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RESEARCH ARTICLE

TO COMPARE AND EVALUATE THE FRACTURE TOUGHNESS AND FLEXURAL STRENGTH OF PROVISIONAL RESTORATIVE MATERIALS WITH AND WITHOUT REINFORCEMENT OF KEVLAR FIBRES - AN INVITRO STUDY

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Abstract

Objective: To compare and evaluate the fracture toughness and flexural strength of PMMA and bisacryl composite provisional restorative materials with and without reinforcement of Kevlar fibre.

Methodology: 40 test specimens of PMMA and bisacryl composite for fracture toughness testing and 40 rectangular specimens of PMMA and bisacryl composite for flexural strength testing were fabricated respectively. Each main group was again divided into 2 sub groups A & B; where A is control group and B is the test group with Kevlar fibre reinforcement. The fibre reinforced specimens were prepared by precutting the fibres into 12mm and 23mm length and wetted using the polymer monomer mix for the PMMA and a bonding agent for the bisacryl resin and then placed in the mold cavity. In both tests, unreinforced resins were used as control group. Specimens were stored in water at 37°C for 24 hours before testing. The specimens were loaded in universal testing machine. The mean fracture toughness and mean flexural strength were compared by one way analysis of variance followed by the Tukeys standardized range test.

Results: The mean fracture toughness and flexural strength values obtained were significantly higher for bisacryl composite when compared to PMMA. Similarly after Kevlar reinforcement bisacryl composite proved to be better.

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Introduction:-

A provisional restoration is an important phase in fixed prosthodontics therapy.¹ It should provide both pulpal and periodontal protection, have good marginal integrity & esthetics and should have sufficient durability to withstand the forces of mastication. Presently there is no single material that meets the optimal requirement for all the situations.² The commonly used provisional restorative resins are polymethyl methacrylate (PMMA), polyethyl methacrylate (PEMA), composite resin (bis-acryl composite) and poly urethane dimethacrylate.³ Historically ethyl

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methacrylate has shown poor wear resistance & poor esthetics. Thus PMMA and bisacryl resin composite materials possess a larger market value.⁴ These materials must be strong enough to withstand the masticatory forces, particularly for long span FPD's for long term use or for patients with parafunctional habits. Therefore the flexural strength of these material is an inevitable property.^{5,6} The resistance of provisional resins to crack propagation is helpful when assessing the strength and serviceability of treatment restorations.⁷ A fracture toughness test measures the resistance of a material to crack extension.⁸ Fibre reinforcement has been used to overcome the mechanical limitations of provisional resins. The fibres that have been incorporated in this manner are carbon, aramid, polyethylene and glass fibers.^{3,9} Kevlar fibres (para aramid) are popular as they exhibit superior mechanical properties than nylon & E glass fibres and have superior wettability compared to carbon fibres and do not require treatment with a coupling agent. They were found to improve tensile strength, elastic modulus, impact strength and fracture resistance and found to be biocompatible with no evidence of toxicity.¹⁰ Since very few evidence has been found where Kevlar fibres have been incorporated in provisional restorative materials such as polymethyl methacrylate and bis-acryl composite, this study aims to investigate the effect of addition of Kevlar fibres to provisional restorative materials and the changes in the properties like fracture toughness and flexural strength.

Methodology:-

Fracture Toughness:

Specimens of polymethyl methacrylate and bisacryl composite provisional restorative material were prepared according to ASTM (American society for testing and materials) no. E 399 83 (Figure:1). The specimens were in the form of a double cantilever beam, with a slot that originates from the center of one edge, extending along the specimen's center line to a 60 degree terminal apex located slightly beyond the midpoint of the specimen. Two loading holes pierces the specimen. The design of the assembled mold provides 3 triangular ports, which allows the escape of excess resin during mold assembly and exposure to pressure during polymerization. PMMA specimens were fabricated at room temperature by mixing the polymer and monomer in a clean glass slab with a stainless steel spatula at the 2:1 ratio (Figure: 3). When the mix reached the dough stage, it is packed into the mold cavity slowly to avoid entrapping of air, the cover and the 2 circular rods of the mold were placed in position, and the entire assembly were placed in a hand press and compressed to allow the material to completely flow into the mold. The bisacryl specimens were prepared in the same manner, except that the material is supplied in an automixing cartridge. The mix is packed directly into the mold cavity using application tips supplied with the kit. (Figure: 4)

