Research Article

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Effect of Pre and Post Polymerization on the Flexural Strength of Glass Fiber Reinforced and by Nylon Fiber Reinforced Denture Base Acrylic Resin: An In Vitro Study

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ABSTRACT

Aim: The aim of the study was to evaluate effect of pre and post polymerization on the flexural strength of glass fiber reinforced; and nylon fiber reinforced denture base acrylic resin.

Materials and method: A total of 60 specimens of standard dimensions (65 mm x 10 mm x 3 mm) according to the ADA specification no. 12 were prepared. They were equally divided into four groups of fifteen specimens each. These specimens were then subjected to three-point bending test on a Universal testing machine (INSTRON 3382). The maximum load at which the specimens fractured was recorded and their flexural strength was calculated. Subsequently all the groups were statistically analyzed and compared.

Results: Postpolymerized glass fiber reinforcements exhibited the highest flexural strength, followed by nylon fiber. The prepolymerized glass fiber reinforcements exhibited the lowest values in comparison to control group specimens.

Conclusions: Postpolymerized glass fibre reinforcements enhanced the flexural strength of acrylic resin, while prepolymerized glass fibre reinforcement decreased the flexural strength. Nylon fibre reinforcements marginally increased the flexural strength of the acrylic resins.

Keywords: Acrylic resins, complete denture, glass fiber, nylon fiber, flexural strength.

INTRODUCTION

Good removable dentures are essential to improve the quality of life of patients. It is a challenge for the prosthodontist to provide a good prosthesis that meets the functional and aesthetic demands of the oral cavity. Since the introduction of Polymethyl methacrylate (PMMA) in 1937, it has become the most commonly used denture base material[1]. The three properties that have contributed most to the success of this material as a denture base are excellent appearance, ease in processing, and ease in repair. An inherent disadvantage is the liability of an acrylic resin denture to break during service. The traditional method to increase denture strength involves the use of high strength resins or adding a cross-linking agent of poly-functional monomer such as polyethylene glycol dimethacrylate. Earlier attempts to use metal wires and metal plates

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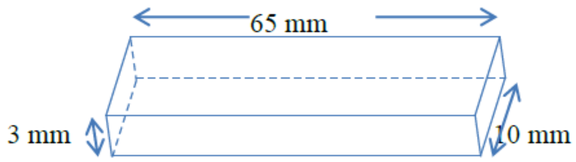

Fig 1: Figure of metal die used for fabrication of specimens.

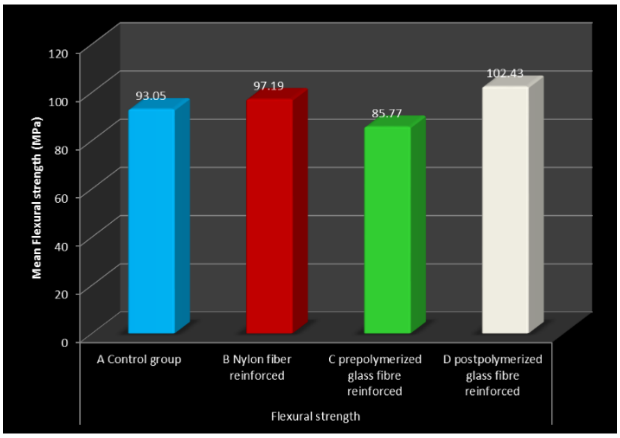

Fig 2: Showing comparison of mean flexural strength of specimens in four groups.

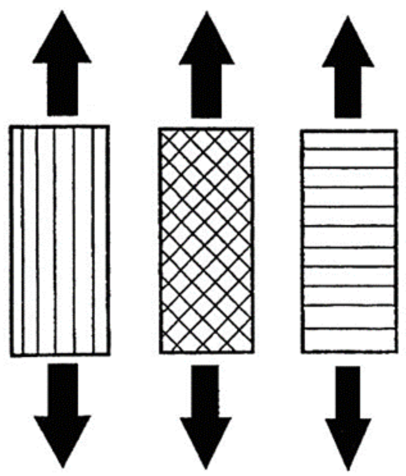

Fig 3: Showing effect of reinforcement (Krenchel`s factor) of unidirectional fibres in the direction of loading (left), bidirectional fibres (middle) and unidirectional fibres vertical in the direction of loading (right).

