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Evaluation of the transverse strength of denture base resin repaired with glass fibre reinforced heat polymerizing and auto polymerizing acrylic resins – An in vitro study

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Abstract

Statement of Problem: Fracture of an acrylic denture base is a common complaint with patients in prosthodontic practice. When the denture base is repaired with auto polymerizing resin recurrent fracture tends to occur at the repaired interface or adjacent areas. In order to overcome this problem,glass fibres can be used as reinforcement into heat cure and self cure acrylic resin, to increase the transverse strength of the denture base at the fractured site.

Aim: The aim of this study is to evaluate and compare the transverse strength of S-glass fiber reinforced acrylic resins at the repaired site.

Methodology: Seven different groups of samples were used in this study. Total no. of samples-70,No. of samples per group – 10: Group A (Control group) Unrepaired Heat polymerized denture base resin Group B Specimens repaired with heat polymerizing acrylic resin Group C Specimens repaired with auto polymerizing acrylic resin GROUP D specimens repaired with 2.5% S-glass fiber

reinforced heat polymerizing acrylic resin. GROUP E specimens repaired with 2.5% S- glass fiber reinforced auto polymerizing acrylic resin GROUP F specimens repaired with silane treated 2.5% S- glass fibre reinforced heat polymerizing acrylic resin GROUP G –10 specimens repaired with silane treated 2.5% S- glass fiber reinforced auto polymerizing acrylic resin. The prepared samples were stored in distilled water in a incubator at 37ºc for 24hours, the transverse strength of the specimens was measured using a three-point bending test. One WAY ANOVA and student t test were performed to identify significant differences ($P < 0.05$).

Results

The test results showed that there was significant difference in transverse strength present between control and repair groups. The intact heat polymerized acrylic resin specimens (Group- A) showed statistically superior transverse strength. In the repair groups the silanated glass fibre reinforced heat polymerized acrylic resin (Group F) showed the highest transverse strength. The lowest transverse strength was obtained for the group (C) specimens, repaired with auto polymerized acrylic resin.

Conclusion

The silanated glass fibre reinforced heat polymerized acrylic resin can be used as a repair material to repair the heat polymerized acrylic denture base.

Keywords: Transverse strength, glass fibre, denture base repair, chemical surface treatment, silane coupling agent.

Introduction

The most common problem encountered in complete denture prosthodontics is the fracture of the acrylic denture base resin. The occurrence of fracture of the prosthesis may be accidental due to an impact outside the mouth or it may be due to fracture while in service inside the mouth. The latter type of fracture is generally due to the fatigue failure caused by repeated flexural load over a period of time[1].

The most commonly used denture base repair materials include auto polymerized acrylic resin, heat polymerized acrylic resin, visible light polymerized resin or a microwave polymerized acrylic resin. Most of the denture base repairs (86%) are made with auto polymerized acrylic resin, because it is easy to manipulate and can be used chair side, but it has an insufficient transverse strength and soft tissue irritation due to its monomers. Denture base repairs are also made with heat polymerized acrylic resin; it has good transverse strength, better color stability and better esthetics[2].

Glass fibres are one of the most commonly used reinforcement material because of their higher transverse Strength, flexural modulus, fatigue strength and impact strength. They also provide better esthetics and do not alter the color of the denture base resin. Glass fibres treated with silane are preferred to provide a better adhesion to the polymer matrix (by increasing the surface energy), and improve its mechanical properties[3]. Glass fibers can be used in either Loose, continuous or woven form. The most commonly used glass fibers are S (Structural grade) and E (Electrical grade).When both S and E glass fibres were compared, the S glass fibres showed good transverse strength, better esthetics and were economical[4].

Thus, the aim of this study is to evaluate the transverse strength of denture base resin repaired with S glass fibre reinforced heat polymerizing and auto polymerizing acrylic resins.

Materials and Methods

Two different types of stainless steel dies were used to make the test specimens (heat polymerized acrylic resin), for investigating their transverse strength. The first die of dimension 65X10X2.5mm (Length X width X thickness)

was used (AS Per ADA Specification No.12),for fabricating the control specimens and for preparation of the mould space for the specimens which had to be repaired[2](FIG NO:1). For the purpose of standardizing the space for the repair material, split dies with a 45° bevel were prepared for the specimens to be repaired. Thereby the following modifications were done in the second stainless steel dies, which were each 32mm long at the bottom surface and 29.5mm at the top surface (which created a 45° bevel, when assembled) and 10.0mm broad and 2.5mm thick (FIG NO:2). When the two parts of the split dies were assembled in the mould space created by investing the first die, there was a 1 mm space at the bottom and 6 mm space on the top, which would be filled by the respective repair materials(FIG NO:3)[5]. The specimens were categorized into seven groups of 10 each: Group A(Control group)-Unrepaired Heat polymerized denture base resin, Group B (Specimens repaired with heat polymerizing acrylic resin),Group-C(Specimens repaired with auto polymerizing acrylic resin),GROUP D(Specimens repaired with 2.5% S-glass fiber reinforced heat polymerizing acrylic resin),GROUP-E(Specimens repaired with 2.5% S- glass fiber reinforced auto polymerizing acrylic resin),GROUP F –(Specimens repaired with silane treated 2.5% S- glass fibre reinforced heat polymerizing acrylic resin),GROUP- G(Specimens repaired with silane treated 2.5% S- glass fiber reinforced auto polymerizing acrylic resin).

Fabrication of Unfractured Heat Polymerizing Acrylic Resin Samples: (Control Group-A)

The stainless steel dies of dimension 65X10X2.5mm (Length X width X thickness) were coated with a thin layer of petroleum jelly and were invested in dental flasks with dental plaster (Type I), in the lower half of the flask taking care that one half of the thickness was embedded in the plaster put in base of the flask. Care was taken so that the dies were placed with sufficient distance between them and also from the walls of the flask. The counter part of the flask was then assembled and another mix of dental plaster was poured to complete the flasking.