The fibre reinforced specimens were made by precutting the fibres into 12 mm lengths and wetted using the polymer monomer mix for the PMMA specimens and a bonding agent for the bis acryl resin. (Figure:5). The mold cavity were filled with the resin, and then the fibres were placed perpendicular to the end of the slot and 1 mm away from it, aligning the fibres perpendicularly to the direction of the crack. After the resin is completely polymerized, the specimens were separated from the mold, and the flash was removed using a razor blade. The specimens were examined for any voids, and all defective specimens were discarded. Specimens were stored in water at 37°C for 24 hours before testing.

A precrack was placed in the compact test specimens by placing a sharp scalpel at the end of the slot and applying hand pressure.

Polymethyl methacrylate

Pmma ft_a - control group - no reinforcement (n=10)

Pmma ft_b - reinforced with kevlar fibre (n=10)

Bis acryl composite

Bac ft_a- control group-no reinforcement (n=10)

Bac ft_b - reinforced with kevlar fibre(n=10)

The specimens were tested in tension in a universal testing machine with the direction of the force perpendicular to the plane of the preformed crack. The peak force (F) in newtons, which caused fracture of the specimens, was recorded and used to calculate the fracture toughness (K1C) measured in MPa.m^{1/2} from the following equation;

$$K1c = \frac{Pc}{bw^{1/2}} \cdot F(a/w)$$

Where pc is the maximum load before crack advance; b is the average specimen thickness (cm); w is the width of the specimen (cm), (a) = crack length (cm).

Flexural Strength:

A specially designed split stainless steel mold was constructed to form rectangular specimens of dimensions 2mm × 2mm × 25 mm (Figure: 2). The specimen preparation were similar to the fracture toughness specimens. When the mix reached the dough stage, it was packed into the mold cavity slowly to avoid entrapping of air; the mold was then covered to remove the excess resin and kept at room temperature for 15 minutes to allow for complete polymerization of the resin. The fibre-reinforced specimens were made from precut 23-mm long fibres, wetted using the polymer-monomer mix (PMMA) and bonding agent (bis-acryl), and then placed in the lower part of the mold cavity and the resin applied on top. After complete polymerization of the resin, the specimens were separated from the mold; flash was removed with the razor blade and examined for voids

Polymethyl methacrylate

Pmma fs_a - control group – no reinforcement (n=10)

Pmma fs_b - reinforced with kevlar fibre (n=10)

Bis acryl composite

Bac-fs_a - control group-no reinforcement (n=10)

Bac -fs_b - reinforced with kevlar fibre(n=10)

The flexural strength for all the specimens was determined by loading the specimens in the same universal testing machine. The load was applied with a crosshead speed of 1 mm/min. The peak force (F) in newtons, from stress strain curve of each specimen was recorded and used to calculate the flexural strength in MPa from the following equation:

$$\delta\beta = 3FI/2Bh^2$$

where $\delta\beta$ is the flexural strength in MPa; F is the maximum applied load in newtons; I is the supporting width in millimeters; B is the breadth of the test specimens in millimeters; and h is the height of the test specimen in millimetre.

Statistical Analysis:

The data was collected and fed in SPSS (IBM version 23) for the statistical analysis. The descriptive statistics included mean and standard deviation. The inferential statistics included One way ANOVA for comparison within and between the groups followed by Post Hoc Tukey's test for the multiple comparisons. The level of significance was set at 0.05 at 95% Confidence Interval.

Results:-

This in-vitro study investigated the effect of reinforcement of Kevlar fibres on fracture toughness and flexural strength of PMMA and bisacryl composite provisional restorative materials. This study comprised of a total of 80 samples, wherein 20 samples of PMMA underwent fracture toughness and 20 samples of bisacryl composite underwent fracture toughness, and 20 samples of PMMA underwent flexural strength and 20 samples of bisacryl composite underwent flexural strength. These 20 samples of each were again divided into subgroups comprising of 10 specimens each.