strengtheners are typified by the work of several researchers[2, 3, 4]. The development of fibrous composite materials in the industry has inspired a new approach to improve the performance of dental acrylic resins. The effect of glass fiber, carbon fiber, aramid fiber and metal wire reinforcement on the fracture resistance of denture base polymer was tested, and a beneficial effect of metal reinforcement was reported[4]. More recently, glass fibers or glass rods have been investigated for the reinforcement of denture base polymer. Although it is well documented that glass fiber reinforcements improve flexural strength of denture base resins, little information exists about the effects of prepolymerization and postpolymerization of preimpregnated glass fibers on this final property of reinforced acrylic resins and less is known about these same effects on comparing the reinforced denture base with nylon fibers. Therefore, the purpose of this study was to compare the effect of the pre- and postpolymerization of preimpregnated glass fiber reinforcements on the flexural strength and comparing the same property with that of nylon fiber reinforced denture base resin according to American Dental Association Specification (ADA) No.12-2002 and International Organization for Standardization, ISO 20795-1:2008.

MATERIALS AND METHODS

Test methods followed those of ISO/FDIS specification 20795-1:2008, which stipulates the use of 3-point bending. Materials used are summarized in Table 1. The moulds were prepared by the investment of 4 metal dies of dimensions 65mm × 10mm × 3mm, which were fabricated complying with ADA specification no. 12, in dental plaster within the flasks (Figure 1). A total of 60 specimens were fabricated for 4 groups of different acrylic resin reinforcements (1 control group and 3 test groups) each consisting of 15 specimens (Table 2). Polymer: Monomer ratio for each specimen was 2.4g: 1ml in all the groups. For polymerization, first the temperature was raised slowly to 73°C and maintained for half an hour and then raised to 100°C at which flasks were kept for another half an hour in a Hanau curing unit.

For group B consisting of nylon fiber reinforced acrylic resins, the amount of nylon fibers which were added in one specimen was 2% by weight of the polymer: monomer ratio. The nylon fibers were weighed on an analytical balance and were cut into 1 cm long pieces, after which they were mixed into the polymer powder in the

Table 1: Materials used

Material	Brand	Chemical composition	Manufacturer
Heat-polymerized acrylic resin	Trevalon denture material Universal denture liquid	Powder: PMMA and copolymer Liquid: MMA and cross-linking agent.	Dentsply India Pvt Ltd., Gurgoan, India.
Glass fiber reinforcement	everStickC&B	Silanated E-glass fibers prewetted and impregnated with polymer and light curing resin matrix.	Stick Tech Ltd., Turku, Finland.
Nylon fiber	*	Non-impregnated unidirectional nylon fibers	Gujarat Nylon Co., Gujlon, Kim, Gujarat, India.

* Manufacturer does not give brand name to nylon fibers.

Table 2: Specimen groups.

Group	Type of acrylic reinforcements
Group A	Control group- Unreinforced conventional heat-cured acrylic resin.
Group B	Heat-cured acrylic resin reinforced with Nylon fibres.
Group C	Heat-cured acrylic resin reinforced with prepolymerized preimpregnated unidirectional glass fibers.
Group D	Heat-cured acrylic resin reinforced with postpolymerized preimpregnated unidirectional glass fibers.

Table 3: Showing one-way analysis of variance for flexural strength in four groups.

GROUPS	MEAN	Std. DEVIATION	Std. ERROR	MINIMUM RANGE	MAXIMUM RANGE	P VALUE (significant if < 0.05)
A	93.05	8.66	2.235	79.67	108.14	0.013
B	97.19	11.43	2.951	68.89	111.15	
C	85.77	16.55	4.273	48.92	103.20	
D	102.43	16.63	4.294	68.36	128.11	

Table 4. Showing multiple comparisons of flexural strength results using Tukey HSD (Honestly significant difference) Post Hoc Test.

GROUP	VERSUS	GROUP	MEAN DIFFERENCE	Std. ERROR	P VALUE	95 % CONFIDENCE INTERVAL	
						LOWER BOUND	UPPER BOUND
A		B	-4.15	5.020	0.842	-17.44	9.15
A		C	7.27	5.020	0.475	-6.02	20.57
A		D	-9.38	5.020	0.253	-22.68	3.91
B		C	11.42	5.020	0.116	-1.87	24.71
B		D	-5.24	5.020	0.725	-18.53	8.05
C		D	-16.66	5.020	0.008	-29.95	-3.36

porcelain jar and then monomer was added. The entire mixture was properly kneaded at dough stage, packed into the mold cavity and polymerization was completed. Deflasking was done after bench cooling the flasks to room temperature.