After 30 minutes, the flasks were opened and the preformed metal dies were retrieved from the dental plaster. The moulds thus obtained were used for the preparation of the acrylic resin test samples(FIG No: 4). Separating medium (cold mould seal, Dental Product India) was applied on exposed dental plaster surfaces. From a pilot study, it was found that the weight of the polymethyl methacrylate for the fabrication of one intact (control) specimen was about 4gms of powder and 3.5ml of liquid which was taken and mixed in a ceramic pot. The mixed resin was left in the mixing pot until it reached the dough stage, then the mix was kneaded thoroughly to make a homogeneous dough. The dough was then packed into the mould, trial closure was performed and excess flash was removed and final closure was done under a bench press at 40,000 N^2.

After the final closure, the flask was left in the clamp for bench curing for 30 minutes at room temperature. The flask was immersed in water bath acrylizer with automatic controls at room temperature. The temperature was slowly raised from room temperature to 74ºC for 2 hours followed by 100ºC for 1 hour (short curing cycle)[6].

After the curing was completed, the flask was removed from the water bath and left for bench cooling. Once the flask was cooled, the samples were retrieved from the flask and necessary finishing was done with 120 grit sand papers (FIG NO-5).Minimum finishing was required to remove excess flash and care was taken to maintain low heat during the trimming procedure.The dimensions of the specimens were measured with the use of a digital vernier caliper.

Fabrication of Heat Polymerizing Acrylic Resin Strips: (Repair Groups)

The study required 120 bevel shaped edge profile heat polymerizing acrylic resin strips for the fabrication of 60 repair specimens. The split dies of dimension :32mm length at the bottom surface and 29.5mm at the top surface (with a 45° bevel) and10.0mm length and 2.5mm thickness were coated with a thin layer of petroleum jelly and were invested in dental flasks with dental plaster (Type I) in the lower half of flask taking care that one half of the thickness was embedded in the plaster put in the base of the flask[2](FIG NO 6). The remaining procedure for the fabrication of these strips was the same as the procedure carried out for the fabrication of unfractured heat polymerizing acrylic resin samples (Control group).

Preparation of the Heat Polymerized Acrylic Resin Strips for the Repair Groups

The mould cavity of dimension (65X10X2.5mm) length X breadth X thickness (AS Per ADA Specification No.12) in the dental flask were coated with a thin layer of petroleum jelly, to aid in easy removal of the repaired heat polymerizing acrylic resin samples. The split heat polymerized, beveled end of each strip was considered as repair site, which was wetted with the auto polymerizing monomer for about 3 minutes[7].The two split, surface treated heat polymerized acrylic resin strips were placed at the two ends of the mould cavity (65X10X2.5mm) length X breadth X thickness with the repair sites facing each other, and maintaining a gap of 1mm at the base and 6mm at top. This gap was maintained constant for all the samples(repair groups) and was stabilized with a drop of cynoacrylate[5].

A) Repair of bevel shaped edge profile heat polymerizing acrylic resin strips using heat polymerizing acrylic resin:(Group -B)

After preparing the 20 bevel shaped edge profile heat polymerizing acrylic resin strips for the repair group. Heat polymerizing acrylic resin (repair material) consisting of 1.25gms of powder and 1.3ml of liquid was mixed in the ceramic pot. When the dough stage was reached, the material was packed into the space present between two heat polymerizing acrylic resin strips, positioned in the mould spaces of the Flask with repair sites facing each other[2].(FIG NO 7)

Trial closure was performed and excess flash was removed. Final closure was done under a bench press and it was kept under pressure (in bench press) for 2 hours to ensure complete polymerization. The flask was immersed in water bath acrylizer with automatic controls at room temperature. The temperature was slowly raised from room temperature to 74ºC for 2 hours followed by 100ºC for 1 hour (short curing cycle)[6].

After the curing was completed, the flask was removed from the water bath and left for bench cooling. Once the flask was cooled, the samples were retrieved from the flask and necessary finishing was done with 120 grit sand papers.

B) Repair of bevel shaped edge profile heat polymerizing acrylic resin strips, using auto polymerizing acrylic resin (Group-C)

After preparing the 20 bevel shaped edge profile heat polymerizing acrylic resin strips for the repair group. Auto polymerizing acrylic resin consisting of 1.25gms of powder and 1.3ml of liquid was mixed in the ceramic pot. When the dough stage was reached, the material was packed into the space present between two heat polymerizing acrylic resin strips, positioned in the mould spaces of the Flask with repair sites facing each other.(FIG NO: 8) Trial closure was performed and excess flash was removed. Final closure was done under a bench press and it was kept under pressure (in bench press) for 2 hours to ensure complete polymerization. After this the flask was

opened to retrieve the repaired bevel shaped edge profile heat polymerizing acrylic resin samples and necessary finishing was done with 120 grit sand papers.

Estimation of weight of heat polymerizing poly methyl methacrylate and auto polymerizing poly methyl methacrylate

From a pilot study, it was found that the weight of the polymethyl methacrylate for the fabrication of one intact (control) specimen was about 4gms of powder and 3.5ml of liquid. The weight of the polymethyl methacrylate (Heat polymerizing and auto polymerizing acrylic resin) for repairing one repair specimen was about 1.25gms of powder and 1.3ml of liquid. The weight of the polymethyl methacrylate (Heat polymerizing and auto polymerizing acrylic resin) for the reinforcement groups was about 1gm of powder and 1.3ml of liquid.

Repair of bevel shaped edge profile heat polymerizing acrylic resin strips; using 2.5% s-glass fibre reinforced heat polymerizing acrylic resin. (Group-D)

The 20 beveled ends of each strip were considered as repair site, which were wetted with the auto polymerizing monomer for about 3 minutes, in a dappen dish. Glass fibres were cut into 2mm (approx) segments and weighed to 6.25mgs, were added to the preweighed heat polymerized acrylic resin powder (1gm) and thoroughly mixed using a motar and a pestle to achieve an equal distribution of glass fibres and to obtain a homogenous mixture[6]. The homogenous mixture was then transferred to the ceramic pot along with the measured monomer (liquid-1.3ml) and mixed thoroughly. When the dough stage was reached, the material was packed into the repair space and the remaining procedure was followed in the same manner as for group B specimens.

