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RESEARCH ARTICLE

EVALUATION OF EFFECT OF ARAMID AND CARBON FIBER REINFORCEMENT IN AUTOPOLYMERIZING REPAIR RESIN USED TO REPAIR HEAT POLYMERIZED POLYMETHYL METHACRYLATE RESIN – AN IN VITRO STUDY

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ABSTRACT

Background: Denture fractures are common, reflecting the fact that both impact strength and flexural strength of the material are barely adequate. Objective: The purpose of the study was to evaluate the effect of aramid and carbon fiber reinforcement in autopolymerizing resin used to repair heat polymerized polymethyl methacrylate at 1mm and 3mm thickness respectively. **Materials and methods:** A total of 180, resin specimens using conventional heat polymerized PMMA resin and measuring (64mm×10mm×3.3mm) were fabricated in a preformed machined mold. A cantilever type bending forces was applied to each specimen till it fractured. The resin was relieved from bonding area to create 1mm and 3mm space. These fragments were realigned and repaired using conventional autopolymerizing resin and reinforced with carbon or aramid fibers. The specimens after repair were tested for impact strength using Izod type impact tester and for flexural strength using Universal testing machine. The data obtained was subjected to statistical analysis. **Results:** The results demonstrated that the mean impact strength values was significantly higher in polyaramid fiber reinforced PMMA repair group at 3mm thickness and the mean flexural strength values was significantly higher in polyaramid fiber reinforced PMMA repair group at 1mm thickness. **Conclusion:** Within the limitation of this study, it can be concluded that fiber reinforcement improved the strength of repair of the fractured heat-polymerized denture base. The strength after repair may be influenced by the gap at the repair region.

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INTRODUCTION

Over the last few decades, research in the field of dental materials has resulted in modification of the present materials and betterment of the existing materials for restorative application. The introduction of Poly methyl methacrylate (PMMA) resin in 1937 as denture base material by Walter Wright was a major breakthrough. It is the preferred material of choice for both complete and partial denture prostheses even with the advent of several newer materials such as polystyrene and light activated urethane dimethacrylate. The dentures made from PMMA resin are popular since they can be easily processed, possessed superior aesthetic properties, easy reparability, low cost factor and low water solubility. The factors that make it more vulnerable to failure generally are its reduced mechanical strength, low thermal conductivity, brittleness, high thermal expansion coefficient and low elastic modulus. Poor mechanical properties are considered to be one of the major drawback for long term clinical success of this material. Several attempts were made to improve mechanical properties of this material by increasing bulk of the material in the region of maximum stress application, by surface treatment with different chemicals or by its reinforcement with different materials. Impact and flexural strength still remain a requisite of denture base material, which needs to be improved in order to overcome the inherent liability for breakage Low laboratory cost and great expediency makes autopolymerizing poly methyl methacrylate repair resin as the choice of material to repair parent dentures. However, the mean flexural strength of parent denture base repaired using auto polymerized PMMA resin was reported as 57% of the parent denture before fracture. Fibres, oriented in a specific manner have been industrially used as a choice of reinforcing material for resins since decades. Such resins with fibers, reported tremendous increase in resistance against applied stress. It is based on the principle that a polymer matrix which is comparatively soft and ductile is capable of transferring the applied load to the fibers through shear forces present at the interface.

The fibers will be the main load-bearing constituents while the matrix forms a continuous phase to surround and hold the fibers in place. This study intends to assess the effect of aramid and carbon fibers reinforcement on autopolymerizing acrylic resin used to repair heat cured PMMA resin.

MATERIALS AND METHODS

Preparation of the mould: A custom made three piece stainless steel metal mold of dimensions (160mm× 100mm×3.3mm) was fabricated (HABIK institute Mangalore). The centre piece of the mold consisted of five rectangular cavities. Each cavity was of the dimension 64mm×1 0mm×3.3mm (Length×Width×Thickness) according to ISO 1567:19991. The three pieces of the custom made mold were assembled using four screws, at the corner of the mold and tightened using Taparia 5mm long ball point mm size Allen Key-KB 5L. (Fig. 1).

