10.5005/jp-journals-10029-1063

ORIGINAL ARTICLE

Flexural Strength of E-glass-reinforced PMMA

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ABSTRACT

Background: Poly (methyl 2- methylpropenoate) (PMMA) is one of the most widely accepted biomaterials due to its acceptable advantageous but the limitations associated with these materials make them far from being ideal. So, the present study is to achieve desirable flexural strength by reinforcing PMMA with E-glass fiber.

Aim: Determination of flexural strength of PMMA by varying the weight percentage of glass fiber (2.5 wt%, 5 wt%, 10 wt%), and by varying the aspect ratio (3 mm/20 μm, 6 mm/20 μm, 12 mm/20 μm) of glass fiber.

Materials and methods: Specimens prepared using a standard rectangular mold of 62 mm length, 10 mm breadth and 2.5 mm thickness. A total of 60 samples prepared (6 samples in each group) polymer—monomer ratio 2.4:1 by weight used to prepare samples. Flexural strength is tested using universal testing machine Instron. The microstructural analysis using scanning electron microscopy performed in order to understand the fiber matrix bonding. Detailed statistical analysis done by one-way ANOVA.

Results: Highest flexural strength is observed for the PMMA reinforced with 6 mm/20 μm fiber 2.5 wt%.

Keywords: PMMA, Flexural strength, Silane treated E-glass fiber.

How to cite this article: Mathew M, Shenoy K, Ravishankar KS. Flexural Strength of E-glass-reinforced PMMA. Int J Experiment Dent Sci 2014;3(1):24-28.

Source of support: Nil

Conflict of interest: None declared

INTRODUCTION

One of the most widely used materials in prosthetic dentistry is polymethyl methacrylate because of its desirable characteristics.[1] Poly (methyl 2-methylpropenoate) is commonly called as PMMA and these biocompatible materials are chemically inert, dimensionally stable having ease in their processing.[2] However, these are far from satisfying the ideal characteristics to be used as a biomaterial in advanced fields like prosthetic bone corrections and craniofacial reconstruction. It possesses inferior mechanical properties. So, in order to achieve the desirable flexural strength characteristic in polymethyl methacrylate, present study conducted by reinforcing it with silane treated E-glass fibers since it is a most commonly used fiber for acrylic reinforcement due to its higher mechanical properties, low susceptibility to moisture absorption, resistance to chemicals, thermal stability and high melting point.[3] Surface treatment like silane treatment on E-glass fiber can improve the adhesion of fiber with the matrix and thereby a polymer composite can be prepared. Polymer composite materials are produced by combining two dissimilar materials into a new material that may be better suited for a particular application than either of the original material alone.[4]

Aim

- To determine flexural strength of PMMA material by varying the weight percentage of glass fiber (2.5 wt%, 5 wt%, 10 wt%).
- To determine flexural strength of PMMA material by varying the length/thickness ratio of glass fiber (3 mm/20 μm, 6 mm/20 μm, 12 mm/20 μm).
- Comparison of the above and determine the optimum property of the PMMA material using the correct weight percentage and aspect ratio.

MATERIALS AND METHODS

Materials

Modeling wax, dental stone type III gypsum product, type II gypsum product, silane treated E-glass fibers, heat polymerizing PMMA powder and monomer liquid, separating medium.

Methods

- Preparation of gypsum molds to obtain the acrylic specimen: Wax pattern (62 × 10 × 2.5 mm) is prepared using modeling wax and invested in the dental flask in the conventional manner using dental stone and model plaster. After 1 hour, the invested flask kept for dewaxing, then

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any waxy residue removed by washing the mould by hot water and then cleaned using soap solution, allowed to dry, thin layer of separating medium is applied in the mould space, allowed to dry. The mold was then ready to be used for the preparation of acrylic specimen.[5]