Repair of bevel shaped edge profile heat polymerizing acrylic resin strips; using 2.5% s-glass fibre reinforced auto polymerizing acrylic resin. (Group-E)

The 20 beveled ends of each strip were considered as repair site, which were wetted with the auto polymerizing monomer for about 3 minutes, in a dappen dish. Glass fibres were cut into 2mm (approx) segments and weighed to 6.25mgs, were added to the preweighed Auto polymerized acrylic resin powder (1gm) and thoroughly mixed using a motar and a pestle to achieve an equal distribution of glass fibres and to obtain a homogenous mixture. The homogenous mixture was then transferred to the ceramic pot along with the measured monomer (liquid-1.3ml) and mixed thoroughly. When the dough stage was reached, the material was packed into the repair space and the remaining procedure was followed in the same manner as for group C specimens.

Repair Of Bevel Shaped Edge Profile Heat Polymerizing Acrylic Resin Strips, Using Silane Treated 2.5% S- Glass Fibre Reinforced Heat Polymerizing Acrylic Resin (Group-F)

Specimens for this group was prepared in the same manner as of group D, except that the S-glass fibres were soaked in a silane coupling agent for 5 minutes in a dappen dish and allowed to air dry,before incorporation with Heat Polymerizing Acrylic Resin powder[7].

Repair Of Bevel Shaped Edge Profile Heat Polymerizing Acrylic Resin Strips, Using Silane Treated 2.5% S- Glass Fibre Reinforced Auto Polymerizing Acrylic Resin (Group-G)

Specimens for this group were prepared in the same manner as of group E, except that the S-glass fibres were soaked in a silane coupling agent for 5 minutes in a dappen dish and allowed to air dry, before incorporation with Auto Polymerizing Acrylic Resin powder[7].

All the above fabricated specimens(ref fig 9 and 10) were then placed in distilled water and incubated at 37ºC for 24 hrs and then were subjected to testing[8].

Three Point Bending Test

Specimens were positioned on a 3-point bending flexural strength testing apparatus with two supports 20 mm apart, and tested at a crosshead speed of 2mm/min[9](FIG NO:11). The load at fracture was recorded in Newtons (N) and Flexural strength (FS) was calculated in Mpa,with the following equation[2]**:**

$FS=3PL/2bd^2$,

Where,

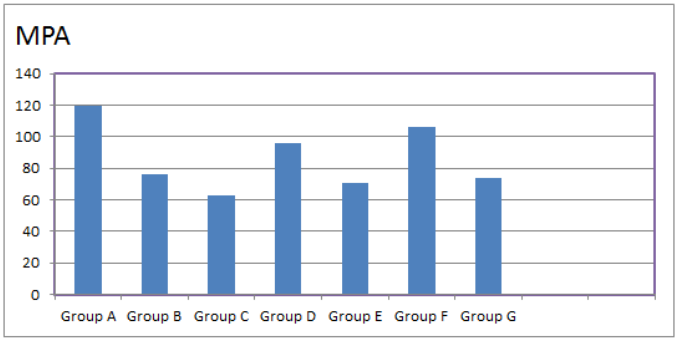
P is the maximum load at fracture in newtons, L is the distance between the supports (20 mm), b is the width of the specimen in mm (10mm) and d is the height of the specimen in mm (2.5mm).

Results

Totally seven groups were included in the study, to compare the mean and standard deviation of transverse strength, One way ANOVA test was used because of the presence of more than two groups. The confidence interval was set at 95%. If p values were < 0.05, a significant difference was considered to be present in the transverse strength between the groups. If p values were >0.05, then the difference in transverse strength between the groups was considered insignificant.

Table 1: the descriptive values of transverse strength of all tested groups (a, b, c, d, e, f and g)

Groups	N	Mean	Std. Deviation	Std. Error
A	10	119.7000	14.02419	4.43484
B	10	76.0200	43.58139	13.78164
C	10	63.0000	16.97711	5.36863
D	10	96.2000	32.90998	10.40705
E	10	70.6000	20.61391	6.51869
F	10	106.1000	26.89672	8.50549
G	10	74.0000	18.27567	5.77927
Total	70	86.5171	32.09210	3.83574



Graph 1: Comparison of mean values of transverse strength (Mpa) for all tested groups (A, B, C, D, E, F and G).

The Control group (group A) showed the highest mean transverse strength as 120Mpa, followed by the repair Groups, (Group F) silane treated fibre reinforced heat polymerizing acrylic resin, (Group D) S- glass fibre reinforced with heat polymerizing acrylic resin, (Group B) Heat polymerizing acrylic resin, (Group G) silane treated fibre reinforced auto polymerizing acrylic resin, (Group E) (Group C) Auto polymerizing glass fibre reinforced auto polymerizing acrylic resin, and g acrylic resin, which showed the lowest mean transverse strength.

Table 2: One Way –Anova for Transverse Strength

	Sum of squares	DF	Mean square	F	Sig.
Between Groups	26516.283	6	4419.381	6.250	.000
Within Groups	44547.036	63	707.096		
Total	71063.319	69			

In this study, since the p value of the groups were <0.05 (p=.000), it showed that there was a highly significant difference present between the groups.

A Paired t-test was performed to find significant differences among the Groups (Table 3).

The mean difference is significant at the 0.05 level and if it is greater than 0.05 was considered as non-significant.

Table 3: Intergroup comparison (Paired t-test)

Intergroup	P value
B vs C	<0.0012;significant
D vs E	<0.000;significant
F vs G	<0.000;significant
B vs D	<0.000; significant
C vs E	<0.023;significant
D vs F	<0.000; significant
E vs G	<0.043; significant
B vs F	<0.000; significant
C vs G	<0.015; significant

Since the p value of the intergroups were <0.05 (p=.000), it showed that there was a highly significant difference present between the groups.

