



RESEARCH ARTICLE

COMPARISON AND EVALUATION OF FLEXURAL STRENGTH OF HEAT POLYMERIZED ACRYLIC RESIN AFTER REPAIR WITH ZIRCONIA OXIDE AND ALUMINIUM OXIDE REINFORCED AUTOPOLYMERIZING ACRYLIC RESIN WITH TWO DIFFERENT REPAIR DESIGNS AND WITH AND WITHOUT SURFACE TREATMENT - AN INVITRO STUDY

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Abstract

Aim: The aim of this study was to evaluate and compare flexural strength of repaired heat polymerized acrylic resin with zirconia oxide and aluminium oxide nanoparticles incorporated autopolymerized acrylic resin and to evaluate effect of butt and bevel joint design of repair with and without chemical surface treatment.

Materials and Method: A total of 165 heat cure acrylic resin specimens were fabricated and divided into 3 main groups. Group A had 15 intact specimens whereas group B and group C were further divided into 5 subgroups depending on repair material, repair design and chemical surface treatment used. Each subgroup had 15 specimens. 7wt% zirconia oxide and 2wt% aluminium oxide nanoparticles used as reinforcement material into autopolymerized acrylic resin and compared with unreinforced autopolymerized resin used for repair. Butt and bevel joint designs and ethyl acetate as a chemical surface treatment used for repair of acrylic specimens. The specimens were subjected to flexural strength in a universal testing machine until specimens fractured and load values were recorded. Flexural strength was calculated in MPa (Megapascal) and analysed using Independent t test, One Way ANOVA and Post hoc Tukey's test.

Results: The flexural strength values obtained were highly significant for nanoparticles reinforced groups than unreinforced autopolymerized resin. Also zirconia oxide nanoparticles showed higher values than aluminium oxide nanoparticles. Similarly, repair with bevel joint design and with chemical surface treatment with ethyl acetate proved to be better.

Conclusion: Under the conditions of this study, 7wt% zirconia oxide and 2wt% aluminium oxide reinforced autopolymerized resin with bevel joint design and chemical surface treatment with ethyl acetate can be recommended for acrylic repair.

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Introduction:-

Polymethyl methacrylate (PMMA) is the most common denture base material used and it was introduced in 1937 by Dr. Walter Wright and Vernon brothers.^{1,2} The main attributes of acrylic resin that have made it successful as denture base material include biocompatibility, aesthetics, accurate fit, stability in the oral environment, ease of fabrication and adjustment, low cost, and possibility of repair.¹ But unfortunately, polymethyl methacrylate has poor mechanical properties, which often results in denture base fractures. These fractures may occur inside the patient's mouth or outside the patient's mouth when the removable prosthesis drops suddenly.¹

Denture fracture is a common problem in prosthodontic practice that troubles both patients and prosthodontists. A new denture fabrication increases the cost and is time consuming, so denture repair is preferred.^{1,2} Satisfactory repair should be easy and rapid and match the original colour of the denture base while maintaining the dimensional accuracy restore original strength.^{1,2} Denture repair depends on many factors including material type, material reinforcement, surface design, and surface treatment.

Several materials have been used to repair fractured denture bases, including autopolymerized, visible light polymerized, heat polymerized, or microwave polymerized acrylic resin.^{1,2} Most (86%) of denture base repairs are made with autopolymerized acrylic resin, because it is easy to manipulate and fast and can be used chair-side.²

Although autopolymerized resin is the most common material used for repair, its strength has been shown to be half that of intact heat-polymerized denture resin.¹ Hence, repeated fracture of the repaired denture bases has been reported to be frequently related to the low strength of the autopolymerized repair resin. For adequate repair strength, many attempts have been made to modify repair surface design and/or reinforce the repair resin. Different design modifications of repaired joints have been made by increasing the surface area, which therefore improves the bond strength. Ninety-degree butt and 45° bevel joint designs have been found to affect repair strength.¹ Furthermore, the fracture of the repaired specimens often occurs at the junction of the old and new materials. This finding clearly indicates that the interface of the old and new materials is the location of stress concentration during flexural strength testing. Denture repairs involve joining two parts of a fractured denture bases with a denture repair material.³ So the effect of surface treatment to the sites to be joined need to be studied.

In recent years, nanomaterials have captured more and more attention because of their unique structures and properties such as they have small size, large surface area, high surface energy etc.^{4,5} Recently, much attention has been directed towards the incorporation of inorganic nanoparticles into polymethyl methacrylate to improve its properties. Various nanoparticles such as zirconia oxide, aluminium oxide, titanium oxide, silicon dioxide have been used to improve the performance of PMMA, and the results showed that desired mechanical property enhancement can be achieved.^{4,5}

Since only limited amount of data regarding the effect of metal oxide nanoparticles on repair resin with different joint designs of repair and with chemical surface treatment are available in literature, this study compared and evaluated effect of two nanoparticles, zirconia oxide and aluminium oxide on flexural strength of repaired heat polymerized acrylic resin reinforced with autopolymerizing acrylic resin for butt joint and bevel joint with and without chemical surface treatment using ethyl acetate.

