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Comparative Evaluation of Transverse Strength of Conventional Denture Base Resin with Reinforced Denture Base Resin: An In-Vitro Study

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Abstract

Statement of problem: Fracture strength of denture base resins is of great concern, and many approaches have been used to strengthen acrylic resin dentures.

Purpose: This study measured the effect of three fibre strengtheners on the fracture resistance of denture base acrylic resin material. Transverse strength of a heat-polymerized denture base resin (DPI), reinforced with glass, carbon, and polyethylene fibres were studied.

Material and methods: Thirty acrylic resin test specimens reinforced with fibres were fabricated. The control group consisted of ten specimens with no fibre reinforcement. Transverse strength was assessed with a three-point bending test by using a screw-driven mechanical testing machine. Ten specimens were used for each test.

Results: There were no significant differences in transverse strength. The lowest transverse strength values were obtained for specimens strengthened with polyethylene fibres, which also insignificantly decreased transverse strength of the acrylic resin.

Conclusion: Tested fibres did not have a significant effect on the transverse strengths.

Keywords: Polymethylmethacrylate, glass fibre, carbon fibre, polyethylene fibre.

Introduction

Introduction of non- acrylic resins in prosthodontics, has led to a marked change in the construction of prosthesis for patients. To be befitting in dental profession the manufacturers have spent millions of rupees for development of advanced dental materials and equipment. Technically plastics are not new but new resins are known as acrylics. Vulcanite, celluloid, phenolic compounds, and other materials are plastics and are used since ages.

Polyesters of vinyl alcohol belongs to vinyl group which includes polystyrene, ester of acylic and methacylic acid.[1]

Polymers are widely used for the fabrication of complete and partial dentures. For prosthetic rehabilitation complete and partially edentulous patients implant retained or supported prostheses are preferred but the hybrid prosthesis is the prosthetic choice in such cases. Conventional dentures can be constructed using polymers, precious metal alloys and base metal alloys.

Back in 700BC material preferred for treatment of edentulous conditions were bone, wood, ivory and cellulose. The acrylic acid as solid transparent polymer was produced by Otto Rohm in 1901. Poly methyl methacrylate (PMMA) material as denture base material were introduced by Walter Wright in 1937 which till now being used as denture base material for complete dentures and partial dentures.[2]

Due to poor strength which include low fatigue resistance and low impact strength acrylic denture to breaks during use which is its inherent property.

There are various methods to improve the strength of acrylic material: a) using Polycarbonates and polyamides in place of PMMA, b) addition of rubber in the form of butadiene styrene, c) incorporation of fibres or metal inserts. To improve the physical and mechanical properties acrylic resin denture different fibers are added such as: glass, polyethylene, silica, polycarbonate, carbon (graphite), sapphire, ceramic, nylon, and aramide (polyamides polyaromatic).[3.] The fiber can be Continuous, Parallel, Chopped and Woven types.[4]

It has been observed through experimental methods that reinforced dentures have improved fracture strength and transverse strength, but further data based evidences and experiments are needed to explain the effect of long term success of these reinforcements, the possibility of bonding between fibers, metal inclusions and fillers into the resin matrix. Further improvements in processing procedures are required to make the process less technique sensitive and help the patients on long term.

Therefore, the present in-vitro study was carried out to compare the transverse strength of conventional denture base resin with reinforced carbon fibers, glass fibers and polyethylene fibers denture base resins.

Materials and Method

I. Materials: (Figure 1 & Figure 2)

1. Conventional heat cured poly (methylmethacrylate) denture base resin in powder and liquid form (DPI-dental products of India limited, Mumbai),
2. Glass fibers (Mechan Co. Ind., Mumbai),
3. Carbon fibers (Mechan Co. Ind., Mumbai)
4. Polyethylene fibers (Stealth Mocroblockers Mumbai)
5. Dental plaster (Asian chemicals, Rajkot),
6. Alginate separating media (Cold Mold seal, DPI)
7. Petroleum jelly (Khona chemical works, Mumbai)
8. Cellophane separating sheets (DPI)
9. Modeling wax (DPI)

II. Armamentarium and equipment

1. Stainless steel mold, Dental flask and Clamps (Kavo Germany)
2. Rubber Bowl and spatula
3. Electronic measuring balance (Chyo balance corp., Kyoto, Japan)
4. Wax bath (Novo Mumbai)
5. Acrylizer (Confident New Delhi)
6. Mechanical vibrator (Confident New Delhi)
7. Steel carbide burs
8. Silicon carbide sand papers (80, 100, 120, 200 grits)
9. Digital Caliper (Aerospace, China)
10. Universal Testing Machine (Tinius Oslen Germany)

III. Methodology

A commercially available denture base resin was selected as control and glass fiber reinforced PMMA, polyethylene fiber reinforced PMMA and carbon fiber reinforced

PMMA were used for comparison. Specimens fabrication were done in accordance to the manufacturer's instructions.