Scanning Electron Microscopic Analysis

Samples that showed the highest and least transverse strength values from each group were selected and analyzed with a scanning electron microscope. The samples were fixed on metal stubs and placed on the chamber provided for it in the sputtering device (QUORUM- Q150R S). Under vacuum, the specimens were then sputtered with gold. The surfaces of the samples were analyzed by Sem (Zeiss Oxford Instruments (X-ACT) focusing on the surface characteristics, presence of voids, bonding and uniformity along the interfaces between glass fibre reinforcement material and the resin matrix. Samples were examined under magnification varying from ×97 to ×6210. The unit was operated at EHT =10kv, WD= 10.7mm.(Fig no:12-25).

Discussion

The fracture of acrylic resin dentures is an unresolved problem in prosthodontics. Although literature reveals that various materials such as auto polymerizing acrylic resin, heat-polymerized acrylic resin, visible light-polymerized resin, and microwave polymerized acrylic resin are being used since ages, selection of an appropriate one seems to be challenging[2].

In this study, heat polymerizing acrylic resin and auto polymerizing acrylic resin was used as a repair material. However, owing to its inadequate transverse strength, this resin can cause refracture at the repaired site. The transverse strength can be enhanced by the incorporation of various reinforcement materials and surface treatments, to eliminate further fracture of the prosthesis and aspiration or ingestion of its fragments[10].

Effect of Glass Fibre Reinforcement on PMMA:

Reinforcement of the acrylic resin, with various fibres (glass fibre, carbon fibre, aramid fibre etc), has shown to increase the fracture resistance of the resin. Acrylic resins reinforced with glass fibres have shown maximum fracture resistance as compared with aramid fibres and carbon fibres. Also, glass fibres do not alter the color of repaired resin, so they can be used in visible locations[2].Therefore, in the present study; S-glass fibres were used as a reinforcement material.

Glass Fibre and Its Form

Glass fibre can be incorporated in chopped, longitudinal and woven form. Longitudinally incorporated fibres may change their position with the applied pressure when the mould is placed in a hydraulic press and in case it is incorporated in the woven form (resembles cloth); its contact with acrylic is problematic. Since both the above mentioned drawbacks are not encountered in the chopped

form, this form was employed in this study according to the study conducted by Quassem AM et al[11]. Since unidirectional fibres enhance the strength only in one direction, this study used randomly oriented fibres which improved the mechanical properties in all directions[11].

Assessment of Fibre Length and Fibre Volume Proportions

A minimum length or critical length of the fibre will be needed for transferring the stress from the resin matrix to the fibre. This critical length should be at least 50 times equal to or greater than the diameter of the fibre. Thus, in this study, for S glass fibre reinforced groups, the fibres were cut into approximately 2mm length (according to the aspect ratio) used randomly in loose form at the repair site, considering the diameter and length of the glass fibre[2].

Gutteridge et al in his study found that the effect of fibre content on the strength of the resin and reported that, any increase in glass fibre, concentration beyond 3% provided no beneficial effect. Ozlem et al found that addition of 2.5 vol% glass fibre, resulted in superior transverse strength. In this study 2.5% (6.25mgs of glass fibers were used for the reinforcement groups (D, E, F and G) Using the mathematical formula Mass = Density X Volume ,it was found that 2.5% wt of glass fibre would comprise of 6.25 mgs of glass fibre and it was measured using a digital Weighing machine.

Estimation of weight of poly methyl methacrylate (Heat polymerizing and auto polymerizing acrylic resin)

From a pilot study, it was found that the weight of the polymethyl methacrylate for the fabrication of one intact (control) specimen was about 4gms of powder and 3.5ml of liquid. The weight of the polymethyl methacrylate for repairing one repair specimen was about 1.25gms of powder and 1.3ml of liquid. The weight of the polymethyl methacrylate for repairing one reinforced repair specimen was about 1gms of powder and 1.3ml of liquid.

Surface Treatment for S-Glass Fibers

Adequate adhesion of the fibres to the resin matrix is the most important variable for the strength of the polymethyl methacrylate, so that stresses can be transferred from resin matrix to the fibres[7]. Nayana Anasane et al found that when the Glass fibers were soaked in a silane coupling agent for 5 minutes and allowed to air dry for 20 mins, it resulted in significant improvement in their transverse and impact strength[7]. In this in vitro study, The non impregnated S-glass fibres 2mm in length (Approx), were soaked in a Silane coupling agent for 5min to improve their bond to resin matrix and were allowed to dry in the air for 20min before they were incorporated in the repair resin for the repair groups (Groups F and G).

Surface Design of the Repair Site

The type of joint used is one of the important factors which will determine the repair strength. Ward et al in his study found that, the geometry of a 45° bevel increased the interfacial bond area between the bonding of repair and parent material and shifted the interfacial stress pattern more toward a shear stress and away from the more damaging tensile stress[12]. In this invitro study all the repair groups were provided with the geometry of 45° bevel to increase the interfacial bond area for all the repair groups (B, C, D, E, F and G).

Mixing Of Powder and Glass Fibre (For Groups D, E, F, G)

The preweighed powder (1gms of powder as obtained from the pilot study and glass fibre 2.5% (6.25mgs of fibre as calculated according to the formula, Mass = Density X Volume) were incorporated into a motar and a pestle which was used to mix them to obtain a homogenous mixture, with no clumps[13]. The homogenous mixture was then transferred to the porcelain jar with the premeasured

monomer (1.3ml of liquid obtained from the pilot study) and thoroughly mixed, when the dough stage was reached the material was packed into the mould cavity.

Surface Treatment of the Repair Site with Monomer

The present study found that the bonding was increased with the chemical surface treatment which may be because the monomers from the repair material may form a penetrating network across the interface onto the parts to be joined[6]. On the contrary, Shen et al. reported that monomer was not a powerful solvent for polymethyl methacrylate (PMMA) and would therefore not remove the debris efficiently[14].