Materials and Method:-

Specimen preparation: A total of 165 specimens of heat-polymerized acrylic resin were prepared and divided into 3 groups. For control group specimens (GROUP A), 15 specimens were prepared for the flexural strength test in dimensions of 65×10×2.5 mm in accordance with the ADA specification no 12. The specimens were prepared using a customized metal trough (Figure 1) of appropriate dimension. Metal trough was placed on a glass slab and modelling wax (Hindustan dental product, Hyderabad, India) was melted and poured into the trough to get wax specimens of appropriate dimensions and another glass slab was placed over it to get a proper finish on both surfaces. Wax patterns were then flaked and invested in dental flask using a type III dental stone. In each flask 3 wax patterns were invested using 2 stage pour technique. Dewaxing was done at 100°C for 5 minutes. Separating medium was applied. Heat polymerized acrylic resin (PMMA)(Dental Products of India, Heat Cure, Mumbai, India) was mixed in polymer to monomer ratio of 3:1 by volume respectively in a porcelain jar. When the material reached

dough stage it was packed in the flask and kept under pressure of 2000 MPa for bench curing of 30 minutes. Once the bench curing was done, the flasks were clamped and polymerized using short curing cycle. After the flasks were cooled, the specimens were deflashed and the excess material was trimmed using tungsten carbide bur. Specimens for repair group were divided into 2 groups, 75 specimens were made up of butt joint (GROUP B) and 75 specimens were made with bevel joint (GROUP C). To standardize the butt and bevel joints modified metal plates were used. For butt joint, plate dimension is 31.25 mm in length, width is 10 mm, thickness is 2.5 mm (Figure 2). For bevel joint, plate dimension is 31.25 mm for lower surface and 30 mm for upper surface, width is 10 mm and thickness is 2.5 mm (Figure 3).

These customized metal plates were used to make wax patterns and were subjected to the same flasking procedure as the control group and mold spaces were cleaned, packed, processed, and finished. Control (Figure 4) and repair group specimens (Figure 5 and 6) were stored in distilled water at 37°C for 7 days.

Silanization of zirconia oxide and aluminium oxide nanoparticle: Silane coupling agent (Monobond-N, Ivoclar Vivadent, India) was added to zirconia oxide (Figure 7) and aluminium oxide (Figure 8) nanoparticles. Aluminium oxide (Sisco Research Laboratories Pvt. Ltd., Mumbai) and zirconia oxide (Sigma Aldrich, India) nanoparticles were silanized using silane coupling agent before incorporation in polymer. To achieve this, silane coupling agent was dissolved in acetone and this mixture was then added into the nanoparticles (Figure 9) to ensure that it would evenly coat the surfaces of the zirconia oxide and aluminium oxide nanoparticles.

Nanocomposite preparation: The silanized nano-zirconia oxide and aluminium oxide nanoparticles were weighed using an electronic weighing machine (Sartorius GE 412, Germany) (Figure 10) and added in concentrations of 7wt% for zirconia oxide and 2wt% for aluminium oxide to autopolymerized acrylic polymer powder which was used as a repairing material.

Repair procedure: The metal molds that were used to fabricate the control group's specimens were used to hold the reassembled specimens for repair (Figure 11). Group B and group C specimens were further divided into 5 subgroups (Subgroup B1, B2, B3, B4, B5 and Subgroup C1, C2, C3, C4, C5) which had 15 specimens in each subgroup, depending on reinforcement and surface treatment received. Subgroup B1 and C1 were repaired with unreinforced autopolymerizing resin (DPI-RR Cold cure, Mumbai, India) without surface treatment. Subgroup B2 and C2 were repaired with 7wt% zirconia oxide reinforced autopolymerized acrylic resin without surface treatment. Subgroup B3, C3 were repaired with 7wt% zirconia oxide reinforced autopolymerized acrylic resin with surface treatment with ethyl acetate for 3 minutes. Subgroup B4 and C4 were repaired with 2wt% aluminium oxide reinforced autopolymerized acrylic resin without surface treatment. Subgroup B5 and C5 were repaired with 2wt% aluminium oxide reinforced autopolymerized acrylic resin with surface treatment with ethyl acetate for 3 minutes. For repair procedure, the mixed nano-composite powder was dispersed in a methyl methacrylate monomer and then the materials were mixed and packed into the repair area, adding an excess amount to compensate for polymerization shrinkage. After polymerization, the specimens were removed from the molds, and the excess acrylic resin was removed with a tungsten carbide bur at a low speed. Next, all specimens were finished, using a 600-grit abrasive paper under running water, and then specimens were stored in distilled water at 37°C for 48±2 hours.

Flexural strength test- To determine flexural strength, fracture load was measured using a three point bending test on a universal testing machine (UTE-20, FIE, Fuel Instruments and Engineers Private Limited, Maharashtra, India). The specimens were placed on a three-point flexure apparatus with a 50 mm distance between two supports. A load was applied at the midpoint of the repaired area (Figure 12) with a crosshead speed of 5 mm/min until the specimen fractured. Fracture load was recorded. The formula $S = 3WL/2bd^2$ was used to calculate the flexural strength values of each specimen, where S is the flexural strength (MPa), W is the fracture load (N), L is the distance between the two supports, b is the specimen width, and d is the specimen thickness.

Statistical Analysis:

Statistical analysis was performed using SPSS software. 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 Independent t test and One Way ANOVA and Post hoc Tukey's test for comparison. The level of significance was set at 0.05 for 95% Confidence Interval.

Results:-

The testing of flexural strength of the specimens were carried out in Universal Testing Machine. The flexural strength values were expressed in megapascals (MPa).