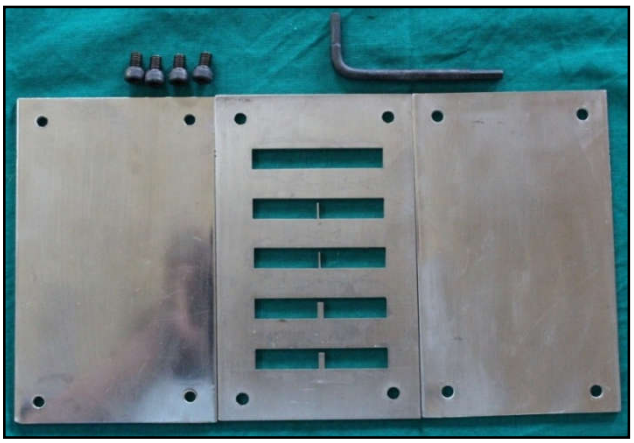

Fig. 1. Stainless steel metal mold

Preparation of the acrylic resin specimens: A total of 180 heat cure acrylic resin specimens were fabricated. The mold space was coated with a thin layer of white petroleum jelly for easy retrieval of the heat polymerized specimens. Conventional heat cured PMMA denture base resin was mixed in a porcelain jar according to manufacturer's recommended ratio (24g polymer to 10 ml of monomer). The resin when in dough stage was kneaded thoroughly and packed in the mould space. Trial closure was not done. Metal mold was closed under 2 MPa pressure in a bench press and bench cured for 60 minutes at room temperature. Following bench curing the screws were tightened at the four corners of the mold to maintain the pressure and the mold was removed from the hydraulic press. PMMA resin was polymerized using conventional compression molding technique. The mold was kept in a temperature controlled acrylizer and processing was carried out using the rapid curing cycle at 74 degree centigrade for 2 hours followed by boiling at 100 degree centigrade for 1 hour. After the curing cycle was completed, the metal mold was bench cooled to room temperature. The test specimens were carefully retrieved from the mold and flash if any was trimmed using fine grade tungsten carbide bur. All specimen surfaces were smoothened using 120 grit sand papers and each specimen was polished using rag wheel and felt cone with pumice slurry for 15 sec at the rate of 2800 rpm. The dimensions of the finished specimens (64mm×10mm×3.3mm) 1 were verified using vernier callipers and soaked overnight in water.

One surface of the test specimens was marked using an indelible marker. All the specimens were divided into two groups containing 90 samples each to check for impact strength and flexural strength respectively. The specimens in each group were distributed randomly into three groups, each group was further divided into two subgroups; each subgroup consisted of 15 specimens (n=15). A cantilever type bending forces was applied to each specimen till it fractured. These fractured specimens were realigned using the markings made earlier on one surface. The resin was relieved from bonding area to create 1mm and 3mm space. These realigned and relieved fragments were placed back into the mold cavity and repaired using conventional autopolymerizing resin and autopolymerizing resin reinforced with carbon or aramid fibers.

Unreinforced auto polymerizing PMMA resin repair: The surfaces to be repaired was wetted with auto polymerizing monomer for 1 minute. The auto polymerizing resin was mixed in a porcelain jar according to manufacturer's recommended ratio (24g polymer to 10 ml of monomer). The resin when in dough stage was kneaded thoroughly and packed in the mold cavity. The repair resin was allowed to polymerize in a pneumatic unit for 30 minutes at room temperature and 20 psi.

Carbon fiber reinforced repair: A two step repair procedure was performed. The first step involved wetting of the surfaces to be repaired with auto polymerizing monomer for 1 minute followed by auto polymerizing resin repair.2 The second step involved preparing a trough 6mm long and 1mm thick /deep and packing the space with Carbon fibers. A little of this space was packed with auto polymerizing resin mixed according to manufacturer's recommended ratio (24g polymer to 10 ml of monomer). The carbon fibers were coated with silane coupling agent (Silane A174) just prior to repair to provide proper adhesion between fibers and PMMA resin. Once the fibers were embedded in the auto polymerizing resin, additional auto polymerizing resin was packed over the fibers until the joint was slightly overfilled. The repair resin was allowed to polymerize in a pneumatic unit for 30 minutes at room temperature and 20 psi. Repair and reinforcement was carried out for carbon fiber reinforced repair at 3mm thickness in a similar manner (Fig. 2).