For standardization of specimens a metallic block was mechanically machined from private engineering works. The metallic blocks had three parts; base, body and lid. Five rectangular spaces of size 60x10x4 mm^3were cut into the central part (Figure 3, 4 & 5). These three parts of molds were superimposed; one upon another by means of two bolts placed on either side of the die (Figure 6).

a) Preparation of the mold

A slight amount of petroleum jelly was applied on the inner surface of slot created in the metallic block, base and lid. The base and mold block assembled with help of bolts. Modeling wax was melted using a wax bath and poured into the mold space. Once the space was filled, it was covered with a lubricated lid and allowed to cool.

Any discrepancy in the size and shape of the wax block was corrected by either pouring or eliminating wax and cooled. After 15 min the base and lid were removed. Any excess wax was carved out with the wax knife. Once the wax was hardened completely, it was removed from the slot carefully without distortion. Then the wax blocks were kept in the room temperature water for 5 min.Forty such wax blocks were prepared (Figure7).

These wax blocks were invested in the flask using dental plaster (Asian chemicals, Rajkot); following the manufacturer's instructions for w/p ratio, mixing time and setting time. A mechanical vibrator was used to prevent air trapping during flasking. Dewaxing was done by keeping the flask in the boiling water for 5 min.[5] Wax was thoroughly removed using boiling water and soap solution. The mold cavities thus obtained were used for the preparation of acrylic specimens that were divided into 4groups (n = 10) : Group I conventional PMMA heat cured denture base resin; Group II conventional PMMA heat cured denture base resin reinforced with 4.0% by weight (wt.) glass fiber of 6 mm length (Mechan Co. Ind., Mumbai) ;Group III conventional PMMA heat cured denture base resin reinforced with 5.3% by wt. carbon fiber of 6 mm length (Mechan Co. Ind., Mumbai) and Group IV conventional PMMA heat cured denture base resin reinforced with 3.1% by wt. polyethylene fiber of 6 mm length (Stealth Mocroblockers Mumbai).

b) Preparation of PMMA resin specimens:

Group I (Fig. 8.)

The material used was conventional heat polymerized denture base material (DPI) in a powder liquid form. Cold mold seal (thin film) was applied on the dental stone mould with the help of a brush and allowed to dry. A mixture of polymer and monomer in the ratio of 3:1 by volume (15 ml + 45 ml) was prepared and weighed prior to mixing.

Thus reweighed polymer powder and monomer liquid was used for 2 flasks, each containing 5 specimens moulds. When the mixture reached the dough stage, it was kneaded and packed into the mould. Flasks were closed with the cellophane sheet in between them. Trial closure was carried out using a hydraulic press (Kavo) using 20 KN of pressure. Excess of the material was trimmed using a BP blade. Finally the flasks were clamped and final closure was done under pressure of 20 KN and kept for 30 min to allow proper the polymerization and for even flow of material. Then the flask was immersed in water in an acrylizer at room temperature and processing was done.

After the completion of the curing cycle, the flasks were allowed to bench cool to room temperature. After overnight bench cooling, cured specimens were carefully removed from the mould and the excess was trimmed and finished. These specimens were finally finished with silicone carbide paper, 80-200 grits size.

Group II

The material used was conventional heat cured denture base material (DPI) reinforced with 4.0% by wt of 6 mm glass fibres (Mechan Co. Ind., Mumbai). 15 ml of monomer and 45 ml of polymer (3:1 by volume) [6] were measured which weighed; 14.195 gm. and 30.611 gm. respectively. This wt was added (14.195 + 30.611 = 44.806) and 4.0 % glass fibres of this wt. (1.792gm) were measured using the electronic balance. This measured quantity of glass fibres were immersed in a beaker for 5 min with the minimum amount of monomer liquid that was compatible with thorough wetting. Then PMMA powder was sprinkled on top and mixed. The remaining amount of monomer and polymer were added in increments.