When independent t test was applied to mean flexural strength for 3 main groups and 5 subgroups each, the results obtained revealed highly significant differences between groups and subgroups. (Table 1). The results showed that mean flexural strength values for the intact specimens were higher than repaired specimens.

Statistical comparison of mean flexural strength values between specimens repaired with butt joint design (SUBGROUP B1, B2, B3, B4, B5) in table 2 showed significantly higher flexural strength values for subgroup B3, B2 followed by B5 and B4. . Subgroup B1 showed lesser flexural strength values compared to subgroups B2, B3, B4 and B5 which revealed that mean flexural strength values of specimens repaired with reinforced acrylic resin with nanoparticles were higher than that of unreinforced acrylic resin. Table 2 also showed that surface treatment with ethyl acetate showed higher mean flexural strength values than without surface treatments for both zirconia oxide and aluminium oxide nanoparticles. The values obtained were highly significant.

Statistical comparison of mean flexural strength values between specimens repaired with bevel joint design (SUBGROUP C1, C2, C3, C4, C5) in table 3 showed significantly higher flexural strength values for subgroup C3, C2 followed by C5 and C4 and subgruop C1 showed lesser value.

Table 3 also showed that surface treatment with ethyl acetate showed higher mean flexural strength values than without surface treatments for both zirconia oxide and aluminium oxide nanoparticles. The values obtained were highly significant.

Statistical comparison of mean flexural strength values between specimens repaired with butt and bevel joint designs (Subgroup B1, B2, B3, B4, B5 and Subgroup C1, C2, C3, C4, C) in table 4 showed significantly higher mean flexural strength values by subgroup C3 and C2 when the specimens repaired with zirconia oxide reinforced acrylic resin and subgroup C5 and C4 showed significantly higher mean flexural strength values repaired with aluminium oxide reinforced acrylic resin. Hence table 4 revealed that mean flexural strength values of specimens repaired with nanoparticles incorporated acrylic resin for bevel joint design were higher when compared to butt joint design for a particular nanoparticle. The values obtained were statistically highly significant.

Multiple comparison between the two repair joint designs with two different nanoparticles with and without surface treatment with ethyl acetate in table 5 showed highly significant values. It revealed that, for both the nanoparticles, specimens repaired with surface treatment with ethyl acetate and bevel joint design showed higher values. It also showed that zirconia oxide incorporated acrylic resin repaired specimens showed higher mean flexural strength values than aluminium oxide incorporated acrylic resin for both butt and bevel joint design.

Comparison of mean flexural strength values of repaired specimens with butt and bevel joint design with and without surface treatment are graphically represented in graph 1. Comparison of mean flexural strength values of repaired specimens between butt and bevel joint design are graphically represented in graph 2.

Table 1:- Comparison of mean flexural strength values between intact specimens and all repaired specimens (by Independent t test)

	Mean (MPa)	Standard deviation	T	Significance
Intact heat polymerized specimens	120.9467	4.86414	54.504	0.003 (H.S)
B1	48.8800	1.60143		
Intact heat polymerized specimens	120.9467	4.86414	51.056	0.027 (S)
B2	50.0800	2.28885		
Intact heat polymerized specimens	120.9467	4.86414	29.063	0.006 (H.S)
B3	81.9200	1.84050		

Intact heat polymerized specimens	120.9467	4.86414	25.176	0.009 (H.S)
B4	86.9600	1.91714		
Intact heat polymerized specimens	120.9467	4.86414	25.222	0.002 (H.S)
B5	88.0800	1.34547		
Intact heat polymerized specimens	120.9467	4.86414	22.397	0.008 (H.S)
C1	90.7200	1.91356		
Intact heat polymerized specimens	120.9467	4.86414	38.492	0.003 (H.S)
C2	70.3867	1.48990		
Intact heat polymerized specimens	120.9467	4.86414	32.608	0.016 (S)
C3	75.6000	2.31270		
Intact heat polymerized specimens	120.9467	4.86414	32.847	0.004 (H.S)
C4	77.1867	1.72124		
Intact heat polymerized specimens	120.9467	4.86414	31.094	0.002 (H.S)

Table 2:- Comparison of mean flexural strength values between specimens repaired with butt joint design (Subgroup B1, B2, B3, B4, B5) (by One Way ANOVA).

		Mean (MPa)	Standard deviation	F	Significance
B	Unreinforced autopolymerizing acrylic resin (B1)	48.8800	1.60143	1321.986	.000 (H.S)
	7 wt % zirconia oxide reinforced autopolymerizing acrylic resin without surface treatment (B2)	81.9200	1.84050		
	7 wt % zirconia oxide reinforced autopolymerizing acrylic resin with surface treatment (B3)	88.0800	1.34547		
	2 wt % aluminium oxide reinforced autopolymerizing acrylic resin without surface treatment (B4)	70.3867	1.48990		
	2 wt % aluminium oxide reinforced autopolymerizing acrylic resin with surface treatment (B5)	77.1867	1.72124		

HS – Highly Significant

Table 3:- Comparison of mean flexural strength values between specimens repaired with bevel joint design (Subgroup C1, C2, C3, C4, C5) (by One Way ANOVA).