Table 1:- Mean values of each specimen of polymethyl methacrylate and bisacryl composite provisional restorative material reinforced with Kevlar fibres for fracture toughness.

Fracture Toughness (MPa)				
Specimen n0	Pmma (without fibre)	Pmma (with fibre)	Bisacryl composite (without fibre)	Bisacryl composite (with fibre)
1	0.66	0.78	0.833	1.25
2	0.81	1.02	0.854	1.45
3	0.8125	0.979	0.833	1.25
4	0.75	1.04	0.854	1.25
5	0.81	1.02	0.833	1.29
6	0.791	0.979	0.833	1.35
7	0.81	1.06	0.833	1.35

8	0.8125	0.979	0.895	1.33
9	0.81	1.04	0.833	1.25
10	0.812	1.02	0.895	1.25
MEAN	.7878	.9917	.8496	1.3020

Table 2:- Mean values of each specimen of polymethyl methacrylate and bisacryl composite provisional restorative material reinforced with Kevlar fibres for flexural strength.

Flexural Strength (mpa)				
Specimen n0	Pmma (without fibre)	Pmma (with fibre)	Bisacryl composite (without fibre)	Bisacryl composite (with fibre)
1	81	90	90	117
2	67.5	94.5	78.75	90
3	78.75	94.5	81	94.5
4	81	92.5	76.5	94.5
5	74.25	94.5	81	96.75
6	76.5	96.75	78.75	101.25
7	78.75	87.75	81	101.25
8	78.75	94.5	85.5	103.5
9	65.25	96.75	78.75	108
10	65.25	99	83.25	96.75
MEAN	74.7000	94.0650	81.4500	100.3500

Table 3:- Comparison of fracture toughness between Kevlar reinforced and unreinforced polymethyl methacrylate and bisacryl composite provisional restorative material using one-way ANOVA.

Fracture toughness	Mean (MPa)	Standard deviation	F	Significance
Pmma (without fibre)	.7878	.04893	150.994	0.000 (H.S)
Pmma (with fibre)	.9917	.07961		
Bisacryl composite (without fibre)	.8496	.02542		
Bisacryl composite (with fibre)	1.3020	.06746		

Table 4:- Comparison of flexural strength between Kevlar reinforced and unreinforced polymethyl methacrylate and bisacryl composite provisional restorative material using one-way ANOVA.

Flexural strength	Mean (MPa)	Standard deviation	F	Significance
PMMA (without fibre)	74.7000	6.34626	42.662	0.000 (H.S)
PMMA (with fibre)	94.0650	3.30497		
Bisacryl Composite (without fibre)	81.4500	3.94018		
Bisacryl Composite (with fibre)	100.3500	7.80865		

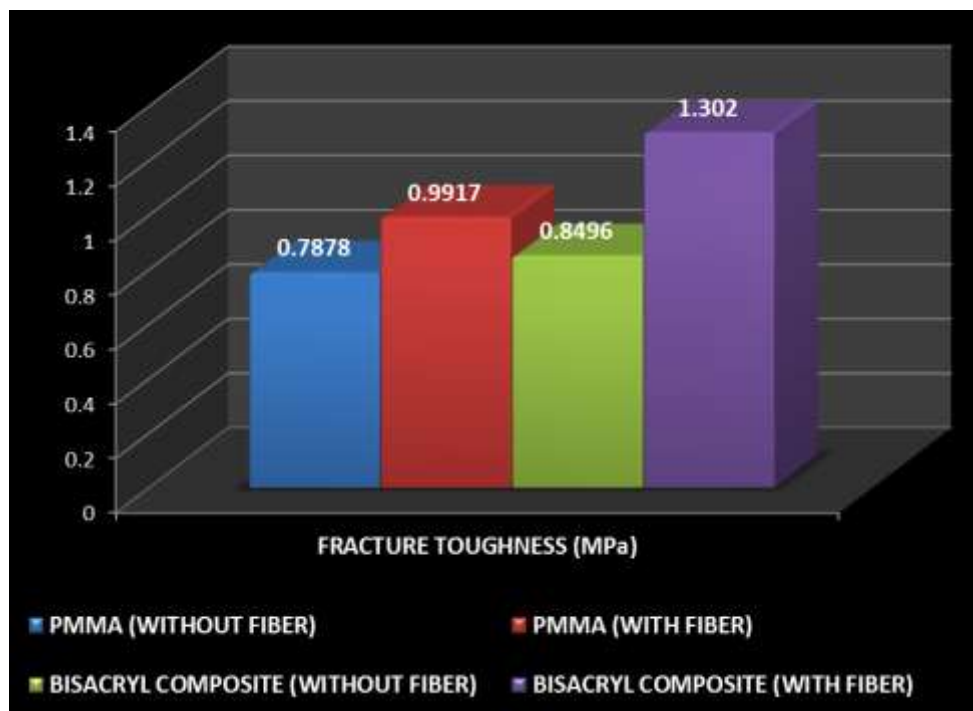
Table 5:- Shows significant difference between the unreinforced group, Kevlar reinforced group of polymethyl methacrylate and bisacryl composite on fracture toughness using Post Hoc Tukeys test.