Curing Cycle for The Fabrication of The Test Samples

H Mahajan et al, in his study used the short curing cycle for the fabrication of the specimens, which showed superior transverse strength[15].Therefore In this study a short curing cycle was followed, the flasks were immersed in a thermostatically controlled acrylizer at 74°C for 2 hrs and then the Temperature of water bath was raised to 100°C and processing was carried out for 1 hour[7].

Storage Medium and Storage Time

Fonseca et al in his study used distilled water as storage medium and maintained the prepared specimens at 37°C for 24 hrs before testing which was done for complete elimination of residual monomer, prior to testing[8]. In this in vitro study, the prepared specimens were stored in distilled water at 37°C for a period of 24 hrs in an incubator, prior to testing.

Summary and Conclusion

Within the limitations of the study it was concluded that,

1. The intact heat polymerized acrylic resin specimens (Control-group A) showed statistically superior transverse strength.
2. The silanated glass fibre reinforced heat polymerized acrylic resin (Group F) showed statistically superior transverse strength when compared with silanated glass fibre reinforced auto polymerized acrylic resin (Group G).
3. The glass fibre reinforced heat polymerized acrylic resin(Group D) showed improved transverse strength when compared with glass fibre reinforced auto polymerized acrylic resin (Group E).
4. The silanated glass fibre reinforced heat polymerized acrylic resin (Group F) showed improved transverse strength when compared with glass fibre reinforced heat polymerized acrylic resin (Group D).
5. The silanated glass fibre reinforced auto polymerized acrylic resin (Group G) exhibited improved strength when compared with glass fibre reinforced auto polymerized acrylic resin(Group E).

From these results it can be concluded that silanated glass fibre reinforced heat polymerized acrylic resin can be used as a repair material to repair the heat polymerized acrylic resin.

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Legend Figures

Fig.1: Metal Die

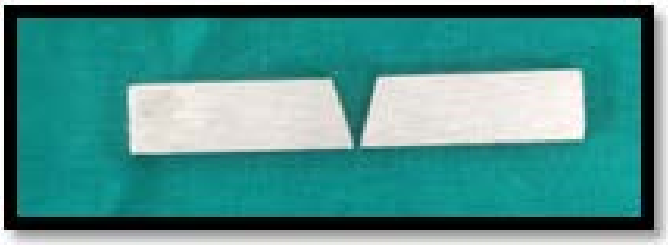

Fig. 2: Split Dies

Fig. 3:Split heat polymerized acrylic strips for the repair groups.

Fig. 4: Mould cavity

Fig. 5: Unfractured heat polymerizing acrylic resin samples

Fig. 6:Split mould cavity for the repair groups

Fig. 7: Repair with heat polymerized acrylic resin

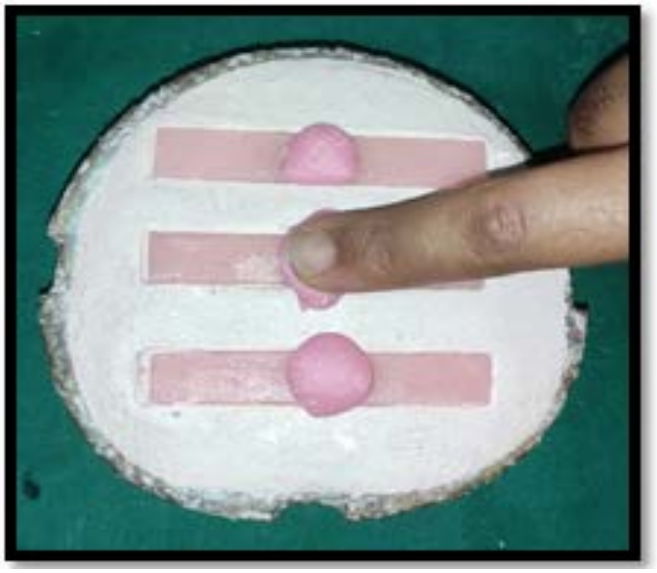

Fig. 8: Repair with Auto polymerized acrylic resin

Fig. 9: Group A,B and C Specimens

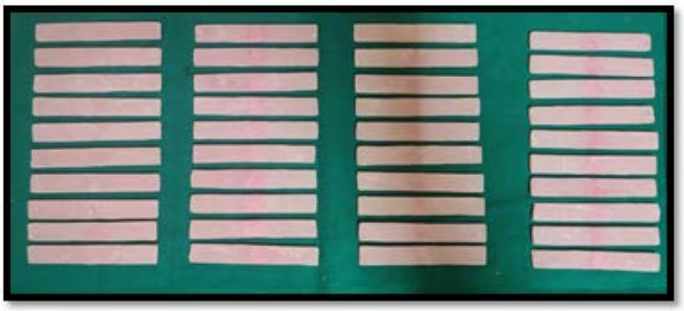

Fig.10: 10: Group D,E,F And G Group Specimens

Fig. 11: Specimen subjected for 3 point bending test

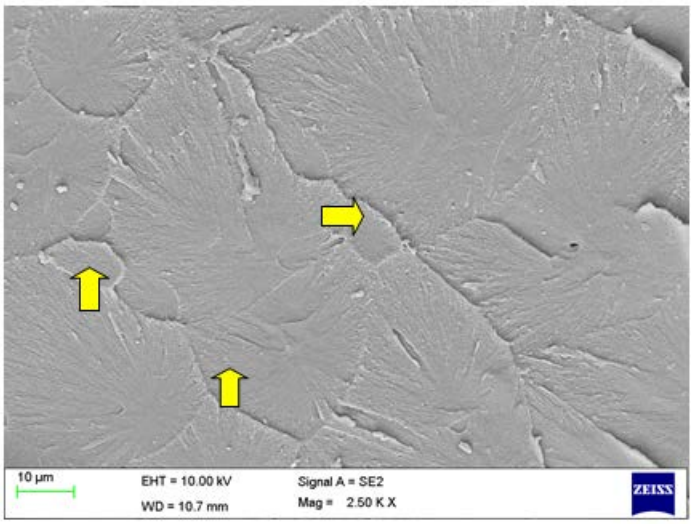

Fig. 12: Fractured surface of specimen (Group A) with the highest transverse strength (148 Mpa). Yellow arrow indicates homogenicity of resin surface.