		Mean (MPa)	Standard deviation	F	Significance
C	Unreinforced autopolymerizing acrylic resin (C1)	50.0800	2.28885	966.901	.000 (H.S)
	7 wt % zirconia oxide reinforced autopolymerizing acrylic resin without surface treatment (C2)	86.9600	1.91714		
	7 wt % zirconia oxide reinforced autopolymerizing acrylic resin with surface treatment (C3)	90.7200	1.91356		
	2 wt % aluminium oxide reinforced autopolymerizing acrylic resin without	75.6000	2.31270		

	surface treatment (C4)				
	2 wt % aluminium oxide reinforced autopolymerizing acrylic resin with surface treatment (5)	80.3200	1.39550		

HS – Highly Significant

Table 4:- Comparison of mean flexural strength values between specimens repaired with butt and bevel joint design (by Independent t test).

		Mean (MPa)	Standard deviation	T	Significance
Unreinforced autopolymerizing acrylic resin	B1	48.8800	1.60143	-1.664	0.107 (N.S)
	C1	50.0800	2.28885		
7 wt % zirconia oxide reinforced autopolymerizing acrylic resin without surface treatment	B2	81.9200	1.84050	-7.345	0.000 (H.S)
	C2	86.9600	1.91714		
7 wt % zirconia oxide reinforced autopolymerizing acrylic resin with treatment	B3	88.0800	1.34547	-4.371	0.000 (H.S)
	C3	90.7200	1.91356		
2 wt % aluminium oxide reinforced autopolymerizing acrylic resin without treatment	B4	70.3867	1.48990	-7.339	0.000 (H.S)
	C4	75.6000	2.31270		
2 wt % aluminium oxide reinforced autopolymerizing acrylic resin with treatment	B5	77.1867	1.72124	-5.477	0.000 (H.S)
	C5	80.3200	1.39550		

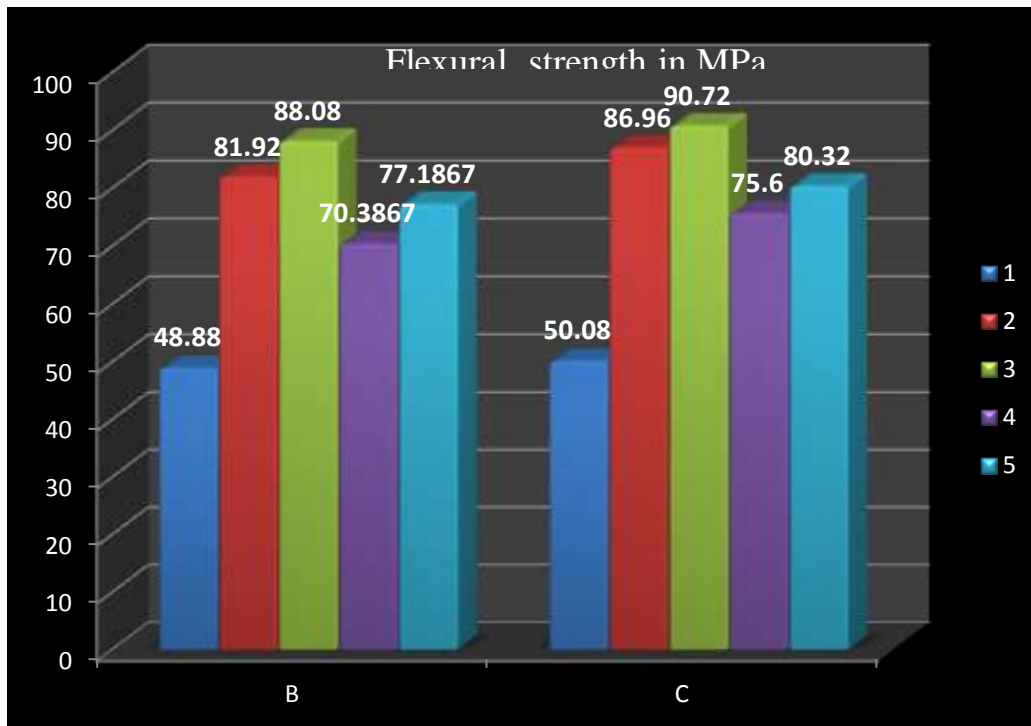
NS – Non Significant

HS – Highly Significant

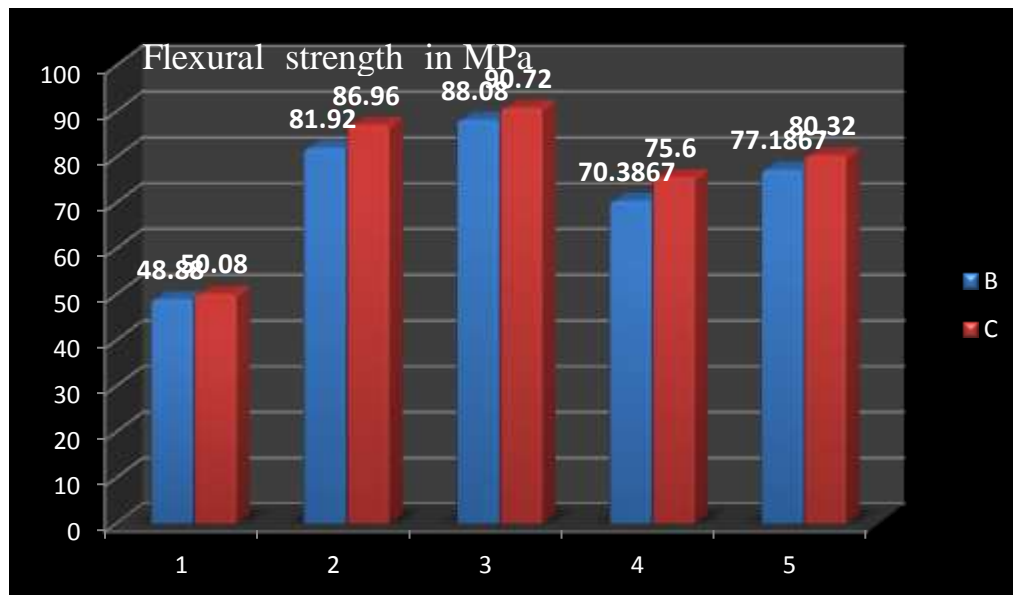
Table 5:- Multiple comparisons between specimens repaired with two different nanoparticles, with and without surface treatment and with two different joint designs (by Post hoc Tukey's test).