During addition of each increment, it was thoroughly mixed for 60 sec for uniform dispersion of the fibres. After the material reached the dough stage, it was kneaded and packed into the mold. The specimens were trial packed, polymerized, recovered, finished and polished as stated for the control group.

Group III

The material used was conventional heat cured denture base material (DPI) reinforced with 5.3% by wt of 6 mm carbon fibres (Mechan Co. Ind., Mumbai). 15 ml of monomer and 45 ml of polymer (3:1 by volume)[6] were measured which weighed; 14.195 gm. and 30.611 gm. respectively. This wt was added (14.195 + 30.611 = 44.806) and 5.3 % carbon fibres of this wt. (2.374gm.) were measured.

This measured quantity of carbon fibres were immersed in a beaker for 5 min with the minimum amount of monomer liquid that was compatible with thorough wetting. Then PMMA powder was sprinkled on top and mixed. The remaining procedure was same as for group II.

Group IV

Material used was conventional heat cured denture base material (DPI) reinforced with 3.1% by wt. for 6 mm. polyethylene fibres(Stealth Mocroblockers). 1.389 gm i.e. 3.1% by wt. of 30.611 gm. (45 ml) of polymer and 14.195gm (15 ml) monomer, were measured. Technique for adding the fibresin acrylic was same as that in G-II group.

c) Transverse strength testing

Transverse strength test was carried out at the Centre for Material and Mechanical Engineering IIT Ropar. Prior to testing, the thickness, length and width of each specimen were verified with digital caliper.

The transverse strength of all the specimens was tested on Universal Testing Machine (Figure 9). To measure the transverse strength, the specimen was oriented between two parallel pins of the jig. These pins were adjusted 50mm apart, which represented the distance between the molars in complete maxillary denture. All the specimens were marked in the center.

The jig was positioned and the specimens were loaded one by one on the universal testing machine. Load was applied at the center of the specimen at a cross head speed of 50mm/min, until it fractured. The point at which fracture occurred on loading was observed and the transverse strength was calculated using the formula. Data collected was statistically analyzed.

Results

The transverse strength (Newton) of four groups with 10 specimens each is shown in Table 1, 2, 3, and 4 and graphs 1 and 2.

For group I lowest value was 208N and highest value was 486N, for group II lowest value was 330N and highest value was 495N, for group III lowest value was 284N and highest value was 430N, and for group IV lowest value was 226N and highest value was 363N

(Table1).

Group II (glass fiber reinforced with 6mm length with 4.0 wt %) was found to have highest mean transverse strength of 394.70N amongst all groups and group IV had the least mean transverse strength of 301.80N. The maximum standard deviation (SD) in table II was seen for group I (control)of 104.45 and least was seen for group II (glass fibre reinforced with 6mm length with 4.0 wt %) of 44.45 (**Table2).**

Transverse strength with a sum of mean square between the four groups was 14817.233 and the transverse strength within the groups was 4351.728. On the statistical scale of ANOVA comparative transverse strength between the groups was found to be statistically significant

(**Table3).**

On comparison of group I (conventional PMMA heat cure resin) with other three materials, the analysis showed the results of transverse strength to be statistically non-significant. However, on comparing group II (conventional PMMA heat cure resin reinforced with 4.0% wt glass fibers of 6mm length) with other materials, the transverse strength on comparison with I and III were statistically non-significant, however it showed significant statistical deviation with group IV

(**Table4).**

This bar graph shows the comparative evaluation of mean transverse strength among four different material groups. The mean transverse strength for glass fibre reinforced denture base PMMA was found to be the highest of 394.7N and for polyethylene fibre reinforced denture base PMMA it was found to be lowest of 301.8N. However for conventional denture base resin and carbon reinforced denture base PMMA mean transverse strength were 334.4N and 345.3N respectively

(**Graphs1).**

This bar graph shows the descriptive statistics of all the groups for mean and standard deviation of transverse strength. The standard deviation was highest for control group was 104.453 and lowest for glass fiber group was 44.452

(**Graph 2).**

Discussion

Acrylic resins is the most popular denture base material and has been used extensively for the fabrication of denture bases because of its advantages than other materials. An ideal denture base material should have adequate mechanical and physical properties, besides biocompatibility and aesthetics.

