# EVALUATION OF THE FLEXURAL STRENGTH OF HEAT POLYMERIZED POLY (METHYL METHACRYLATE) DENTURE RESIN REINFORCED WITH FIBRES – AN *IN VITRO* STUDY

*A Dissertation submitted to*

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*in partial fulfilment for the degree of*

**MASTER OF DENTAL SURGERY**

**BRANCH – I**

**DEPARTMENT OF PROSTHODONTICS & CROWN AND BRIDGE**

**2016 – 2019**

# CERTIFICATE

This is to certify that the Dissertation entitled **"EVALUATION OF THE FLEXURAL STRENGTH OF HEAT POLYMERIZED POLY (METHYL METHACRYLATE) DENTURE RESIN REINFORCED WITH FIBRES – AN *IN VITRO* STUDY"** by **Dr. AARTHY S** Post Graduate student **MDS Prosthodontics & Crown and Bridge**, Madha Dental College & Hospital-Chennai – 69 Submitted to The Tamilnadu Dr. M.G.R. Medical University the MDS Degree Examination April 2019 is bonafide research work carried out by her under my supervision and guidance.

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## CERTIFICATE - II PLAGIARISM

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# DECLARATION OF THE CANDIDATE

I, **Dr. AARTHY S** hereby declare that this dissertation titled **"EVALUATION OF THE FLEXURAL STRENGTH OF HEAT POLYMERIZED POLY (METHYL METHACRYLATE) DENTURE RESIN REINFORCED WITH FIBRES – AN *IN VITRO* STUDY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. P. SHARMILA HUSSAIN, MDS, PhD., Professor & Head,** Department of Prosthodontics & Crown and Bridge, Madha Dental College and Hospital, Chennai -600069 .


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**Title of the work:** Evaluation of the Flexural strength of heat – polymerized poly (Methyl Methacrylate ) Denture Resin Reinforced with Fibres – An in vitro study

**Principal Investigator:** Dr. S.Aarthy - 2016

**Department:** Prosthodontics And Crown And Bridge

The request for an approval from the Institutional Ethical Committee (IEC) considered on the IEC meeting held on at the Principal's Chamber Madha Dental College and Hospital, Kundrathur, Chennai- 69 is granted subsequent to her modification letter dated and you are

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# ABSTRACT


**EVALUATION OF THE FLEXURAL STRENGTH OF HEAT POLYMERIZED POLY (METHYL METHACRYLATE) DENTURE RESIN REINFORCED WITH FIBERS – AN *IN VITRO* STUDY**

**Introduction:** Synthetic resins are employed in a variety of dental and medical applications such as contact and intraocular lens, bone cements in orthopaedics, filler for bone cavities and skull defects, vertebrae stabilization in osteoporosis patients, dentures, cavity filling, sealants, maxillofacial reconstructive materials, impression materials, orthodontic appliances, equipment etc. Among the synthetic resins, poly methyl-methacrylate is considered as the most suitable biomaterial due to its favourable properties such as biocompatibility, chemical inertness, dimensional stability, ease in processing and other such advantages. However, PMMA based restorations cannot withstand higher rate of loading due to the inferior flexural strength. Therefore, the present study aimed to improve the flexural strength of conventional PMMA

**Aim:** The aim of this *in - vitro* study is to compare the flexural strength of conventional heat polymerized PMMA resin with that of glass fibres, carbon fibres, and polypropylene fibres reinforced heat cure acrylic resin.

**Null Hypothesis:** Reinforcement using glass fibres, carbon fibres, polypropylene fibres to improve the mechanical properties of PMMA.

**Alternate Hypothesis:** Reinforcement with glass fibres, carbon fibres, and polypropylene fibres did not affect the mechanical properties of PMMA.

**Materials:** Heat activated acrylic resin considered as the matrix material for the present study obtained from DPI (Dental products of India) was in powder – liquid from. Glass fibres, carbon fibres, polypropylene fibres are used for reinforcement. Other materials used for the preparation of the mould for the fabrication of the acrylic samples include polyvinylsiloxane impression material, Type II gypsum products, Modelling wax for the preparation of the wax pattern, cold mould seal as the separating medium.

**Method:**

**Preparation of gypsum molds to obtain the acrylic specimen:** Wax pattern (65 mm x 10 mm x 3 mm) is prepared using modelling wax and invested in the dental flask in the conventional manner using model plaster. After 1 hour, the invested flask kept for dewaxing, and then any wax residue removed by washing the mould by hot water and then cleaned using soap solution, allowed to dry. The mold is then ready to be used for the preparation of acrylic specimen.