For group C consisting of prepolymerized preimpregnated glass fiber reinforced acrylic resins, the fibers were placed in the center of the acrylic resin specimens by packing the acrylic mixture in two equal halves in the mold cavity of both the base and the counterparts of the flask separately. The fiber bundle were spread wider using a suitable instrument after which they were light cured for 5 to 10 sec per region of fiber. The flask was then carefully closed and the polymerization process was carried on.

Group D specimens consisting of postpolymerized glass fiber reinforcements were fabricated with the same technique as group C, except that the fibers were not light cured during their placement in the acrylic resin. After the retrieval of the samples, the light curing of the samples was done so as to polymerize the fibres and thereby allowing their bonding to the polymer matrix. After deflasking, if the specimens revealed exposed fibers at the periphery, trimming was performed with diamond burs to avoid delamination. All the specimens were measured with a vernier caliper. These specimens were then tested for flexural strength on a Universal testing machine.

Mechanical testing of the prepared specimens

The specimens were placed on jigs that were 50 mm apart (L) and tested for flexural strength with a three-point bending test in a Universal Testing Machine (Instron 3382) at a crosshead speed of 2 mm/min. They were then loaded at the center until fracture occurred. The maximum load required to fracture each specimen was recorded. The fracture load of each specimen was converted to flexural strength (σ) using the following mathematical formulae:

$$\sigma_f = \frac{3 \times F \times L}{2 \times b \times h^2}$$

Where σ_f = Flexural strength (MPa)
F = Maximum load applied (N)
L = Span between two supports (mm)
b = Width of the specimen (mm)
h = Thickness of the specimen (mm)

All the readings were subjected to statistical analysis using statistical software SPSS PC+ to finalize the result. Mean, standard deviation and standard error were estimated from the sample for each study group. One-way analysis of Variance (ANOVA) was conducted on the flexural strength, followed by Tukey HSD (honestly significant difference) post hoc comparisons (α = 0.05). All statistical analyses were performed at a confidence level of 95%. In the present study, $p \le 0.05$ was considered as the level of significance.

RESULTS

The flexural strength of the unreinforced and reinforced acrylic resins was determined by three-point bending test. A graphical depiction of mean flexural strength of four groups is presented in Figure 2. The 1-way ANOVA results for flexural strength are presented in Table 3. Significant differences were found for acrylic resin reinforcement type (P<.001). After significant effects were detected, the Tukey HSD post hoc test was used and found a statistical significant difference among the groups at the 95 % confidence level (Table 4).

Nylon fiber (97.19 MPa) as well as post polymerized glass fiber (102.43 MPa) reinforcements increased flexural strength significantly, as compared to control group. Prepolymerization of the glass fiber reinforcements (85.77 MPa) decreased the flexural strength of heat polymerized acrylic resins. All the results were statistically significant. In all groups, specimens reinforced with post polymerized glass fibers showed the highest flexural strength, followed by nylon fibers. The prepolymerized glass fiber reinforcements exhibited the lowest values in compared to control group specimens without reinforcements.

DISCUSSION

The present study has compared the flexural strength of conventional polymethyl methacrylate resin and the same reinforced with pre and post polymerized preimpregnated glass fibers and that with nylon fibers. The Novel glass fiber reinforcement system (everStickC&B) tested in this study is based on the preimpregnated fibers with cross-linked and linear polymer mixture. The fibre reinforcement is made from unidirectional glass fibres and a polymer/resin gel matrix. In the present study, everStickC&B glass fibers were cut to a length of 65 mm, width of 10 mm and thickness of 3 mm to confine them in the specimens of standard dimensions (65mm length, 10 mm width and 3 mm thickness according to the ADA specification no. 12), which is in consensus with a study carried out by Bertassoni LE et al who used Fibrex-lab glass fiber reinforcements[5].

Nylon is a type of thermoplastic polymer belonging to the class known as polyamides. Polyamides contain the amide group - CONH – spaced at intervals in carbon chain. The outstanding features of nylon are toughness, low density, abrasion resistance, high melting point, high strength coupled with ductility and resistance to chemical attack[6]. The quantity of nylon fibers used in this study is 2% by weight of the polymer-monomer mixture used for each specimen[7]. As already mentioned, proper impregnation of fibers is necessary to achieve bonding with the polymer matrix.