Fig. 2. Carbon fiber reinforced repaired sample

Polyaramid fiber reinforced repair: A two step repair procedure was performed. The first step involved wetting of the surfaces to be repaired with auto polymerizing monomer for 1 minute followed by auto polymerizing resin repair.2 The second step involved preparing a trough 6mm long and 1mm thick /deep and packing the space with reinforcing Polyaramid fibers. A little of this space was packed with auto polymerizing resin mixed according to manufacturer's recommended ratio (24g polymer to 10 ml of monomer). The polyaramid fibers of 6mm length were prewetted using monomer and placed evenly such that their orientation was perpendicular to the applied force. Once the fibers were placed, additional auto polymerizing resin was packed over the fibers until the joint was slightly overfilled. The repair resin was allowed to polymerize in a pneumatic unit for 30 minutes at room temperature and 20 psi. A uniform flat surface was created for all samples by finishing them using 120 grit sand paper and polishing with rag wheel and felt cone using pumice slurry. Repair and reinforcement was carried out for polyaramid fiber reinforced repair at 3mm thickness in a similar manner (Fig. 3).

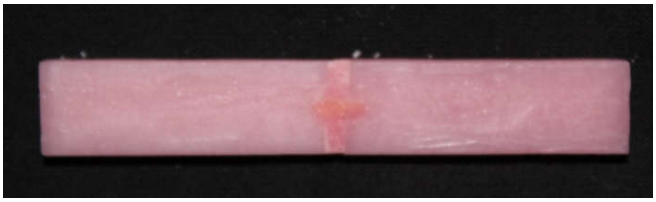

Fig. 3. Aramid fiber reinforced repaired sample

Testing of samples for impact strength and flexural strength: The specimens after repair were tested for impact strength using Izod type impact tester (computerized, software based) (Fig. 4). and for flexural strength using Universal testing machine [ACME Engineers, Model no.UNITEST-10, India] (Fig. 5). The specimens used for testing of impact strength were mounted vertically between the plates of Izod type impact tester (computerized, software based). The striker was raised to a specific height and then released; this striker then swung downwards hitting the mounted specimen mimicking a sudden impact. The impact strength value of the material was determined from the energy required to break the specimens.

Fig. 4. Izod impact testing machine with specimen in position

Fig. 5. Universal testing machine with specimen in position

Impact strength was calculated by the software within the machine using the formula: KJ/m2: Where, J was impact energy, m was thickness of specimen. The specimens used for testing flexural strength were mounted on the plates of Universal Testing Machine. Accuracy of the machine was +|-1% with cross head speed set at 5mm/minute and distance between supports was 50 mm. A three point bending test was carried out for each specimen till they were fractured. The energy needed to break the specimen was recorded and flexural strength values were calculated. Flexural strength was calculated using the formula: 3PL/2bd2 Where, P was fracture load, L was span between supports, d was thickness of specimen, b was width of specimen.

Statistical analysis: The data obtained was subjected to statistical analysis using, one-way ANOVA and the differences among the groups were assessed using Newman-Keuls multiple posthoc tests. P-values less than 0.05 were considered to be statistically significant.