**Preparation of PMMA resin specimen:** The test specimens are made with dimensions of 65 mm x 10 mm x 3mm as per the ISO 1567 standards. This enables the specimen to be tested for flexural strength on Instron Universal Testing Machine.

A total of 80 specimens are fabricated for the study, which are divided into four groups (Group 1, 2, 3 & 4) of 20 specimens each. Group 1 (control) comprised of unreinforced PMMA resin specimens; Group 2 comprised of glass fibre reinforced PMMA resin specimens, Group 3 comprised of Polypropylene fibres reinforced PMMA resin specimens, Group 4 comprised of carbon fibre reinforced PMMA resin specimens.

**Measurement of Flexural strength:** All the prepared samples are tested for flexural strength using universal testing machine. Specimens are placed in a position where its two edges supported from the lower side and the load was given in the middle of the specimen from an upper side. Specimen dimension was measured and recorded into the computer.

**Results:** After data collection, the mean and the standard deviation (SD) values of transverse strength of each group were analysed statistically with one- way ANOVA analysis. Then significant differences between the mean of the test groups were determined by Turkey’s post hoc test using SPSS V22 software.

**Conclusions:** For the fabrication of denture base PMMA resin is the material of choice for usage. Because of poor transverse, impact, and flexural strength of PMMA fracture of the base may occur. So in this study I analysed increase in flexural strength after incorporation of fibres.

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# LIST OF ABBREVIATIONS

FPD - Fixed partial denture

% - Percentage

PMMA - Polymethylmethacrylate

W - Watt

MW - Megawatt

$BaTiO_3$ - Barium titanate

$Al_2O_3$ - Aluminium oxide

mm - Milli meter

μm - Micrometer

min - Minute

SD - Standard deviation

MPa - Mega pascal

N - Nitrogen

O - Oxygen

kN - kilo Newton

ISO - International Organization for Standardization

# INTRODUCTION

# INTRODUCTION

Loss of tooth material is a common phenomenon which is most significant among geriatric population. Owing to the advances with continuous improvements in medical domain, rapid increase in specialization and treatment modalities are observed in practice. So, it is realized that these improvements prolonged the life span of the human and drastically increased the life expectancy of elderly people within past few decades.[1] Denture base material plays an important role in the construction of complete denture and removable partial denture prosthesis. Although the metallic denture bases are successfully tried in the field of prosthodontics, the resin denture bases still hold an appreciable place with favorable mechanical and physical properties in the construction of removable prosthesis.

Several materials have been tried as denture base which includes wood, swaged metal, plastic, vulcanite, bakelite etc. For the past few decades the poly methyl-methacrylate is successfully used and it has been accepted as the material of choice for denture base fabrication. Since the introduction of acrylic polymers to dentistry in 1937 by Dr. Walter Wright, poly methyl-methacrylate resin has become the most commonly used denture base material.

The properties that have contributed most to the success of this material as a denture base are excellent appearance, simple processing, easy repair, color stability and ease of polishing. One of the problems inherent in providing any prosthesis is whether its limitation of life, strength and design will meet its optimum functional requirement. In the oral cavity careful consideration is required in that a balance may have to be followed between esthetics and function.

The relative delicacy of oral appliances together with their repeated handling for cleaning makes them prone to fracture after a period of usage. An inherent disadvantage is the liability of an acrylic denture to break in the mouth during function or outside the mouth as a result of fatigue failure or an impact failure

As the cost incurred for making the metal based denture and other implants used in dental applications are more, dentures made up of polymeric materials are most widely used. Although different polymers are used, poly methyl methacrylate is the most common material used for denture fabrication. PMMA has the ability to fulfill the aesthetic demands, long lasting color, processing ability and polishing for making the denture base.[2,3]

Poly methyl methacrylate was found as a suitable material for denture base and bone cement from 1930's and 1950's respectively.[4] Due to the combination of qualities, rather than the mechanical properties, poly methyl methacrylate material is still widely used for dental applications. Earlier studies reported that the mechanical properties of the poly methyl methacrylate is poor compared to other dental materials. So, different ways were used by researchers to investigate and improve the mechanical properties such as performing some chemical modification to poly methyl methacrylate, and making poly methyl methacrylate based composite with proper reinforcement process.[2,3]

