week at 37˚ C in a bacteriological incubator to simulate the intra oral conditions. All the specimens were subjected to 500 thermal cycles in a customised thermocycler machine prior to flexural strength and fracture resistance testing to create artificial ageing in the samples. Then the specimens were tested for flexural strength and fracture resistance by 3- point bending test on INSTRON universal testing machine. The fracture loads were recorded in flexural strength testing and loads at which initiation of crack propagation were recorded in fracture resistance testing. ANOVA and Scheffe's Post Hoc tests were used to statistically analyze the data. It was observed in the study that reinforced specimens showed more fracture resistance and flexural strength when compared to non-reinforced specimens which were taken as control. Among the reinforced specimens, specimens reinforced with 5 wt% E-glass fibers showed more flexural strength and fracture resistance than specimens reinforced with 5 wt% nylon fibers. Among specimens manufactured from DPI and UNIFAST III, UNIFAST III specimens showed more flexural and fracture resistance than DPI specimens.

CONCLUSION

Within the limitations of the study it can be concluded

1) Specimens which are reinforced with fibers had more flexural strength than non reinforced specimens.
2) Specimens which are reinforced with fibers had more fracture resistance than non reinforced specimens.
3) Among reinforced specimens, specimens with E-glass fiber reinforcement exhibited more flexural strength than specimens reinforced with nylon.
4) Among reinforced specimens, specimens with E-glass fiber reinforcement exhibited more fracture resistance than specimens reinforced with nylon.
5) UNIFAST specimens exhibited superior flexural and fracture resistance properties than DPI specimens.

Though the study has been undertaken in a standardized and systemic manner involving the commonly available materials still there is a requirement of further studies which aim at incorporating various other reinforcements and materials in future for the benefit of the patients.

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