		Mean difference	Standard error	Significance	95% Confidence Interval	
					Lower Bound	Upper Bound
PMMA (without	BISACRYL	-.51420	.02639	.000 (H.S)	-.5853	-.4431

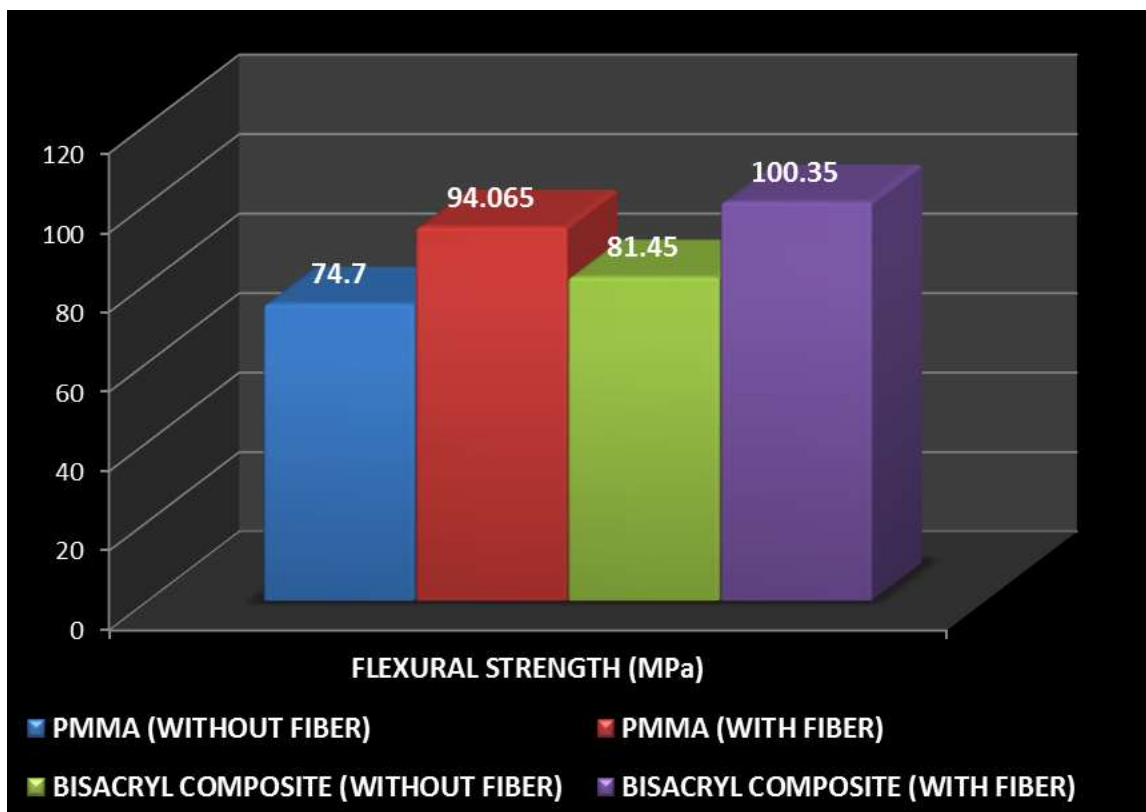
fibre)	COMPOSITE (with fibre)					
	BISACRYL COMPOSITE (without fibre)	-.06180	.02639	.107 (N.S)	-.1329	.0093
	PMMA (with fibre)	-.20390	.02639	.000 (H.S)	-.2750	-.1328
BISACRYL COMPOSITE (with fibre)	BISACRYL COMPOSITE (without fibre)	.45240	.02639	.000 (H.S)	.3813	.5235
	PMMA (with fibre)	.31030	.02639	.000 (H.S)	.2392	.3814
BISACRYL COMPOSITE (without fibre)	PMMA (with fibre)	-.14210	.02639	.000 (H.S)	-.2132	-.0710