Polymethylmethacrylate (PMMA) has various advantages which including low cost, biocompatibility, ease of processing, stability in the oral environment, and acceptable esthetics. Even then, it is not an ideal material because of its inferior physical and mechanical properties. One of its major drawbacks is the susceptibility to fracture. The PMMA-based denture base polymer is far from being a satisfactory denture material in fulfilling the mechanical requirements of dental prosthesis, the impact strength and fatigue strength of PMMA denture base polymer is not satisfactory.

Two types of failures have been discussed by Smith one is inside the mouth that is fatigue failure due to continuous use under stresses in form of midline fracture. This failure under low power magnification appears as series of curved ridges at the junction of tooth and denture base. Second failure is outside the mouth due to high stresses in the form of impact forces. Both the failures can be distinguished easily as the inside mouth failure smooth and shiny surface is observed.

The mechanical behavior of polymer is dependent on both stress and temperature[7.] Some energy is lost in the internal friction within the material. This energy loss varies with

stress and temperatures which in turn related to the rotational and vibration frequencies of the various bonds and side chains in the polymer which is higher during mastication inside the mouth. This friction energy propagate the crack, it should be as low as possible for better material quality.

Either due to masticatory stresses or accidental fall, if the denture fractures, cause is due to inadequate strength of the denture base materials. The strength of the denture[8] depends on the shape, masticatory stresses and the mechanical properties of the material. The intrinsic strength of the material cannot be concluded as deficient if a denture fractures, but all the other factors must be considered.

The effect of shape of denture base materials on strength can be best explained with reference to Notch effect, which is due concentration of forces in the notch region due to abrupt change in shape. Same effect is applied to a hole due to porosity in the denture base or inclusion of foreign bodies.

Additional stress concentration in the material may be present in the unloaded state when thermal changes have occurred. Differential thermal contraction between an inclusion and the denture material or between the surface and the inner side of the material itself produces residual forces due to the local restriction of the shrinkage of the polymer. The residual stresses reveal themselves by crack formation. These stresses may add to those created at the free surface during loading of the denture and so initiate fracture.

The stress concentration is superimposed on the general pattern of stress dissipation in the denture due to mastication or gliding movement. The highest stresses are in the polished surface of the palatal side of the denture behind central incisor area. The intrinsic strength of the material is also affected by the composition, curing method and the amount of monomer remaining after curing.

So, it is clear that failure in the form of fracture of the denture base not only depend on strength of the material but also on the shape and form of the denture base. These factors should therefore be kept in mind in assessing the practical problem.

With the advancements dental materials in the form of composites which have high strength and low mass, have fibre matrix of resin which bind them together.

To strengthen the commercially available polymers by means of long continuous fibres is well established. However their use in dentistry requires balance of properties like biocompatibility, esthetics, bonding of fibers, laboratory manipulation and stability in the oral environment.

Nearly half a century back reinforcement of dental resin by short or long fibres has been described. But its routine clinical practice is very less. Reinforcement of resin is dependent on various factors, like types, the percentage in the matrix, distribution, fibre length, orientation, forms, and interfacial bond.[9, 10, 11]

Carbon fibres when added[12, 13, 14]to the resin matrix has proved to increase the strength of the denture base but the demerits are, the black colour which is not acceptable, difficulties in handling and the possibility of toxicity, has restricted their use.

Addition of aramid fibres for reinforcement of acrylic resin has been described by Mullarky (1985)[15] and Berrong, Weed and Young (1990)[16]. This enhances the fatigue resistance of acrylic resin denture base material only with a problem of yellow color of denture base, thus necessitating thick layers of acrylic resin that was added to the bulk of the denture to mask it.

Jagger, Harrison and Jandt (2000)[17] had studied the self-reinforcement (with a material that is chemically identical

to the matrix holding the fibre in place). But the effect of the addition of surface treated and untreated PMMA fibres did not improve the strength of acrylic resin.

In this study different concentrations (4.0 wt% of glass fibres, 5.3 wt% of carbon fibres and 3.1 wt% of polyethylene) of 6mm length were used as a reinforcement of the PMMA heat cure denture base resin. The short fibre length represented a convenient size for manipulation and inclusion into acrylic resin dough.[18]Fiber loading levels of low percent by weight were selected because the early studies revealed that any greater fibre level means that a large volume of material to be wetted by the monomer during mixing and producing a dry, friable dough that was difficult to pack[19]. To cut the fibres, they were wrapped tightly in aluminum foil and cut with a sharp surgical blade so that the resultant individual fibres had free ends.