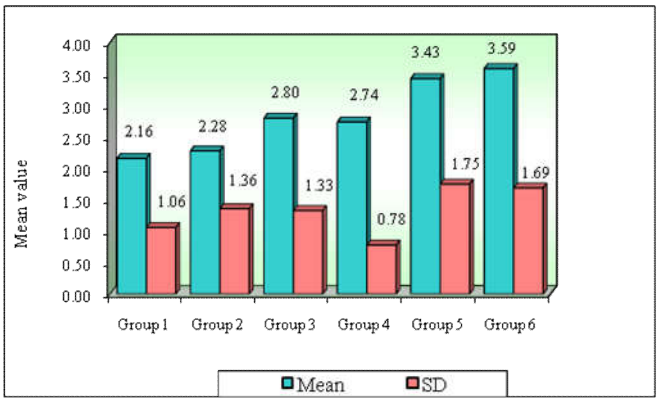

Fig. 6. Comparison of six study groups with mean impact strength scores

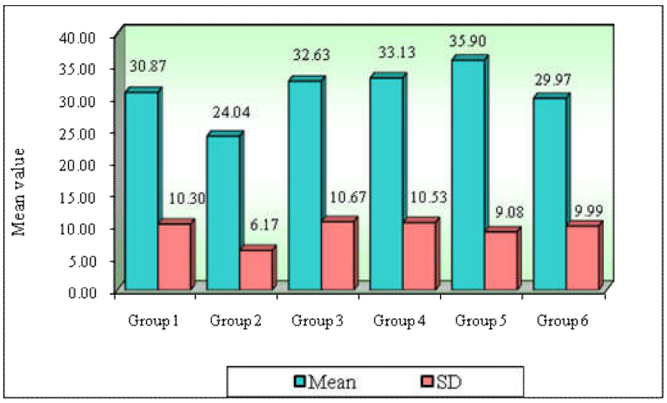

Fig. 7. Comparison of six study groups with mean flexural strength score

RESULTS

The mean impact strength of the unreinforced auto polymerizing PMMA repair at 1mm thickness subgroup was 2.15 KJ/m2 and repair at 3mm thickness subgroup was 2.27 KJ/m2. Carbon fiber reinforced repair at 1mm thickness subgroup was 2.80 KJ/m2 and repair at 3mm thickness subgroup was 2.74 KJ/m2. Polyaramid fiber reinforced repair at 1mm thickness subgroup was 3.43 KJ/m2 and repair at 3mm thickness subgroup was 3.59 KJ/m2. The data obtained was validated for normal distribution using Kolmogorov Smirnov test and were further analysed using One-way ANOVA test.

Table 1. The materials used in this study

Material	Manufacturer
DPI Heat Cure acrylic resin	Dental Products of India Ltd. Mumbai, India.
DPI cold Cure acrylic resin	Dental Products of India Ltd. Mumbai, India.
Aramid fibers (Kevlar)	DuPont company, Wilmington, Delaware.
Carbon fibers	Techinstros, Nagpur, India.
Silane A 174(coupling agent).	

One way ANOVA test done to compare the mean impact strength between the 6 study groups as P values were 0.0249, which was statistically significant. Newman-Keuls multiple posthoc procedures was done for pair wise comparison of the 6 study groups. The results demonstrated that the mean impact strength was found to be significantly higher in polyaramid reinforced PMMA repair group at 3mm thickness when compared to remaining groups. The mean flexural strength of the unreinforced auto polymerizing PMMA repair at 1mm thickness subgroup was 30.87 MPa and repair at 3mm thickness subgroup was 24.03 MPa. Carbon fiber reinforced repair at 1mm thickness subgroup was 32.63 MPa and repair at 3mm thickness subgroup was 33.12 MPa. Polyaramid fiber reinforced repair at 1mm thickness subgroup was 35.90 MPa and repair at 3mm thickness subgroup was 29.96 MPa. The data obtained was validated for normal distribution using Kolmogorov Smirnov test and analysed using One-way ANOVA test. One way ANOVA test done to compare mean flexural strength between the 6 study groups as P values were 0.0290, which was statistically significant. Newman-Keuls multiple posthoc procedures were done to check for pair wise comparison of the 6 study groups. The results demonstrated that the mean flexural strength was found to be significantly higher in polyaramid reinforced PMMA repair group at 1mm thickness when compared to remaining groups.

DISCUSSION

The present study was conducted to evaluate the effect of aramid and carbon fiber reinforcement in auto polymerizing resin used to repair heat polymerized polymethyl methacrylate with the repair gap at 1mm and 3mm thickness. Impact strength and flexural strength were the parameters tested to determine the changes if any after reinforcement. The measurement conditions used in this study were designed to simulate clinical conditions, where the thickness of the test specimens was around 3.3mm which stays within the thickness range of actual denture base polymer and the span of the impact and flexural test approximates to chewing.