Table 6:- Shows significant difference between the unreinforced group, Kevlar reinforced group of polymethyl methacrylate and bisacryl composite on flexural strength using Post Hoc Tukeys test.

		Mean difference	Standard error	Significance	95% Interval	Confidence
					Lower Bound	Upper Bound
PMMA (without fibre)	BISACRYL COMPOSITE (with fibre)	-25.6500	2.52683	.000 (H.S)	-32.4553	-18.844
	BISACRYL COMPOSITE (without fibre)	-6.75000	2.52683	.053 (N.S)	-13.5553	.0553
	PMMA (with fibre)	-19.3650	2.52683	.000 (H.S)	-26.1703	-12.559
BISACRYL COMPOSITE (with fibre)	BISACRYL COMPOSITE (without fibre)	18.90000	2.52683	.000 (H.S)	12.0947	25.7053
	PMMA (with fibre)	6.28500	2.52683	.079 (N.S)	-.5203	13.0903
BISACRYL COMPOSITE (without fibre)	PMMA (with fibre)	-12.6150	2.52683	.000 (H.S)	-19.4203	-5.8097



Graph 1:- Mean fracture toughness between polymethyl methacrylate and bisacryl composite provisional restorative material with and without Kevlar reinforcement.



Graph 2:- Mean flexural strength between polymethyl methacrylate and bisacryl composite provisional restorative material with and without Kevlar reinforcement.

Discussion:-

Fixed partial dentures have become a well-established treatment modality for many partially edentulous patients. Because these restorations are made indirectly in a dental laboratory, several days or weeks are usually required for their completion.¹ Therefore provisional restoration is an essential element of fixed prosthodontic treatment. They should shield pulpal tissue against physical, biochemical and thermal injuries, maintain positional stability and occlusal function, should provide strength, retention and aesthetics for the prepared teeth. In addition, they may be used for correcting irregular occlusal plane, altering vertical dimensions and changing the contour of the gingival tissue.²

The commonly used provisional restorative resins are polymethyl methacrylate (PMMA), polyethyl methacrylate (PEMA), composite resin (bisacryl composite) and poly urethane dimethacrylate.³ PMMA is the most commonly used material for indirectly made provisional fixed partial dentures. Its strength, color stability, ease of manipulation and polishing make it a desirable material. Bis-acryl composite resins are more expensive but show low exothermic reaction on setting, good marginal fit, and moderate color retention and strength. Thus PMMA and bisacryl resin composite materials possess a larger market value.³

Kevlar fibres are popular as they exhibit superior mechanical properties than nylon and E-glass fibres. The commercial name for aramid fibre is Kevlar and chemically it is an organic compound such as poly paraphenyleneterephthalamide with chemical formula $(-CO-C_6H_4-CO-NH-C_6H_4-NH-)_n$. Polyaramidfibres have superior wettability compared to carbon fibres and do not require treatment with a coupling agent. They were found to improve both tensile strength and modulus of elasticity of denture bases. Acrylic resin appliances reinforced with fibre content up to 2% and with unidirectional orientation showed significantly higher impact strength and fatigue resistance.

Since very few evidence has been found where Kevlar fibres have been incorporated in provisional restorative materials such as poly methyl methacrylate and bis-acryl composite, this study aimed at evaluating the effect of Kevlar fibre reinforcement on fracture toughness and flexural strength of PMMA and bisacryl composite provisional restorative material. It also intended to compare between the two materials on fracture toughness and flexural strength without any fibre reinforcement.