The role of poly methyl methacrylate as a main component in making denture base was very wide in dentistry for long period of times. So, these types of denture base materials and their fracture and crack behavior were investigated by researchers for clinical use.[5] It was also observed by researchers that flexural strength of the denture base was influenced by the fatigue strength of the material and is the most important reason for fracture of denture base materials. Researchers reported that fracture in dentures normally occurred inside the mouth during its function and it is because of the resin fatigue.[6,7]

Compressive stress, tensile stress, and shear stress are the various stresses created in denture base resin during its function. It was observed that change in geometry of the denture base in the contour, scratch marks, mechanical stresses applied due to the processes, notch formation at the labial frenum are some of the important factors for denture fracture.[8]

Researchers are being continuously worked to improve the strength of the denture base polymers. In general polyethylene glycol dimethacrylate is added to improve the strength. In some studies, fibers or rods, metal wires or metal nets were used and reinforcement of denture base resin was carried out.

These two methods were normally used to improve the strength of the denture base polymer .[9,10]

In the earlier times, denture reinforcement was performed by embedding the metal wires or nets which improved the denture strength partially to some extent. Then by adding fibers to the denture base materials, the physical and mechanical performances of the acrylic dentures were found increased by researchers. Graphite, glass, aramid, and polyethylene fibers were used as fibers for reinforcement of the acrylic material. Researchers used polyethylene, carbon-graphite and glass for fiber reinforcement in order to obtain the mechanical properties which can be used in dental, aeronautical, civil and automotive industry.[11-14] Recently because of the ability to aesthetically shape, and bond with dental polymers, glass fibers are widely used in dentistry.

# AIM AND OBJECTIVES

# AIM AND OBJECTIVES

**Aim:**

The present study aimed at investigation of the flexural strength of the poly methyl-methacrylate resin with the addition of different fibers and evaluation of their mechanical performances.

**Objectives:**

This experimental study was conducted with the following objectives:

To conduct the experimental tests in order to determine the flexural strength of

1. Unreinforced PMMA resin
2. Glass fibers reinforced PMMA resin
3. Polypropylene fibers reinforced PMMA resin
4. Carbon fibers reinforced PMMA resin

# REVIEW OF LITERATURE

# REVIEW OF LITERATURE

The movable frame or plate used to hold the artificial teeth is called as the denture. Dentures are in general classified into (1) complete dentures, and (2) partial dentures. Researchers are continuously working to introduce dentures with different materials to improve their properties.

**Ruffino AR (1985)** [10], studied the fracture resistance of the acrylic denture base influenced by steel. In that work, two different groups of specimens were prepared for experimental tests, namely in one group steel strengtheners used reference to the line of fracture, and in the other group acrylic resin used without any strengthener. Experimental results revealed that the steel strengtheners could improve the flexural strength, and reduce the fracture. It was also confirmed that the performance of the specimens prepared using thick gauge steel strengtheners was better than the thin gauge strengtheners.

**Mullarky et al. (1985)** [15] used very thin aramid woven fibers to strengthen the poly-methyl-methacrylate base material. From the study, the authors concluded that the unidirectional reinforcement done in the PMMA could considerably increase the strength and fatigue resistance.

**Larson et al. (1991)** [16] conducted experiments to investigate the strength of the provisional crown and tooth color acrylic resins. Their study included the effect of fiber reinforcement to improve the strength. As performance measure, Young's modulus of three different acrylic resins reinforced with carbon fibers was evaluated individually. The result obtained from the experimental tests revealed that PMMA acrylic resin with carbon fiber significantly increased the Young's modulus about 80 % than PMMA acrylic resin without the presences of carbon fibers.

**Vallitu (1996)** [17] evaluated the dimensions and stability of the denture base reinforced using semi-circular steel wire or pre-fabricated E-glass fibers. Based on the experimental study, the authors concluded that the polymerization shrinkage of PMMA was lesser than the denture base reinforced with E- glass fibers.

**Stipho et al. (1998)** [3] investigated the effects of adding different percentages of glass fibers into acrylic resin. In their study, authors investigated the acrylic resin by measuring the transverse strength, deformation, and elasticity modulus. Six different weight percentages of glass fibers, quantitatively 0 %, 1 %, 2 %, 5 %, 10 % and 15 % were considered for the investigation. The addition of 1 % of glass fibers in the acrylic resin could give good fracture strength and deformation. It was observed that the addition of higher percentage of glass fiber weaken the resin.