- Preparation of PMMA resin specimen
  a. Control group: Control group test specimen made with conventional heat polymerized PMMA resin (DPI heat cure) polymer and monomer (2.4 gm: 1 ml) are mixed and allowed to reach dough consistency. Dough is kneaded and then packed into the mould, flask is closed and a pressure of 1400 psi is given and bench cured for 30 minutes in hydraulic press apparatus. Then the flask is clamped and transferred it into the water bath. Temperature of the water bath elevated slowly to 72°C, and maintained for 90 minutes. Then the temperature of the water bath elevated to 100°C and maintained for 60 minutes. After completion of polymerization cycle, the flask is allowed to cool in same water bath to room temperature, and the acrylic resin specimens are retrieved after deflasking. The specimen obtained were finished and polished in the conventional manner.[5]
  b. Reinforced group: Silane treated E-glass fibers of varying length and concentration is taken and impregnated in the measured monomer for 5 minutes, then the polymer powder is weighed and mixed with monomer and glass fiber, and allowed to reach dough consistency. Then it is packed and a pressure of 1400 psi is given and bench cured for 30 minutes in hydraulic press apparatus. Then the flask is clamped and transferred it into the water bath. Temperature of the water bath elevated slowly to 72°C, and maintained for 90 minutes. Then the temperature of the water bath elevated to 100°C and maintained for 60 minutes. After completion of polymerization cycle, the flask is allowed to cool in the same water bath to room temperature, and the acrylic resin specimens are retrieved after deflasking. Specimens obtained were finished and polished in the conventional manner.[5]

Flexural Strength Testing

Flexural strength is measured using Instron, universal testing machine (Fig. 1). Test performed in controlled atmospheric temperature 18°C and 50% humidity. Specimen placed in position where its two edges supported from lower side and the load is given in the middle of the specimen from upper side (3 point bending) as shown in Figure 1. Samples were loaded until the failure was complete. Flexural strength values were recorded directly from the computer attached.

RESULTS

- All modified groups shown significant increase in the flexural strength compared to control group having no fiber (Graph 1).
- Among the fiber reinforced groups, 20 μm diameter, 6 mm long E-glass fiber in 2.5 wt% showed superior flexural strength (Table 1).
- Comparing different fiber weight with same fiber length, there was significant change in the flexural strength value.
- Except for 3 mm long fiber, increase in the fiber weight percentage showed decrease in the flexural strength value (*see* Table 1).

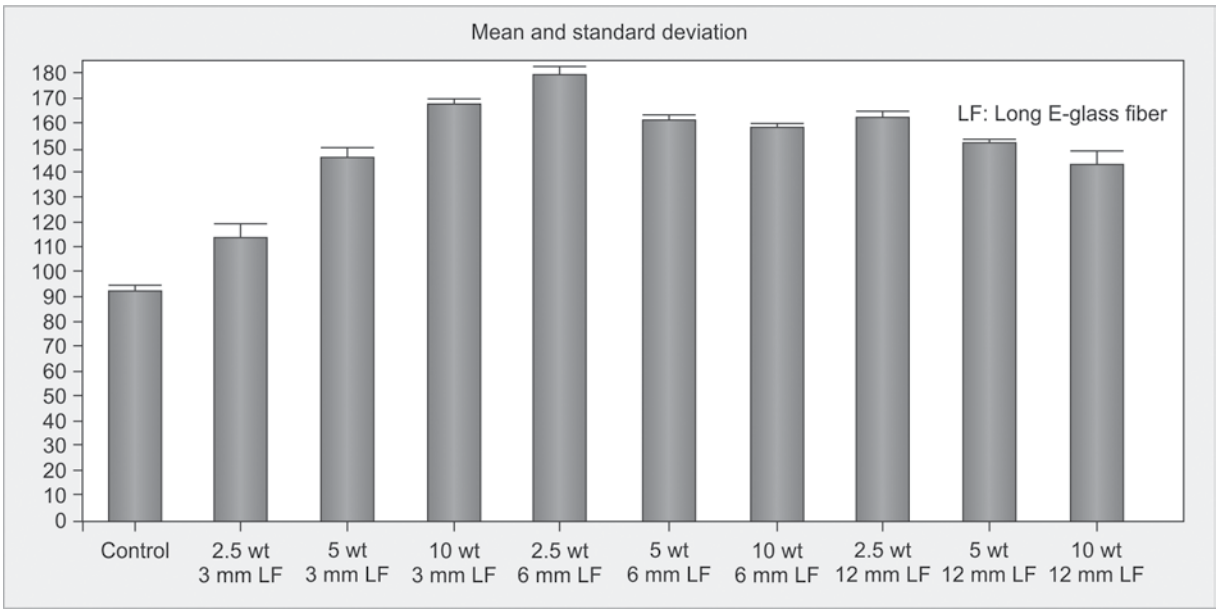
DISCUSSION

Flexural strength, a mechanical parameter also known as modulus of rupture, bend strength or fracture strength. This defines the material's ability to resist deformation under load.