Results of the test are showed in table I, II, III and IV. On comparing the transverse strength in four groups, group II displayed highest mean transverse strength of 394.70N followed by group III with 345.30N, control group with 334.40N and the lowest transverse strength was found with polyethylene group.

To know whether any statistical difference exists between the groups (P value was set to 0.05) One way ANOVA statistical analysis test was done.

It was found that there was statistical difference in the mean transverse strength in between the groups ($P<0.05$) group II and group IV and no statistical difference in the mean of transverse strength was found between the groups.

A significant increase in the transverse strength due to incorporation of glass fibres and carbon fibres is in accordance with the previous studies done by Uzun, Tenser, Hersek, Vallittu, Lassilla, Lappalainen and Marie[20, 21]. An increase in the transverse strength with incorporation of glass fibres was due to good interfacial bond between the fibres and the acrylic resin. Vallittu, Lassilla and Lappalainen showed that an increase in the amount of fibres enhanced the fracture resistance[22]. Also in this study, incorporation of 2% wt glass fibre showed higher means transverse strength (90.24 N) than that of 1% wt glass fibres.

When polyethylene fibres were used as reinforcing agents, a decrease rather than an increase in the transverse strength was seen with both 1 wt% and 2 wt% concentrations of fibre. This might be due to poor interfacial bond between the fibres and the acrylic resin. As there were no previous studies available on polyethylene fibres as a reinforcing medium for denture base PMMA, further studies are required for better understanding of the interaction between polypropylene fibres and denture base PMMA.

The present study showed that glass fibres considerably enhances the strength of dental polymers because these fibres could embed into resin matrix.Other factors which enhances the strength were the quantity , the orientation and the adhesion of the fibres which is clinically important. When glass fibre was used, a clear improvement in strength was found.. The result of this study revealed that reinforcement of denture base resins with glass fibres may be a useful to strengthening denture bases.

Summary and Conclusion

To improve quality of life of edentulous patient's acrylic dental prosthesis has been used routinely. There are various advantages like economically cheap, aesthetics and ease of manipulation. But only disadvanges is fracture or deformation due to its inferior mechanical and physical properties. Several techniques have been implemented to improve the properties of PMMA including addition fibres and recently, Nanoparticles have been added. Since transverse strength of denture base resins is of great

concern, many approaches have been used to strengthen acrylic resin dentures.

Within the limitations of this study, the following conclusion were drawn: Incorporation of 4.0% weight glass fibres increases the transverse strength of denture base PMMA, incorporation of 5.3% weight carbon fibres increases the transverse strength of denture base PMMA and incorporation of polyethylene fibres in 3.1 wt. % concentration decreases the transverse strength of denture base PMMA.

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Table.1 Transverse strength of individual samples in various groups in newton.

SR. No.	Control Group (Newton)	Glass Fibers(Newton)	Carbon Fibers (Newton)	Polyethylene Fibers (Newton)
1.	208	330	284	226
2.	208	361	287	248
3.	233	368	305	256
4.	274	378	317	296
5.	284	378	345	299
6.	393	399	346	323
7.	400	404	357	326
8.	405	413	368	340
9.	453	421	414	341
10.	486	495	430	363

Table.2 Descriptive statistics of all of the groups

Group	N	Mean	Std. Deviation	Std. Error Mean
Control	10	334.40	104.453	33.031
Glass fiber	10	394.70	44.452	14.057
Carbon fiber	10	345.30	49.585	15.680
Polyethylene fiber	10	301.80	45.406	14.359