**Kanie et al. (2000)** [5] used various measures namely flexural strength, deflection, flexural modulus, and impact strength of the acrylic denture base polymer. In their study, the authors used woven glass fiber and then the effect of adding the fibers was analyzed. In order to make comprehensive study, three silanized and unsilanized woven glass fibers were used. From their study, it was concluded that specimens reinforced with both silanized or unsilainized woven glass fibers had improved flexural strength, deflection and impact strength.

**Katja et al. (2001)** [17] evaluated the clinical relevance and durability of continuous glass-fiber in repair of acrylic resin based removable dentures. In their study, the dentures were reinforced with polymer-preimpregnated E-glass fiber at the region of the fracture. Then fracture and discoloring of dentures were inspected after the follow-up period of four months to four years. Among the cases investigated, almost 80 % the clinical condition of the dentures investigated were good and did not require any further adjustment.

**Saygili et al. (2003)** [18] conducted experimental tests to investigate the provisional restorative materials in order to determine the flexural strength and the factors influencing the flexural strength. In their study, effect of placement of fibers on flexural strength was investigated. Glass fibers and aramid fibers with base materials such as PMMA and bis-acryl composite provisional materials were considered for investigation. Three point bending test was performed to determine the flexural strength. The authors reported that the use of glass and aramid fibers in the denture base materials improved the flexural strength. However, compared to aramid fibers, glass fibers delivered about 20-50% better transverse strength.

**Tamer et al. (2004)** [19] considered numerous provisional restorative materials reinforced with fibers such as bis-acryl, glass fibers and polyethylene fibers for experimental tests, and then the mean fracture toughness and mean flexural strength were compared. It was concluded from the study that the addition of fibers to the provisional resin could improve the fracture toughness as well as flexural strength.

**Hamza et al. (2004)** [20] studied the effect of methacrylated polyhedral sil sesquioxanes (POSS) on the fracture toughness of poly methyl-methacrylate. The study was conducted with four groups with different concentrations of POSS (0%, 0.5%, 1% and 10%). It was observed from their study that the addition of POSS did not show effective change in the fracture toughness of the PMMA denture material. But, reduction in fracture toughness of the PMMA was observed, when the concentration of the POSS increased.

**Tacir (2006)** [21] conducted experimental tests on acrylic denture base resins processed by four different techniques. The authors used, (a) conventional heat polymerized acrylic resin cured by conventional polymerization cycle, (b) conventional heat polymerized acrylic resin reinforced with glass fibers cured by conventional polymerization cycle, (c) conventional heat polymerized acrylic resin cured using 600W microwave oven, and (d) shera-Med MW 2000 (PMMA) reinforced with 2 % weight of the glass fibers cured by conventional polymerization cycle. Finally the effects of different fibers were investigated and found that compared to injection molded fiber group showed lower flexural strength than the injection-molded fiber reinforced group. Similarly, micro wave molded fiber group showed lower flexural strength than the microwave molded fiber reinforced group.

**Vojdani and Khaledi (2006)** [22] reinforced acrylic resin with metal wire and glass fibers, and then the transverse strength of the heat polymerized samples were measured using three point bending test. Their study concluded that because of the reinforcement of the acrylic resin with metal wire and glass fibers, the transverse strength of the denture base was improved compared to pure acrylic resin. The study also reported that the use of unidirectional glass fibers had effectively increased the flexural strength of the denture base.

**Lee et al. (2007)** [23] investigated the effect of different weights (3%, 6% and 9%) of short glass fibers on denture base. In that study, heat-polymerized denture base acrylic resin was used, and the transverse strength and roughness of resin complex were investigated. It was concluded from their study that the incorporation of 3% and 6% glass fiber in the resin showed similar surface roughness value. But, 6% and 9% addition of silane-treated short glass showed significant increase in the transverse strength.

**Kostoulas et al. (2008)** [24] investigated heat-polymerized denture base resin repaired with auto polymerized resin, visible light-polymerized resin or auto polymerizing resin reinforced with unidirectional and woven glass fibers. Their study reported that the fracture force, deflection and toughness unreinforced repaired groups were lesser than the control group. Repair with visible light-polymerized resin showed reduction in the mechanical properties. But, it was observed that the reinforcement with glass fibers increased the original strength.