Carbon fibers: Carbon fibers were made commercially available by Edison in the late 19th century by carbonizing thin bamboo shoots. The bulk of carbon fibers today is made by heating polyacrylonitrate in air at 200–250 °C and then in an inert atmosphere at 1200 °C. This process removes hydrogen, nitrogen and oxygen, leaving a chain of carbon atoms and thus forming carbon fibers (Yazdanie and Mahood, 1985). Carbon fibers can be added to PMMA as loose strands or in woven mat form. Dry fibers are difficult to handle, so the fibers can be wetted with monomer to form tows of wet fiber which have improved handling characteristics. In the present study carbon fibers were used in the form of loose strands, as it has been concluded that the properties after reinforcement with carbon in strand form were superior to woven mat form.3 Although use of carbon as a method of reinforcing PMMA had produced promising results, it has certain disadvantages like difficult handling characteristics of the fibers, need for precise placement in the resin, difficulty in polishing the denture base with carbon fibers incorporated and poor aesthetics due to the black color. The potential toxicity of these fibers was addressed in a study by Manley, Bowman and Cook (1979) who reported no long term toxicity or carcinogenicity involving the implantation of carbon fibers in rats.

Aramid fibers: Aramid is an organic compound called polypara-phenylene terephthalamide synthetic aramid polymer and is marketed as Kevlar. Polyaramid fiber has superior wettability compared to carbon fiber and does not require treatment with a coupling agent. Polyaramid fibers have greater tensile strength and modulus when compared to nylon, E-glass and carbon fibers. Problems encountered with the use of polyaramid fibers during trial packing may limit its routine application in denture base reinforcement. Lateral spreading of the fibers during packing of the acrylic resin results in a rough denture surface with extruded fibers that may cause mucosal irritation and discomfort to the patient. This can be avoided by careful handling of fibers during packing, proper finishing and polishing of dentures. Studies conducted by (Lee, Kelly and Kennedy, 1983; Dunnigan, Nadeau and Paradis, 1984) found no evidence of toxicity with the use of polyaramid fibers.

A sudden blow to the denture or accidental dropping during cleaning, coughing or sneezing results in denture fracture. Energy absorbed by the denture due to a sudden impact exceeds the mechanical capacity of the denture base material resulting in impact failure. The resin specimens with carbon and aramid fiber showed an increase in the impact strength compared to the unreinforced auto polymerizing PMMA specimens. This might be attributed to the presence of reinforcement fibers which absorb the impact force along their length to provide strength and stiffness to the specimen in one direction, resulting in higher absorption of energy compared with un-reinforced specimens. Increase in impact strength shown by aramid fiber reinforced group was significantly higher than that shown by carbon fiber. Aramid fibers are hydrophilic in nature and have high surface energy exhibiting good interfacial energy and better compatibility with PMMA when compared to carbon fibers. Increased bulk of the repair material helps to absorb the impact energy better. Hence repair with 3mm thickness shows improved impact strength characteristics, when compared to 1mm thickness repair. The results of present study are in agreement with the findings of Mullarky (1985) who concluded that the increase in the impact strength and fatigue resistance of acrylic resin appliances reinforced with unidirectional aramid fibre. The research work of Berrong, Weed and Young (1990) also reported a significant improvement of impact strength with aramid fiber content up to 2%. Flexural fatigue in the denture occurs, when denture is subjected to repeated biting and masticatory load as microscopic cracks develop in the area of stress concentration. Continued loading, causes these cracks fuse to an ever growing fissure that insidiously weakens the material. Failure eventually results from a final loading cycle that exceeds the mechanical capacity of the remaining sound portion of the denture base material. In this study all fiber reinforced specimens showed higher flexural strength than unreinforced auto polymerising PMMA resin group. This is because the addition of synthetic fibers will strengthen the resultant acrylic resin and prevent the propagation of a crack when stresses are applied. The specimen group showing the most significant improvement in flexural strength values was polyaramid fibers incorporated at 1mm repair gap. Aramid fibers are hydrophilic

in nature and have high surface energy exhibiting good interfacial energy and better compatibility with PMMA. Unlike impact strength where increased bulk of the repair material helps to absorb the impact energy better, for transverse strength an increase in the repair gap results in increased volume of the repair material, increased degree of polymerization shrinkage and resultant reduced transverse strength across the gap. Hence transverse strength value of polyaramid reinforced material is higher at 1mm repair gap than at 3mm repair gap.

Conclusion

Within the limitations of the present study, it may be concluded that fiber reinforcement improved the strength of repair of the fractured heat-polymerized denture base. Out of the two reinforcement material used, reinforcement with aramid fibers improved mechanical properties of the repaired resin better than the carbon fibers. It can be further concluded that the width of the repair gap is an influencing factor for strength values. Further clinical studies are essential to validate this claim.

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