Table.3 Intergroup comparison of transverse strength of all of group by ANOVA

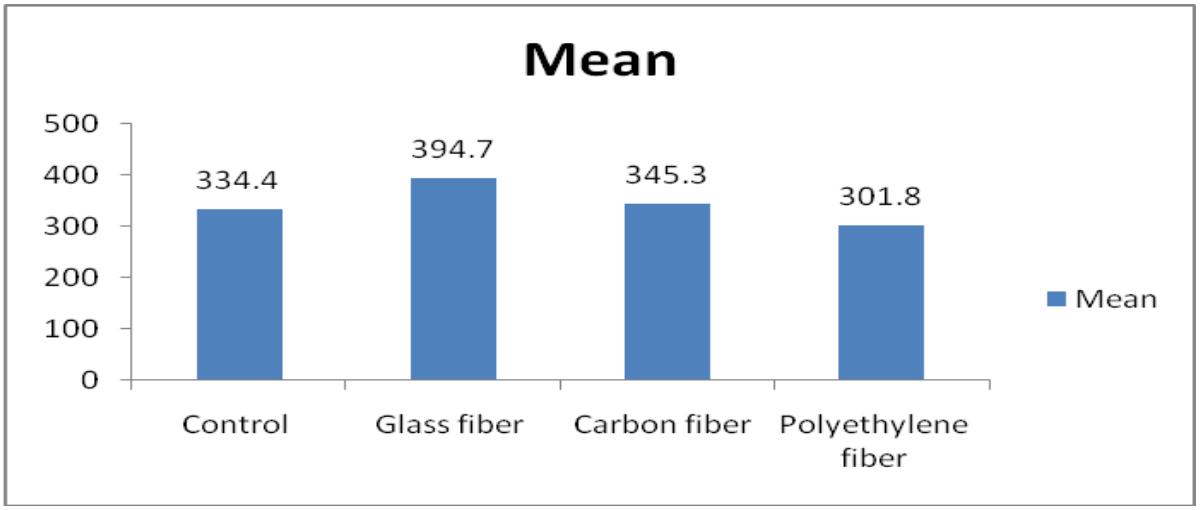
Transverse strength	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	44451.700	3	14817.233	3.405	0.02*
Within Groups	156662.200	36	4351.728		

Table.4Multiple comparison of transverse strength of all of the groups by BONFERRONI

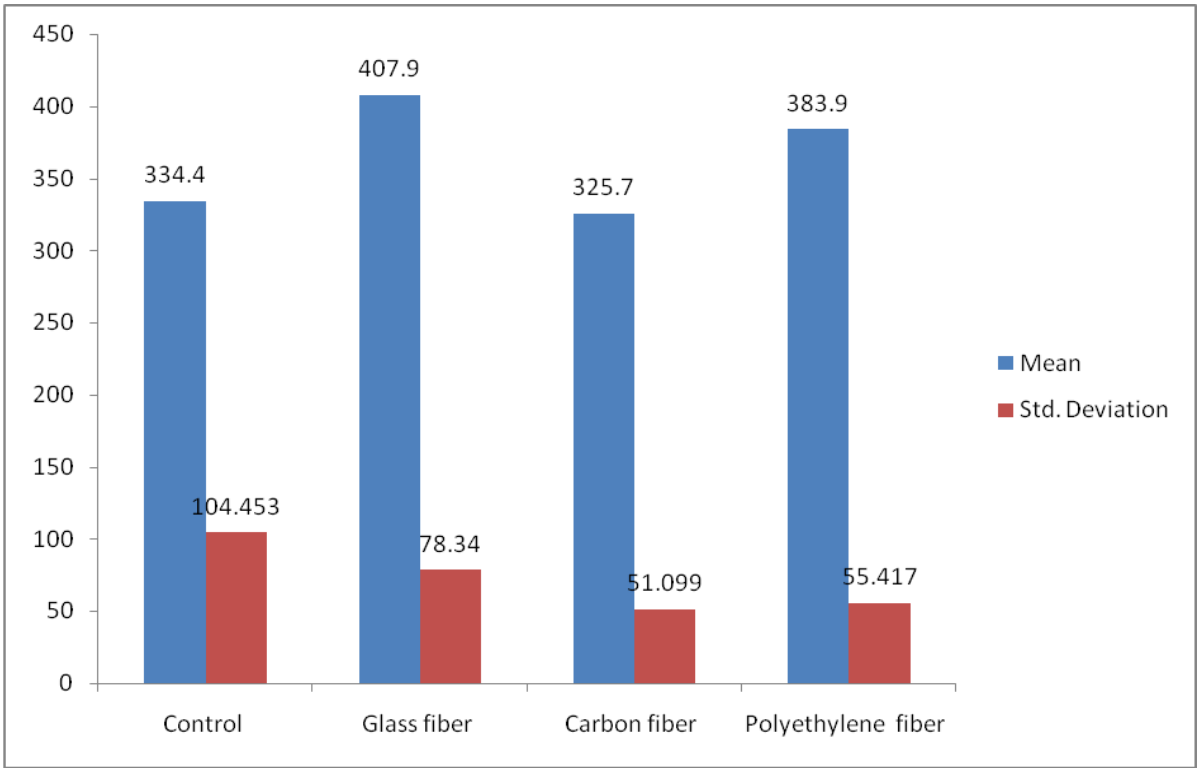
(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	60.300	29.502	0.2**	142.67	22.07
	3	10.900	29.502	0.1**	93.27	71.47
	4	32.600	29.502	0.1**	49.77	114.97
2	1	60.300	29.502	0.2**	22.07	142.67
	3	49.400	29.502	0.6**	32.97	131.77
	4	92.900*	29.502	0.02*	10.53	175.27
3	1	10.900	29.502	0.1**	71.47	93.27
	2	49.400	29.502	0.6**	131.77	32.97
	4	43.500	29.502	0.8**	38.87	125.87
4	1	32.600	29.502	0.1**	114.97	49.77
	2	92.900*	29.502	0.02*	175.27	10.53
	3	43.500	29.502	0.8**	125.87	38.87