			Mean difference	Standard error	Significance	95% Confidence Interval	
						Lower bound	Upper bound
B	1	2	-33.04000	.58753	.000 (H.S)	-34.6852	-31.3948
		3	-39.20000	.58753	.000 (H.S)	-40.8452	-37.5548
		4	-21.50667	.58753	.000 (H.S)	-23.1518	-19.8615
		5	-28.30667	.58753	.000 (H.S)	-29.9518	-26.6615
	2	3	-6.16000	.58753	.000 (H.S)	-7.8052	-4.5148
		4	11.53333	.58753	.000 (H.S)	9.8882	13.1785
		5	4.73333	.58753	.000 (H.S)	3.0882	6.3785
	3	4	17.69333	.58753	.000 (H.S)	16.0482	19.3385
		5	10.89333	.58753	.000 (H.S)	9.2482	12.5385
	4	5	-6.80000	.58753	.000 (H.S)	-8.4452	-5.1548
C	1	2	-36.88000	.72796	.000 (H.S)	-38.9184	-34.8416
		3	-40.64000	.72796	.000 (H.S)	-42.6784	-38.6016
		4	-25.52000	.72796	.000 (H.S)	-27.5584	-23.4816
		5	-30.24000	.72796	.000 (H.S)	-32.2784	-28.2016
	2	3	-3.76000	.72796	.000 (H.S)	-5.7984	-1.7216
		4	11.36000	.72796	.000 (H.S)	9.3216	13.3984
		5	6.64000	.72796	.000 (H.S)	4.6016	8.6784
	3	4	15.12000	.72796	.000 (H.S)	13.0816	17.1584
		5	10.40000	.72796	.000 (H.S)	8.3616	12.4384
	4	5	-4.72000	.72796	.000 (H.S)	-6.7584	-2.6816

HS – Highly significant



Graph 1:- Comparison of mean flexural strength values of repaired specimens with butt joint design (GROUP B) and bevel joint design (GROUP C).



Graph 2:- Comparison of mean flexural strength values of repaired between butt (GROUP B) and bevel joint design (GROUP C).

Discussion:-

Polymethyl methacrylate (PMMA) is the most commonly used denture base material used.^{1, 2} Despite PMMA's wide use as a main component of denture bases, this material will sometimes fracture during clinical use. One of the factors that can lead to fracture is low resistance to impact, flexural or fatigue, or poor fabrication technique.^{3, 21} These fractures may occur inside the patient's mouth or outside the patient's mouth when the removable prosthesis drops suddenly. A new denture fabrication increases the cost and is time consuming, so denture repair is

preferred.¹Denture repair depends on many factors including material type, material reinforcement, surface design, and surface treatment.⁴

The purpose of this in vitro study was to evaluate flexural strength of heat polymerized acrylic resin after repair with zirconia oxide and aluminium oxide nanoparticles reinforced autopolymerizing acrylic resin with two different repair designs and with and without surface treatment.

Although various methods have been proposed for repairing fractured denture bases, the use of autopolymerizing acrylic resin, allowing for simple and quick repair, is the most common and popular.⁵ Most (86%) of denture base repairs are made with autopolymerized acrylic resin, because it is easy to manipulate and fast and can be used chair-side.⁴For adequate repair strength, many attempts have been made to modify repair surface design and/or reinforce the repair resin.¹In recent years, nanomaterials have captured more and more attention because of their unique structures and properties such as they have small size, large surface area, high surface energy.^{14,15} Hence metal oxide nanoparticles are suitable additives for the improvement of PMMA formulations.^{6,7} In this study, 7wt% zirconia oxide nanoparticles (Sisco Research Laboratories Pvt. Ltd., Mumbai) and 2wt% aluminium oxide nanoparticles(Sigma Aldrich, India) were used.

The resin and filler interface adhesion was an important factor that affected PMMA and nanoparticle composite properties.¹Hence, modification of filler surface was necessary to achieve good bonding between filler and resin matrix.^{1,17} So, surface modification of filler was done by using silane coupling agent to improve surface bonding with resin matrix. In this study, silane coupling agent (Monobond-N, Ivoclar Vivadent, India) was added to nanoparticles resulted in the creation of reactive groups on its surface, which allows for adequate adhesion between nanoparticles and the resin matrix.