Apart from the proper impregnation of reinforcing fibers with the polymer matrix, other factors that relate to the strength of fiber composites are:

1) Quantity of fibres in the polymer matrix.
2) Adhesion of fibers to the polymer matrix.
3) Orientation of fibres.

It has been demonstrated that an increase in the quantity of fibers in the acrylic resin polymer matrix enhances the transverse and impact strength of the test specimen made from denture base polymers[8]. As evidenced from the past literature, in order to achieve adequate adhesion and bonding of glass fibres to the polymer matrix, use of silane coupling agent such as γ-methacryloxypropyl trimethoxysilane (γ-MPS) or resin having characteristics similar to those used for commercial composite resin restorative materials, is necessary to treat the glass fibers. The glass fiber reinforcement everStickC&B tested in this study have been already wetted with light curing matrix by the manufacturer and consists of cross-linked and linear polymer mixture. The polymer/resin gel holds the individual glass fibres in a bundle, the reason why single fibers inside the bundle do not spread during the use; which facilitates handling of the fibre bundle. Also, these polymerized fibres contain an Interpenetrating polymer network structure, which can be reactivated with resin. This reactivation dissolves linear polymers and forms new chemical bonds improving micromechanical retention when resin penetrates deeper into the fibre matrix. As a result of this, the adhesion between fibres and acrylic resin is improved. Unlike glass fibers, preimpregnated nylon fibers are not available commercially. Therefore, in the present study, nylon fibers were wetted in methyl methacrylate monomer for 10 mins to ensure proper bonding with acrylic resin[9, 10].

Orientation of fibers in the polymer matrix also influences the mechanical properties of the fiber composites. The fibers oriented perpendicular to the direction of applied forces offer the greatest potential for improvement of flexural fatigue and bending properties of denture base resins[11]. The efficiency of woven bidirectional fiber reinforcement is one-half (½) in contrast to the unidirectional fiber reinforcement, which has the reinforcing efficiency of one (1). This theoretical estimate of the effectiveness of fiber reinforcement is known as Krenchel's factor[8] (Figure 3). In this study, unidirectional glass fibers had been placed perpendicular to the direction of applied forces i.e. parallel to the long axis of the specimen. The monomer wetted nylon fibers were cut into 1 cm long pieces and which were then added to polymer powder, after which monomer was added to ensure easy manipulation and packing of the mixture in dough stage in the mold cavity. The nylon fibers were therefore randomly oriented in the acrylic resin specimen.

The results obtained in this study with everStickC&B glass fibre reinforcements can be seen in Tables 3 and 4; and figure 2. It shows that post polymerized glass fiber reinforcements considerably improved the flexural strength of acrylic resin. Also, prepolymerized glass fiber reinforcements lead to decrease in flexural strength. It was initially hypothesized that in postpolymerized glass fibers, structural damage occurs due to interaction of polymerizing acrylic resin mixture and the unpolymerized impregnating resin in the reinforcements that were subsequently postpolymerized. The experimental results showed that this was not valid. It, however, proved that postpolymerization of the impregnated reinforcements provided increased flexural strength by allowing the formation of an effective graded interface between the reinforcement and the acrylic resin[5].

In the present study, as can be seen in figure 2, flexural strength of acrylic resin increased following reinforcement with nylon fibers. Jacob et al also reported an increase in flexural strength of acrylic resin following use of nylon as a reinforcing fiber[12]. The chief advantage of nylon lies in its resistance to shock and repeated stressing, but, however, water absorption affects the mechanical properties of nylon. This feature was not accessed in this in vitro study. Kelly et al showed that nylon fibers acted as foreign bodies and decreased the fatigue resistance of acrylic resin[13].

CONCLUSION

The present study was carried out to assess the flexural strength of heat-cured denture base acrylic resin material following reinforcement with fibers. Flexural strength of commercially available conventional heat-cured acrylic resin was compared with those of heat-cured acrylic resin reinforced with prepolymerized and postpolymerized glass fibers and nylon fibers. Within the limitations of this study, results showed differences in flexural strengths of different fiber reinforcement of acrylic resin. The postpolymerized glass fiber reinforcements exhibited significantly higher mean flexural strength, followed by nylon fiber reinforcements. On the contrary, prepolymerized fiber reinforcements exhibited lower flexural strength than unreinforced acrylic resins. Nylon fibre reinforcements marginally increased the flexural strength and flexural modulus; and also improved toughness of acrylic resin.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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