The stress at which a brittle material fractures is called the fracture strength. In the present study specimens were tested in tension in a universal testing machine with the direction of the force perpendicular to the plane of the preformed crack. Each specimen was held in a specially designed tension device in the machine, and tension force was applied with a crosshead speed of 5 mm/min.³

The present study shows higher fracture toughness of the control BAC resin (0.8496) over the control PMMA resin (0.7878). The reason for greater fracture toughness of BAC may be because of its molecular structure when compared to other provisional restorative materials. This observation was in correlation with the studies of Geertset al⁶, Samadzadeh A et al¹⁴ who showed higher fracture toughness of the control BAC resin over the control PMMA resin. This study confirms the higher fracture toughness of the control BAC resin as compared to PMMA resin. Studies done by Viswabarane et al¹⁶, Knobloch et al²⁵, Yilmaz et al²⁸ have also shown similar results that higher fracture toughness of the control BAC resin over the control PMMA resin.

The present study shows higher flexural strength of the control BAC resin (81.4500) over the control PMMA resin (74.7000). This result is consistent with those of past studies in which the flexural strength of bis-acryl resins was higher than other conventional PMMA interim restorative material.^{2,3,5,15,21,22} According to Nejatidanesh et al⁵, the differences between flexural strength of methacrylate resins and bis-acryl resins are a result of the different monomer composition.

When subjected to fracture resistance, bisacryl composite after Kevlar reinforcement (1.3020) showed better resistance to fracture than PMMA after Kevlar reinforcement (0.9917) and the control groups bisacryl composite (0.8496), PMMA (0.7878). This result is consistent with those of past studies in which the fracture toughness of bis-acryl resins after Kevlar reinforcement was higher than other conventional PMMA interim restorative material after Kevlar reinforcement.^{7,13,14,16}

Similarly when subjected to flexural strength, bisacryl composite after Kevlar reinforcement (100.3500) showed better resistance to flexure than PMMA after Kevlar reinforcement (94.0650) and the control groups bisacryl composite (81.4500), PMMA (74.7000). This result is consistent with those of past studies in which the flexural strength of bis-acryl resins after Kevlar reinforcement was higher than other conventional PMMA interim restorative material after Kevlar reinforcement.^{15,21,22,26}

This study had some limitations. In vitro static load tests differ from the dynamic intraoral conditions. Cyclic loading can be incorporated in the testing method to simulate the clinical environment. Microcracks and defects that grow inherently during thermal and mechanical processes can significantly reduce strength measurements. No cyclic loading in a moist environment was performed in the present study, and this is a study limitation.

After filling the mold, hand pressure was applied for 30 seconds until contact was established between the mold. The pressure was not standardized and this is a study limitation.

Conclusion:-

When the mean fracture toughness values of the two provisional restorative materials were evaluated and compared before and after reinforcement of Kevlar fibre and the following conclusions were drawn:

1. The mean fracture toughness values of the bisacryl composite were comparatively greater than that of PMMA provisional restorative material.
2. The mean fracture toughness values of the bisacryl composite after Kevlar reinforcement were comparatively greater than that of PMMA provisional restorative material after Kevlar reinforcement.
3. Comparing the mean values, Kevlar reinforcement technique proved to be efficient method to improve the fracture toughness for both the materials.
4. Comparing the mean values of both the materials before and after reinforcement with Kevlar fibre, bisacryl composite after Kevlar reinforcement shows greater fracture toughness values.

When the mean flexural strength values of the two provisional restorative materials were evaluated and compared before and after reinforcement of Kevlar fibre and the following conclusions were drawn:

1. The mean flexural strength values of the bisacryl composite were comparatively greater than that of PMMA provisional restorative material.
2. The mean flexural strength values of the bisacryl composite after Kevlar reinforcement were comparatively greater than that of PMMA provisional restorative material after Kevlar reinforcement.
3. Comparing the mean values, Kevlar reinforcement technique proved to be efficient method to improve the flexural strength for both the materials.
4. Comparing the mean values of both the materials before and after reinforcement with Kevlar fibre, bisacryl composite after Kevlar reinforcement shows greater flexural strength values.