Based on the results of the current study, the flexural strength of intact heat cure acrylic specimens was significantly higher than all the repaired acrylic specimens which was in agreement with the results of previous studies.^{1,4} This decrease in the flexural strength may be due to lower strength of autopolymerized acrylic resin which was used as a repair material, insufficient polymerization process and the residual monomer retained at the repair site⁴

Addition of aluminium oxide and zirconiaoxide nanoparticles has significantly improved the flexural strength of repaired PMMA specimens. Results obtained were highly significant. This may be attributed to the uniform distribution of the filler within the matrix.^{1,2,4} Aluminum oxide possesses strong ionic interatomic bonding, giving rise to its desirable material characteristics. Alpha phase alumina is the strongest and stiffest of the oxide ceramics. Addition of alumina significantly improved the flexural strength of the polymer tested, and this may be attributed to the proper uniform distribution and bonding of the filler within the matrix.¹⁶

Increase in flexural strength shown by addition of zirconia oxide nanoparticles could be attributed to nano-ZrO₂ particle sizes, their uniform distribution within the repair material and in addition, the transformation of ZrO₂ from the tetragonal to monoclinic phase resulted in absorbing the energy of crack propagation in a process called transformation toughening. In addition, during this process, the expansion of ZrO₂ crystals occurred and placed the crack under a state of compressive stress, which led to the arresting of crack propagation.^{1,4}Ahmed and Ebrahim investigated effect of zirconium oxide nano-fillers addition on the flexural strength, fracture toughness, and hardness of heat-polymerized acrylic resin and results showed that zirconium oxide nanofillers added to PMMA has a potential as a reliable denture base material with increased flexural strength, fracture toughness, and hardness.²²Hence, it could be inferred that the autopolymerized acrylic resin reinforced with aluminium oxide and zirconia oxide nanoparticles was helpful in repairing fractured PMMA acrylic specimens.

The fracture of the repaired specimens often occurs at the junction of the old and new materials rather than through the center of the repair where the load is applied. Hence correct surface preparation means a strong bonding interface, which can improve the repair strength and reduce stress concentration.⁶In this study, to evaluate the effect of surface treatment on flexural strength of repaired acrylic specimens, half of the specimens were treated with chemical ethyl acetate(SDFCL – s d fine – chem limited, Mumbai, India)for 180 seconds. Remaining half specimens were without any surface treatment.The results of this study showed that, specimens which were treatedwith chemical ethyl acetate showed higher mean flexural strength than specimens without surface treatment. This could be explained by the fact that the chemical surface treatment cause superficial crack propagation, as well as the formation of numerous pits approximately 2 mm in diameter. This surface morphologic change may enhance the

mechanical retention between fractured surface and repaired acrylic resin. This enhances mechanical interlocking, further improving adhesion between surfaces to be joined.^{5,6}

As all the specimens treated with chemical surface treatment showed higher mean flexural strength values than specimens without surface treatment, it could be inferred that surface treatment with ethyl acetate could be an effective alternative chemical surface treatment.

In the current study, two types of surface joint designs were used that is butt joint design and bevel joint design. Specimens repaired with reinforced autopolymerized acrylic resin with nanoparticles with bevel joint design showed higher mean flexural strength values than specimens repaired with butt joint design. The values obtained are highly significant. This strength increase might be due to the 45° beveling, which increased the interface surface area and consequently provided a wide bond area. Mechanically, the 45° beveling might also shift the damaged area's tensile stress to the shear stress at the interface of the repaired specimens.¹ On the other hand, small surface area provided by the butt joint, which resulted in decreased flexural strength than bevel joint design.^{1,26}

Ward et al observed that the transverse strength of the butt joint was significantly less than that of the rounded or 45° bevel joints.²⁹ The 45° bevel joint is preferred clinically, since it is easier to prepare and finish a beveled joint than a rounded joint.²⁶

Denture fracture in clinical use occurs from a large transitory force caused by an accident or a small force during repeated chewing. Flexural stresses that are counteracted by the flexural strength of the material are a constant phenomenon during mastication. Considering that complete dentures are subjected to repeated flexural forces, it is important to evaluate the flexural strength of acrylic resins. Flexural strength is a combination of tensile and compressive strengths and is considered relevant to the masticatory loading characteristics of a denture base in the clinical situation.^{1,20,21,30,31} Therefore, flexural strength test method was performed in this study.

This study had some limitations. The limitations of the study include the absence of artificial aging with thermal cycling and the use of rectangular specimens instead of more complex denture shapes. Also, this study has tested only flexural strength of repaired specimens, it is suggested that for future research, other mechanical properties can be investigated.

Future studies are required that evaluate the effects of different nanoparticles reinforcement on the properties of repaired denture base resins when specimens are stored in water or artificial saliva for a longer duration. Further clinical studies should be proposed that investigate the clinical performance of these nanomaterials inside the oral cavity and its effects in cases of repeated denture fracture. Further, in vivo studies would definitely give more information and clear understanding about the clinical performance of nanoparticles.