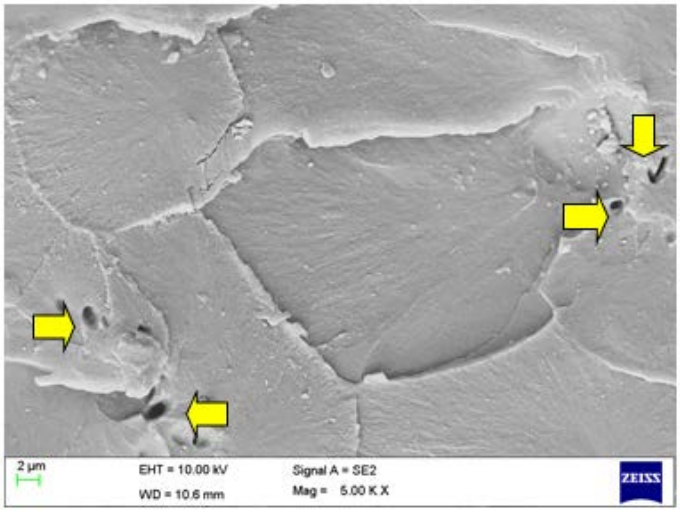

Fig. 13: Fractured surface of specimen (Group A) with the lowest transverse strength (102Mpa). yellow arrow indicates presence of voids on the surface of specimen.

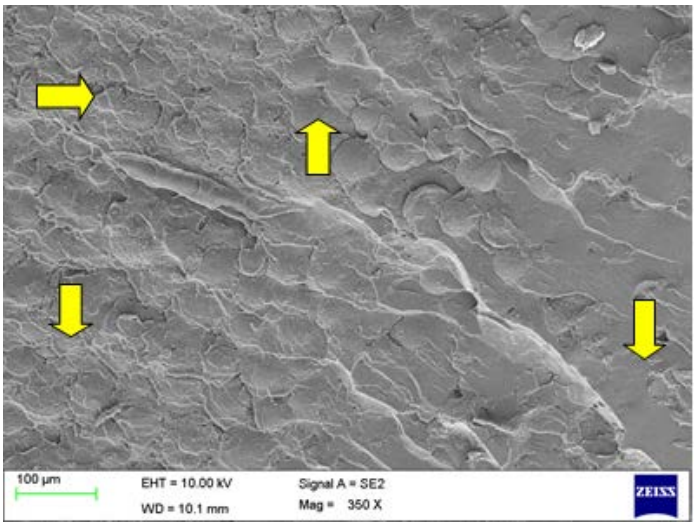

Fig. 14: Fractured surface of specimen (Group B) with the Highest transverse strength (136Mpa). yellow arrow indicates homogenicity on the repair resin surface

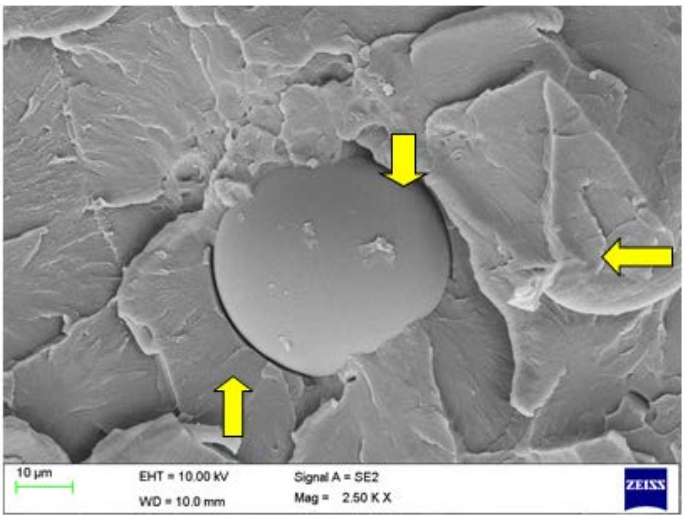

Fig. 15: Fractured surface of specimen (Group B) with the lowest transverse strength (21 Mpa). Yellow arrow indicates irregularity on the repair resin surface and the presence of a large defect.

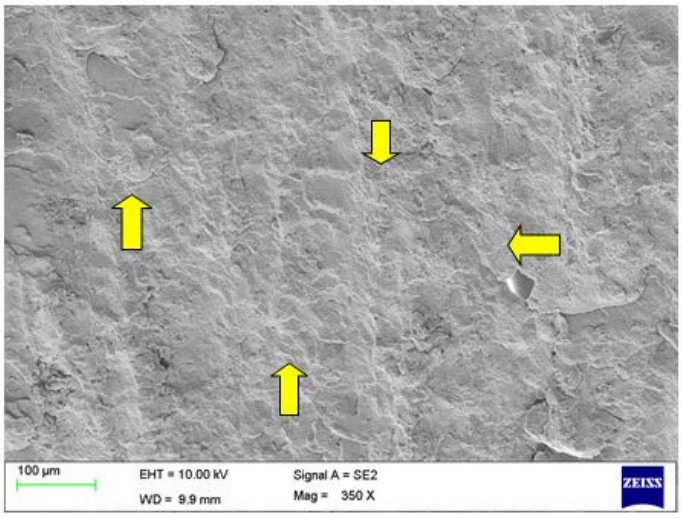

Fig .16 : Fractured surface of specimen (Group C) with the highest transverse strength (88Mpa). yellow arrow indicates homogenicity on the repair resin surface.