Figure 1:- Fracture toughness mold.



Figure 2:- Flexural strength mold.



Figure 3:- Polymethyl methacrylate polymer and monomer.



Figure 4:- Bisacryl composite.



Figure 5:- Kevlar fibre.

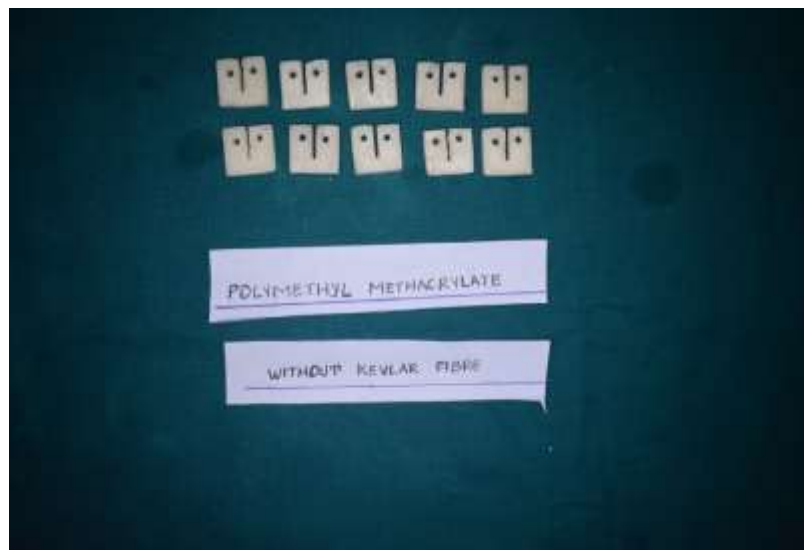


Figure 6:- Polymethyl methacrylate without Kevlar fibre (Fracture toughness).



Figure 7:- Bisacryl composite without Kevlar fibre (Fracture toughness).



Figure 8:- Polymethyl methacrylate with Kevlar fibre (Fracture toughness).



Figure 9:- Bisacryl composite with Kevlar fibre (Fracture toughness).



Figure 10:- Polymethyl methacrylate without Kevlar fibre (Flexural strength).



Figure 11:- Bisacryl composite without Kevlar fibre (Flexural strength).

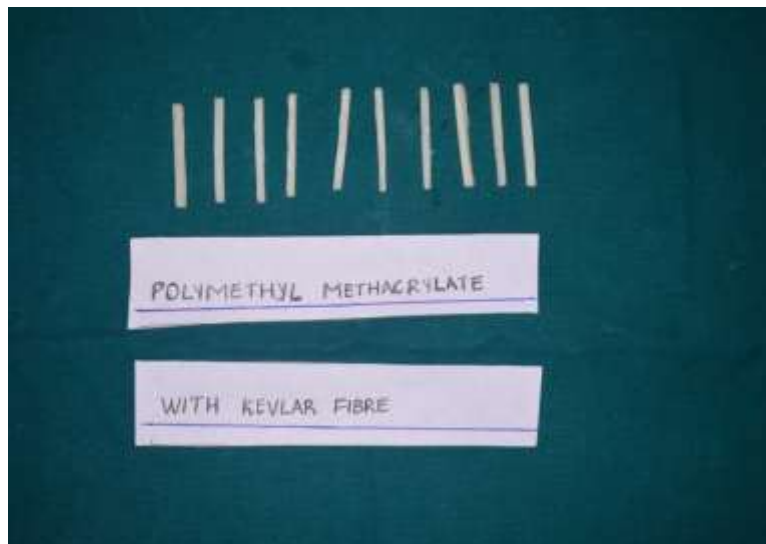


Figure 12:- Polymethyl methacrylate with Kevlar fibre (Flexural strength).



Figure 13:- Bisacryl composite with Kevlar fibre (Flexural strength).



Figure 14:- Samples subjected to fracture toughness on universal testing machine.



Figure 15:- Samples subjected to flexural strength on universal testing machine.

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