Fig. 1: Measurement of flexural strength using Instron

Table 1: Flexural strength of samples in MPa

Serial nos.	Control specimen	3 mm long fiber			6 mm long fiber			12 mm long fiber		
		2.5 fiber wt%	5 fiber wt%	10 fiber wt%	2.5 fiber wt%	5 fiber wt%	10 fiber wt%	2.5 fiber wt%	5 fiber wt%	10 fiber wt%
1	91.43	110.12	146.03	169.06	186.2	162.4	156.21	162.46	153.29	146.14
2	94.74	108.34	143.62	168.87	178.1	158.14	158.87	163.29	152.4	139.57
3	91.02	108.12	139.26	169.4	175.58	160.42	156.12	163.94	150.28	143.64
4	94.83	121.21	149.94	164.44	174.26	160.68	160.1	159.15	152.09	147.63
5	92.07	118.45	148.1	165.74	176.4	158.28	158.72	164.7	149.98	147.14
6	91.08	114.14	149.2	166.5	180.1	164.64	156.88	158.39	151.59	133.15
Mean	92.52	113.39	146.02	167.33	178.44	160.76	157.81	161.98	151.60	142.87
SD	1.787	5.5006	4.0314	2.0600	4.3105	2.4851	1.6417	2.6108	1.2730	5.6132



Graph 1: Flexural strength of E-glass-reinforced PMMA

Flexural strength represents the highest stress experienced within the material at its moment of rupture.[6] It is measured in terms of stress using a three point bending. When stress is given to the rectangular specimen, it experiences a range of stresses across its depth. At the edge of the specimen on the inside of the bend (concave face), the stress will be at its maximum compressive value. At the outside of the bend (convex face), the stress will be at its maximum tensile value. At the two extreme edges, the material experiences shear mode of loading. Those biomaterials used for the fabrication of denture, denture bases, bridges or similar appliances undergo complex stresses, a combination of compressive, tensile, shear stresses in service. Flexural strength analysis is an important parameter for such prosthesis.[7]

Conventional polymethyl methacrylate exhibits inferior flexural strength values,[1] so a polymer composite can be made by reinforcing the PMMA silane treated E-glass fiber. Composite materials are composed of matrix and dispersed phase having bulk properties. Matrix phase is the primary phase having continuous character. Dispersed phase is secondary phase embedded in the matrix in a discontinuous form.[8] Composite materials are heterogeneous in composition and they are strong having low density and not easily corroded. The mechanical properties of the polymer composite are obtained from the combination of the reinforcing material and the matrix material properties and the ability to transfer the stress across the fiber-matrix interface.[4] Fracture mechanism of polymer composite materials are still in process of development. Fiber reinforced PMMA belongs to the polymer composite class of materials. During stress, the fiber reinforced polymer matrix absorbs energy and the high strength fibers break up by brittle cleavage. Factors that contribute to the toughness of polymer composite are debonding between fiber and matrix, crack deflection due to tilting and twisting movement around the fiber, fiber pullout of the matrix.[9]

The glass fiber is an inorganic substance. E-glass fibers are most commonly used reinforcing fiber for acrylic because it provides good electrical, thermal insulation and strongly resist attack by water in addition to the superior mechanical properties and easy manipulation.[4] In the present study, silane treated E-glass fiber used to reinforce the PMMA