*significant **non-significant

Graph 1: Descriptive statistics of all of the groups by Mean



Graph 2: Descriptive statistics of all of the groups by mean St D



Legends Figure

Figure 1: Materials used in study

Figure 2: Different types fibres used in study

Figure 3: Metallic mould

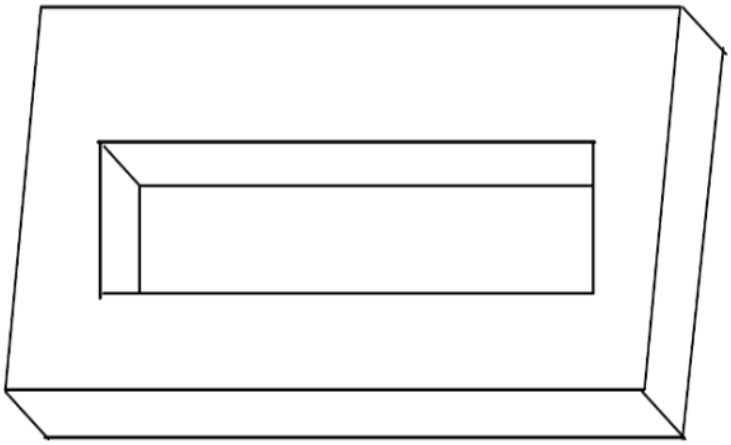


Figure 4: Sample size