**Vojvodic et al. (2008)** [25] measured the flexural strength of polymer based common denture materials and polymers with industrial E-glass fibers reinforcement and then compared with dental high impact strength resin. In order to provide the aging process of the denture base that normally occurred in the mouth, samples were experimentally inspected. After polymerization, samples were tested in distilled water at 37° C for 28 days storage and thermocycling procedure was followed. It was concluded from the study that reinforced glass fiber samples showed significant higher flexural strength (130.1-163.88 MPa) when compared with unreinforced control group (91.77 – 122.75 MPa) and high impact strength resin (145.67 MPa).

**Vojvodic et al. (2009)** [26]**,** followed the artificial aging procedure and then the flexural strength of denture base polymers reinforced with dental fiber and industrial fiber was individually measured. The microscopic investigation made in the denture showed a partial bonding between the glass fibers and polymer materials. It was also found from their study that the use of industrial glass fiber showed significant benefit for dental laboratory.

**Ishak et al. (2009)** [27] investigated the barium titanate ($BaTiO3$) material as a radio pacifier for PMMA. In their study, $BaTiO3$ was immersed in a simulated body fluid for 28 days and then checked for fracture toughness in comparison with PMMA. It was concluded that the PMMA possessed considerably higher fracture toughness than the PMMA composite. Further, it was also found that after 28 days of immersion in $BaTiO3$, the values of fracture toughness were reduced by 4.8% in PMMA and 3.4% in PMMA composite.

**Al-Nema et al. (2009)** [28] evaluated the acrylic denture base resin and investigated the transverse strength as a function of thickness. In that study, the fracture resistance of the denture base resin was analyzed. Transverse strength, impact strength, tensile strength and hardness test were conducted to investigate the denture base. Cobalt-chromium, stainless steel and nickel alloy plate, and three forms of glass fibers were included in that study. The authors concluded that thickness significantly increased the transverse strength of the denture base.

**Gurbuz (2010)** [29] conducted a study to find out the effect of reinforcement on the transverse strength of denture base materials. In that study, effect of different concentration of E-glass fibers on transverse strength of the denture base materials was studied. Heat-cured acrylic resin with different concentration, and different E-glass fibers such as chopped, woven and continuous type were considered for the study. The study reported that the transverse strength of the denture base was effectively improved by chopped glass fiber than other types.

**Kumar et al. (2011)** [30] investigated the optimal placement of different types of fibers reinforced with the fixed partial denture made of PMMA using the fracture resistance. Two different stages were used in that study namely; in stage one, various methods of reinforcement for interim FPD, and in stage two, fibers with high fracture resistance to identify the appropriate site. The author found considerable improvement in the fracture resistance after performing reinforcement both with fibers and stainless steel. The study finally reported that the occlusal third region of the pontic as the most appropriate site of placement for reinforcement in interim FPD.

**Mohammed et al. (2011)** [31] conducted the experimental tests on maxillary complete dentures made of high impact acrylic resin to determine the impact strength. The effect of silane treated glass fiber on impact strength of the denture and woven E-glass fiber on impact strength of the denture was investigated. The study concluded that the reinforcement could significantly improve the impact strength of the dentures.

**Elkawash (2011)** [32] conducted a study on acrylic resin with the addition of $Al_2O_3$ and acrylic resin without the incorporation of $Al_2O_3$. In that study 2 different techniques namely, conventional water bath technique, and microwave technique were used to prepare the test samples. Samples were prepared with and without using the 5% $Al_2O_3$. Different processes such as, 5% $Al_2O_3$ processed by conventional water bath technique, and modified acrylic resin with 5% $Al_2O_3$ processed by microwave technique were used to prepare the samples (acrylic resin+ $Al_2O_3$). Samples were also prepared using normal acrylic resin by microwave technique. Their study reported that the flexural strength of the heat-cured acrylic resin reinforced with 5% $Al_2O_3$ filler could not be better than the normal acrylic resin. It was also observed that the specimens prepared using the heat cured acrylic resin reinforced with $Al_2O_3$ filler could not give any increase in flexural strength under microwave technique.

**Yondem et al. (2011)** [33] determined whether the reinforcement of fibers in the heat-polymerized acrylic resin denture base could significantly improve the flexural strength or not. In that study, carbon, aramid, and glass are the three different types of fibers considered for investigation. Compared to the specimens prepared using conventional acrylic resin, the specimens prepared using the reinforcement could show better flexural strength. The study revealed that specimens reinforced with fibers showed improvement in the flexural strength. The highest flexural strength was given by carbon/graphite fiber followed by aramid fiber, and glass fiber.