Within the limitations of the study, following conclusions were drawn:

1. The mean flexural strength of intact heat cure acrylic specimens were significantly higher than repaired acrylic specimens.
2. Acrylic specimens repaired with reinforced autopolymerized acrylic resin with 7wt% zirconia oxide and 2wt % aluminium oxide showed significantly higher mean flexural strength values than specimens repaired with unreinforced autopolymerized acrylic resin.
3. When compared among the repaired groups with incorporation of both zirconia oxide and aluminium oxide nanoparticles after chemical surface treatment with ethyl acetate, it showed that specimens repaired after chemical surface treatment showed significantly higher mean flexural strength values than specimens repaired without chemical surface treatment.
4. When compared among the groups with two different joint designs used for repair, specimens repaired with bevel joint design showed higher mean flexural strength values than butt joint design.
5. Among the groups repaired with both butt joint design and bevel joint designs, repair with zirconia oxide nanoparticles showed higher mean flexural strength than repair with aluminium oxide nanoparticles, but for both the nanoparticles, values obtained were highly significant than repair with unreinforced acrylic resin.

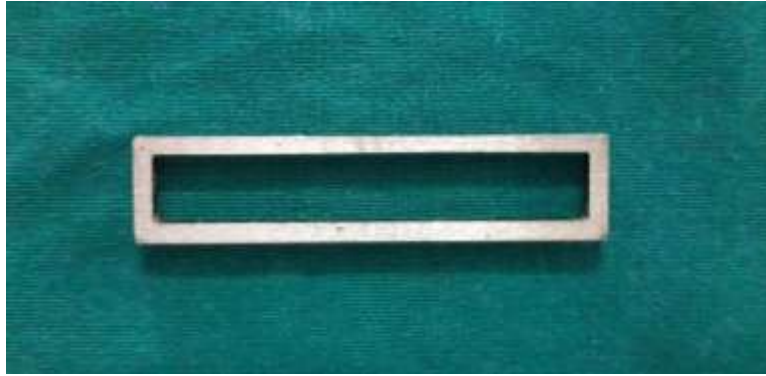


Figure 1:- Metal trough used for making intact acrylic specimens.

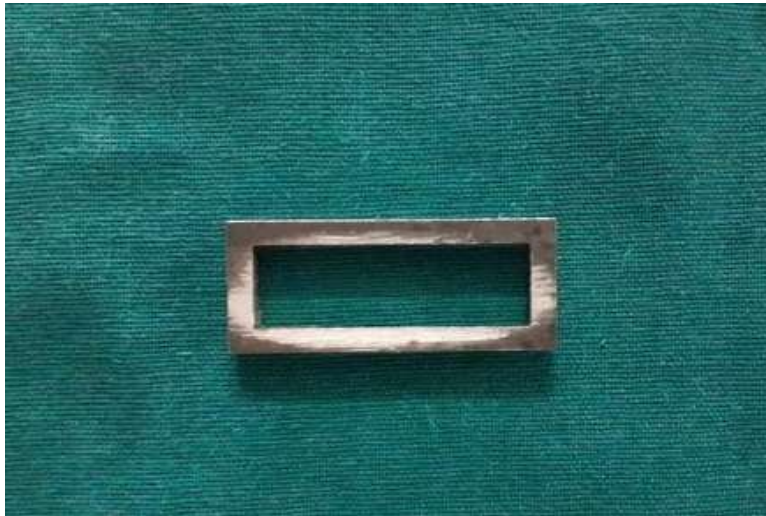


Figure 2:- Modified metal plate used for Making repair specimens with butt joint design.

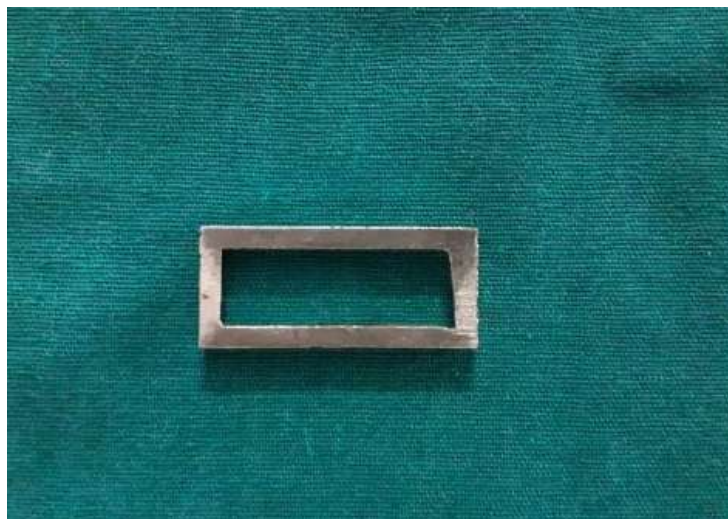


Figure 3:- Modified metal plate used for making repair specimens with bevel joint design.

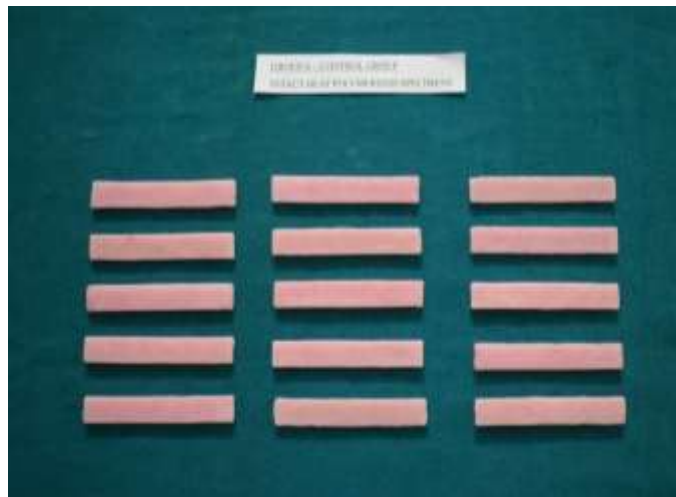


Figure 4:- Heat cured acrylic resin specimens.