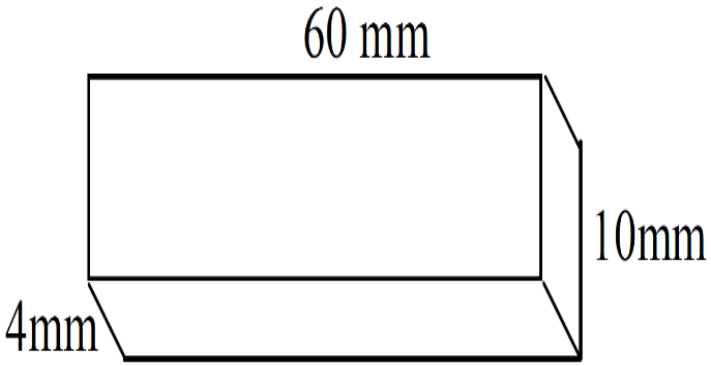


Figure 5: 3Pointbending test

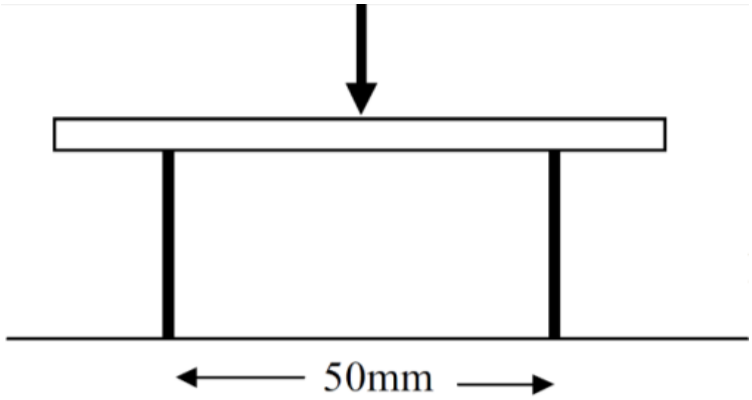


Figure 6: Metal Die

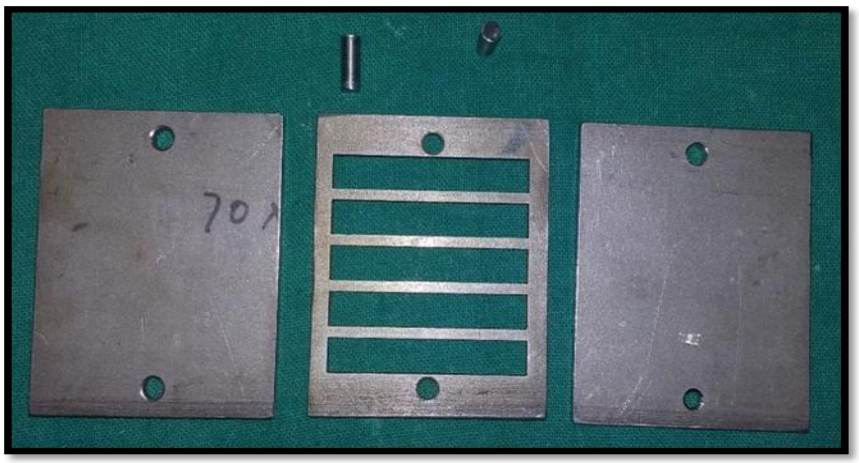


Figure 7: Wax samples

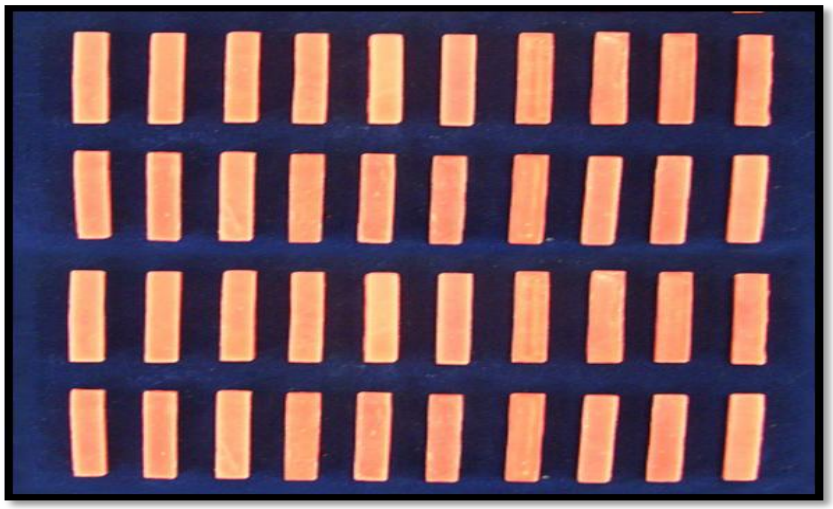


Figure 8: Acrylic samples

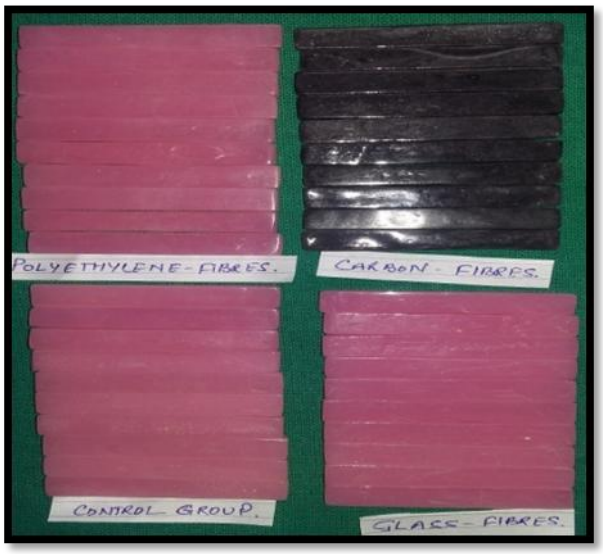


Figure 9 Universal testing machine