**Asgor and Rahman (2012)** [34] investigated the proper curing time and flexural strength of heat cured acrylic resin cured in boiling water. In that work, time difference was used and then the maximum flexural strength was compared with the optimum time. Different span of times such as 20, 40, and 60 minutes were considered at 100° C and concluded that, due to time span, there is no significant differences in the flexural strength of the specimens.

**Kamble and Parkhedkar (2012)** [35] compared the fracture toughness of the PMMA resin and bis-acryl composite (BAC) resin reinforced with the Polyethylene and Glass fibers. From the study, the authors concluded that, highest fracture toughness could be obtained by PMMA reinforced with glass fiber and BAC resin.

**Kamble and Mowade (2012)** [36] conducted experimental tests and compared the flexural strength of PMMA and bis-acryl composite resin. In that study, glass fibers and polyethylene fibers were used as reinforcement. The author concluded that the glass fiber reinforcement for the composite resin materials produced highest flexural strength.

**Qasim et al. (2012)** [37] reinforced single walled carbon nanotubes (SWCNT) in three different denture base materials, and then the flexural strength and impact strength were investigated. In that procedure, each acrylic resin was first solubilized in tetrahydrofuran (THF), and then different percentages of carbon nanotubes were added for investigation. The result revealed that because of the increase in SWCNT percentage, the flexural strength of the material was improved.

**Saritha et al. (2012)** [38] investigated the flexural strength of conventional heat polymerized denture base resin. In that investigation, different percentages (0%, 5%, 10% and 15%) of aluminium oxide ($Al_2O_3$) powder by weight were added. The authors concluded that the flexural strength of conventional heat cure denture base resin increased with addition of increased percentage of $Al_2O_3$ powder 5% by weight. It was observed that insignificant in the flexural strength when 10 % weight of $Al_2O_3$ powder was used. Similarly, the addition of 15 % weight of $Al_2O_3$ powder showed the highest flexural strength values.

**Hachimin et al. (2013)** [39] evaluated the impact strength, flexural strength and hardness of the heat cured acrylic resin by the addition of polyester fibers. In that work, two different reinforcements were done, in the first type 2 mm length polyester fiber was reinforced, and in the second type 4 mm length polyester fiber was reinforced. Comparative study showed that a statically significant improvement in impact strength of the 4 mm length fiber.

**Polat et al. (2013)** [40] conducted a study to determine the transverse strength as well as the elastic modulus. In that study, heat polymerized denture base resin was repaired by glass fibers into an auto polymerizing acrylic resin. Different form such as stick, woven and chopped glass fibers were used for investigation and found that highest transverse strength was found in stick fiber reinforced sample

**Dikbasi et al. (2013)** [41] conducted a study to find out the impact strength of poly methyl-methacrylate. In their study, different forms and concentration of E-glass fibers and their reinforcement effects were studied. Chopped strand mat, woven, and continuous unidirectional fibers were investigated and found highest mean impact strength on the test group in which 5% continuous glass fibers were added. But the obtained mean impact strength was noticed less when 2.5% woven glass fibers added. It was also observed that, both with concentration as well as fiber addition could increase the impact strength of PMMA.

**Asar et al. (2013)** [42] studied the effect of various metal oxides on heat cured acrylic resin. It that study, impact strength, fracture toughness, water sorption, and solubility effects of the metal oxides were investigated. Among the metal oxides investigated, heat cured acrylic resin with ZrO2 showed potential to prevent the denture from fracture and physical changes because of oral fluids.

**Alla et al. (2013)** [43] reviewed the works related to fiber reinforcement of denture base resin. In their work, investigations about the effect of reinforcement on the properties of denture base resins were carried out. The author used metallic fillers, carbon fibers, aramid fibers, glass fibers, jute fibers and ultra-high molecular weight polyethylene for reinforcement. It was observed from their study that the use of different fibers showed significant change in flexural strength, impact strength, and fatigue resistance.

**Poonacha et al. (2013)** [44] evaluated three different crown materials. Materials such as methyl methacrylate based auto polymerized resin, bis acryl composite based auto polymerized resin and urethane dimethacrylate based light polymerized resin were tested after storing them in artificial saliva with 24 hours, and 7 days intervals. The author concluded that methacrylate based auto polymerizing resin showed the highest flexural strength and elastic moduli after fabrication and storing in artificial saliva.