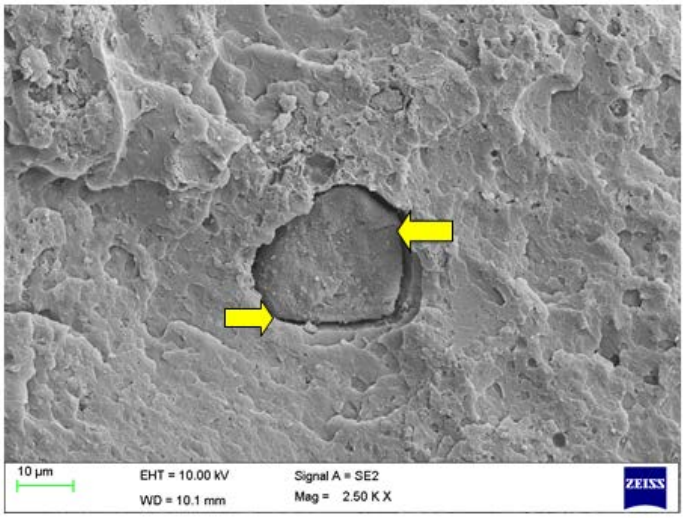

Fig 17: Fractured surface of specimen (Group C) with the lowest transverse strength (45 Mpa). yellow arrow indicates presence of a large void on the repair resin surface

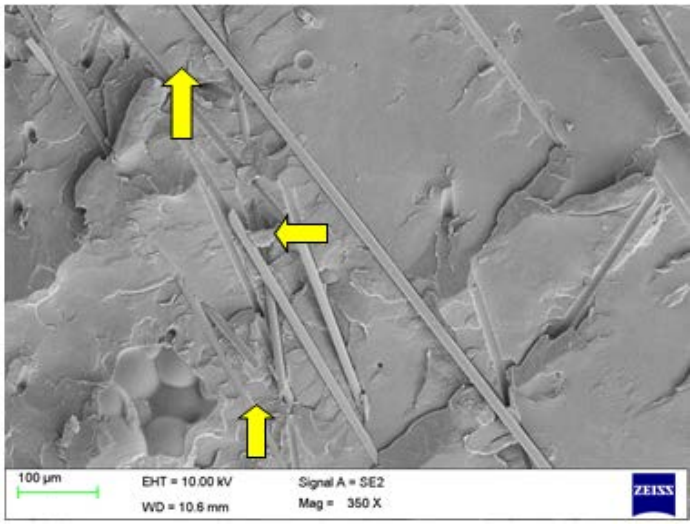

Fig .18:Fractured surface of specimen (Group D) with the highest transverse strength (158 Mpa). yellow arrow indicates presence of better bonding of fibre to the resin matrix on the repair resin surface.

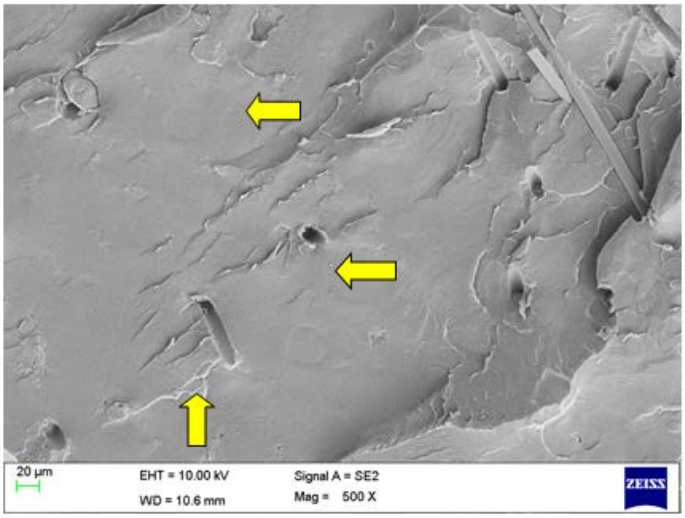

Fig. 19: Fractured surface of specimen (Group D) with the lowest transverse strength (43 Mpa). yellow arrow indicates presence of voids and the fibre concentration were minimal on the repair resin surface.

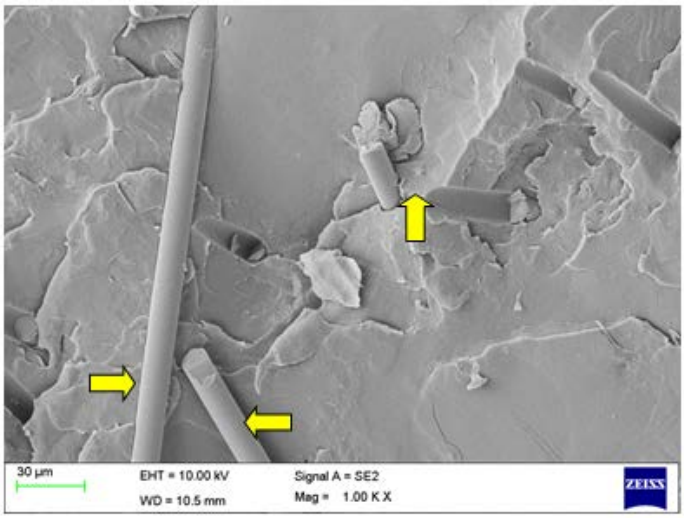

Fig.20: Fractured surface of specimen (Group E) with the highest transverse strength (103 Mpa). yellow arrow indicates presence of better bonding of fibre to the resin matrix and multidirectional orientation of fibres on the repair resin surface.

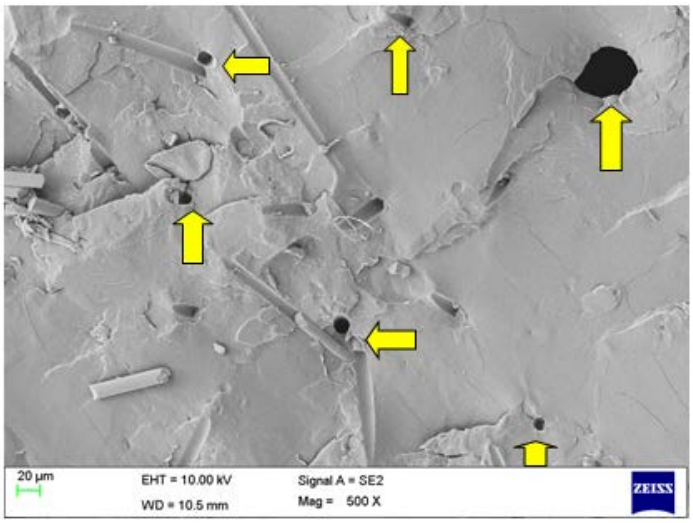

Fig. 21: Fractured surface of specimen (Group E) with the lowest transverse strength (44 Mpa). yellow arrow indicates presence of poor bonding of fibre to the resin matrix and presence of many voids on the repair resin surface.