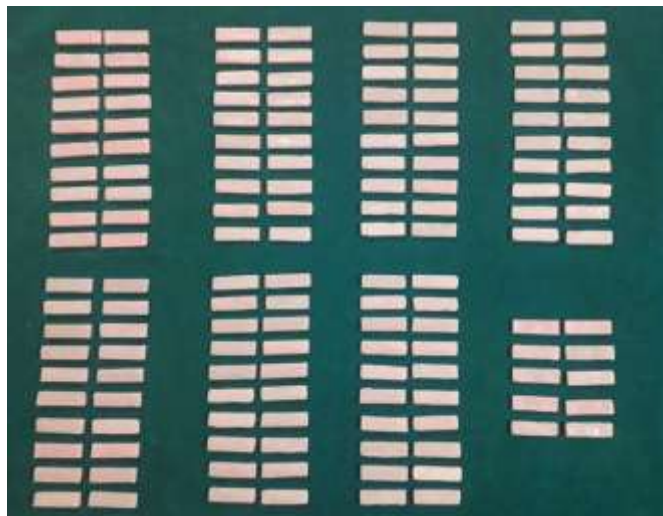


Figure 5:- 75 Pairs of heat cured acrylic resin specimens used for repair group with butt joint design.

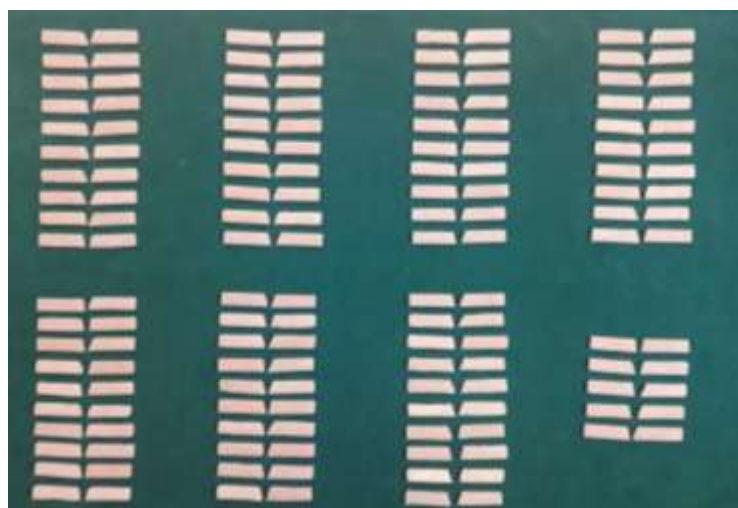


Figure 6:- 75 Pairs of heat cured acrylic resin specimens used for repair group with bevel joint design.



Figure 7:- Zirconium oxide Nanoparticles.



Figure 8:- Aluminium oxide nanoparticles.



Figure 9:- Addition of acetone into nanoparticles.



Figure 10:- Electronic weighing machine.

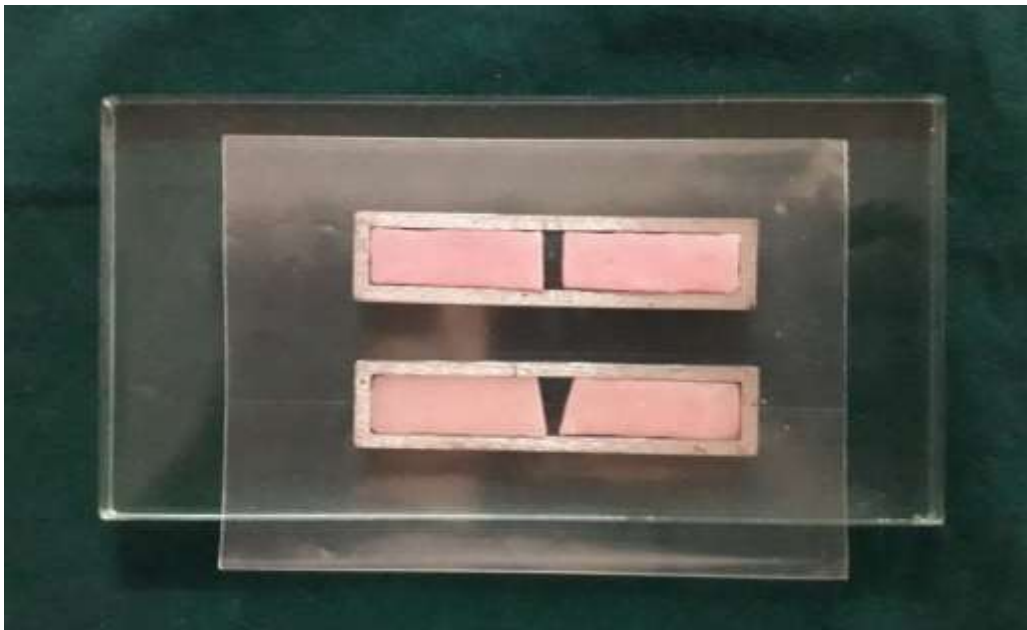


Figure 11:- Metal trough used to hold the specimens for repair for butt and bevel joint design.



Figure 12:- Load applied in repaired area of the specimen.

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