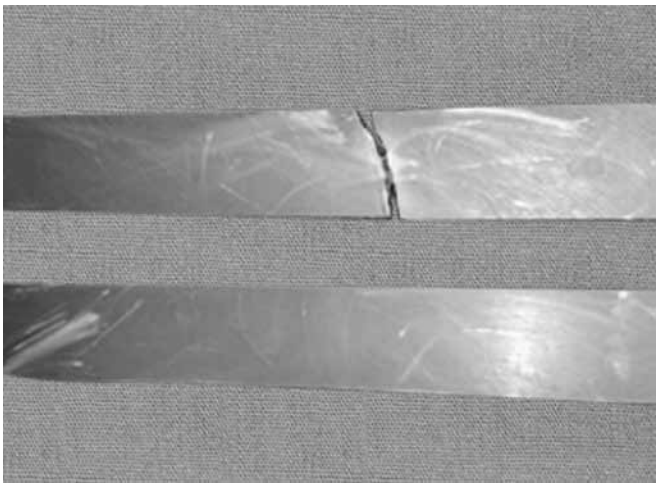


Fig. 2: Samples before and after fracture

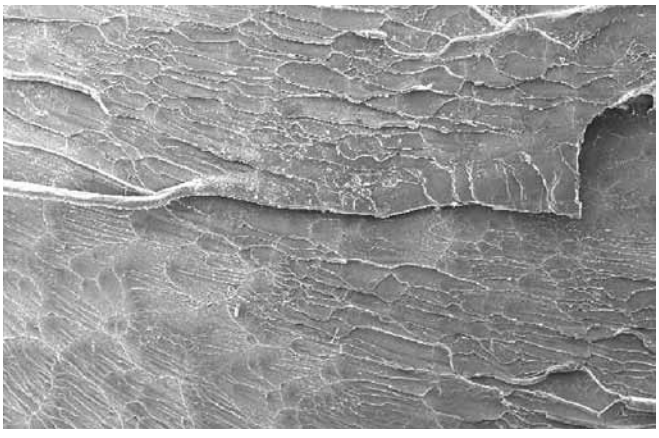


Fig. 3: SEM of control specimen

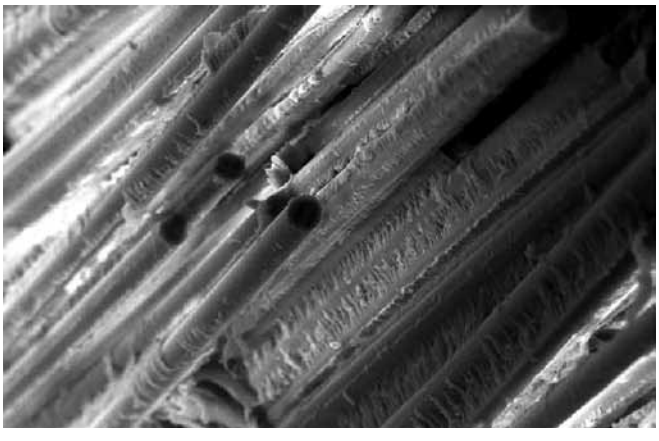


Fig. 4: SEM of fiber reinforced specimen

matrix. Silane treatment on E-glass fiber gives better bonding of fiber with the matrix so that the fiber-matrix interface could be strong and polymer matrix can absorb more energy and the toughness of composite increases. Untreated fibers actually weaken the PMMA resin matrix by breaking the homogeneous matrix. So the strength parameter will be inferior to the unreinforced matrix.[10] Coupling mechanism of the silanes have not been fully clarified because of the complex nature of the interfacial interactions. Chemical bonding theory states that silane undergoes chemical reaction with glass particles and there by coupling of both polymer and fiber occurs.[11]

In the present study, all reinforced groups' exhibit increase in the flexural strength than control. This is due to the presence of silane treated fibers. Fibers intersect micro cracks and bridge the gap between two surfaces of the crack. Under loading condition, when a crack starts to propagate, the fibers apply force opposing the crack propagation, so the strength increases.[12]

Morphology of the fractured surface of the specimens was examined using SEM. Scanning electron microscopy analysis is used to examine the matrix-fiber interface of the fractured surface and to correlate with the mechanical properties of composite (Figs 2 to 4).[13] Scanning electron microscopy for control group indicates the brittle fracture mode. Polymer composite material often shows both ductile and brittle mode of failure. The fractured-end of the reinforced groups indicates that the E-glass fibers bonded well with the matrix. So, the failure could be due to delamination or interlaminar fracture, matrix cracking or intralaminar fracture, matrix-fiber debonding, fiber breaking, fiber pull-out, etc.[9]

CONCLUSION

All fiber reinforced groups showed higher flexural strength value than the control group having no fiber in it indicates that E-glass fiber bonded well to the PMMA matrix. Superior flexural strength value obtained for 6 mm long fiber reinforced in 2.5 wt%. Present study suggests that 6 mm long fiber added in 2.5 wt% can perform better under flexural loading. However, more studies should be performed because the flexural strength not only depends on the fiber matrix bonding, fiber concentration, and aspect ratio, it is also controlled by orientation of fibers, quality of the matrix, scratches in the surface and several similar factors.

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