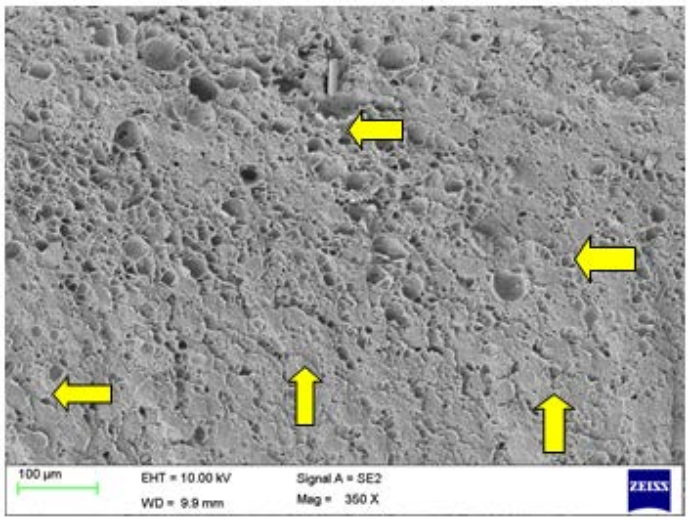

Fig. 22:Fractured surface of specimen (Group F) with the highest transverse strength (152 Mpa). yellow arrow indicates presence of better bonding of fibre to the resin matrix and presence of homogenicity on the repair resin surface.

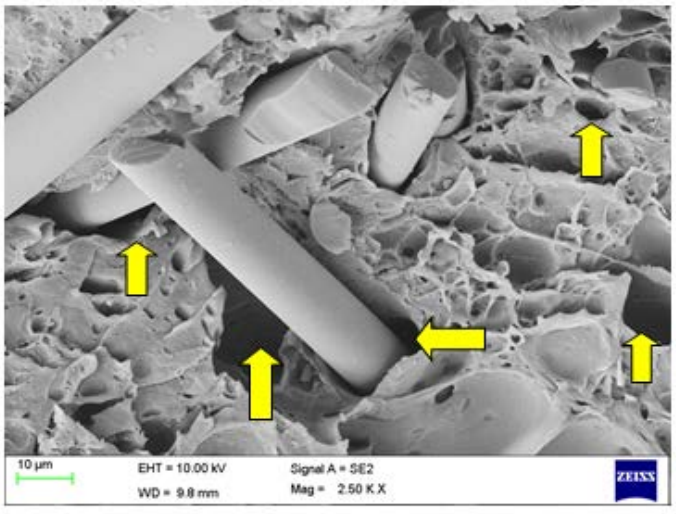

Fig. 23:Fractured surface of specimen (Group F) with the lowest transverse strength (67 Mpa). yellow arrow indicates presence of large void on the repair resin surface and poor bonding of the fibre to the resin matrix.

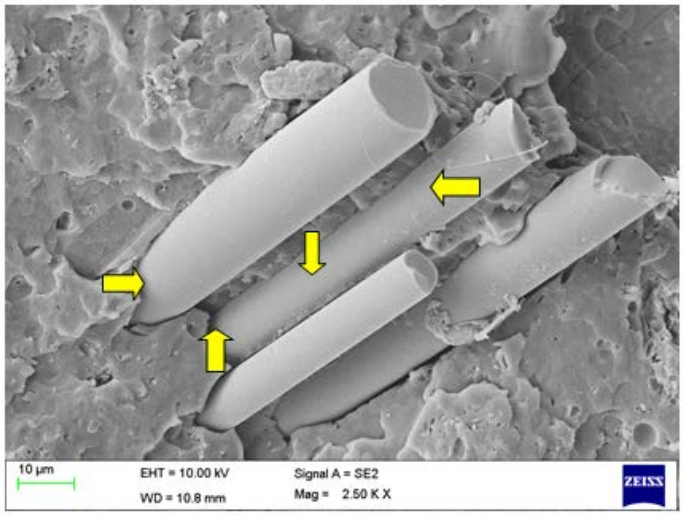

Fig.24:Fractured surface of specimen (Group G) with the highest transverse strength (98Mpa). yellow arrow indicates presence of good bonding of the fibre to the resin matrix.

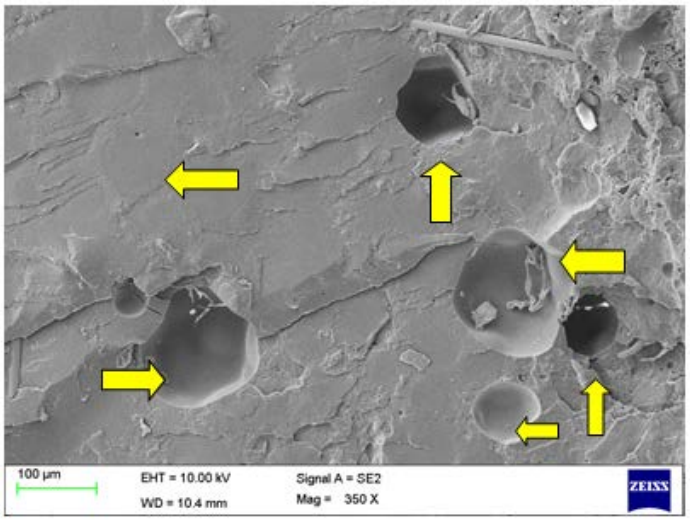

Fig. 25: Fractured surface of specimen (Group G) with the lowest transverse strength (41Mpa). Yellow arrow indicates absence of fibre in the resin matrix and the presence of large voids in the resin surface.