**Mathew et al. (2013)** [45] experimentally studied the impact strength of PMMA denture base with the variations in weight percentage of glass fiber (2.5 wt%, 5 wt%, 10 wt%), and variations in the length/ thickness ratio of glass fiber (3 mm/ 20 µm, 6 mm/ 20 µm, 12 mm/ 20 µm) and to determine the optimum property of the PMMA denture base. The author concluded that the impact strength obtained with 12 mm long fiber reinforced in 10 weight percentage concentration showed the best among the other considered.

**Nagpal et al. (2014)** [46] investigated the different concentration of glass fiber reinforcement on transverse strength of heat cure denture. In their study, four different brands of heat cure denture base resins were considered and for investigation, 1%, 2%, 5% and 10% of glass fibers by weight were included. It was reported from the authors that up to 2% increase in glass fiber concentration in denture base resins showed marked improvement in the transverse strength. Further increase in concentration of glass fibers showed weakening effect on the transverse strength.

**Duymus et al. (2014)** [47] evaluated the fracture strength of various provisional crown and fixed partial denture resins. Provisional crown-bridge materials (autopolymerizing PMMA, autopolymerising PEMA, BAC resin and light cured composite resin), and the reinforcement materials like polyethylene fiber and glass fiber were compared. The highest average flexural strength value was found in the Charisma with Construct fiber reinforcement (442.00 MPa). The lowest average flexural strength value was found in the Dentalon Plus without fiber reinforcement (70.50 MPa). There was significant difference between fiber-splint ML, construct and control group.

**Hamouda and Beyari (2014)** [48] conducted a study to evaluate the conventional acrylic resin with the addition of glass fibers and titanium dioxide nanoparticles. The tested parameters were monomer release, deflection at fracture, flexural strength, flexural modulus and toughness. The modified acrylic resin groups were compared to the conventional unmodified and high impact types. The author concluded that the conventional acrylic resin denture base material could be reinforced by glass fibers but not with titanium dioxide nanoparticles. The tested materials released comparable amounts of monomer.

**Anne et al. (2015)** [49] conducted experimental tests to analyse the effect of adding 5-20% aluminum oxide (Al2O3) powder by weight on the heat-polymerized acrylic resin. In that study 50 heat-polymerized acrylic resin samples were fabricated and these samples were further divided into 5 groups, each with 10 samples. In their work, the control group of the work was the samples of group A i.e. unmodified acrylic resin specimens. Remaining four groups i.e., Groups B, C, D and E were reinforced with Al2O3 powder to achieve loadings of 5%, 10%, 15% and 20% by weight. Results were analyzed by one-way analysis of variance. For Groups A, B, C, D and E the mean flexural strength values of the heat-polymerized acrylic resin were (in MPa) 92.01, 114.46, 116.77, 123.11 and 129.72, respectively. There was a significant increase in the flexural strength with the incorporation of Al2O3.

**Yaseen (2016)** [50] conducted a study to determine the tensile bond strength between acrylic denture base and denture teeth after manipulation with different surface treatments. Thirty central incisors from acrylic denture teeth were cut at the neck (ridge lap surface). Such teeth were then allocated into three groups of different surface treatments. In the first group teeth received no further treatment. In the second group teeth were surface treated with a groove placed and reinforced with a metal wire. Then, in the third group teeth were reinforced with a glass fiber. Results showed that in all the treated groups, the tensile bond strength had improved significantly with significant level ($P<0.01$), while the third group glass fiber had the highest mean values. The metal wire and glass fiber can significantly enhance the tensile bond strength between acrylic denture base and denture teeth.

**Fouda et al. (2017)** [51] reviewed the works done about the enhancement of acrylic denture base resin in the past decades. Their scholarly review dealt about the articles in which the effect of additives, fibers, fillers as well as reinforcement materials on PMMA was included, and published from 1974 until 2016. Most of the studies reviewed in that period reported the effect of adding the fibers and fillers for reinforcement only. But, the main limitation of all these studies is the *in-vitro* nature of the investigation. Also, in most of the works, studies carried out without considering the bioactivity and clinical significance of the materials. So, based on the comprehensive studies, it was concluded that there was no supreme denture base material. But, by using the salinized nanoparticle and by hybrid reinforcement technique, the properties of PMMA could be considerably improved.

**Mathew et al. (2018)** [52] aimed at evaluation of flexural strength of the PMMA polymer composite. In their study, the authors considered reinforced PMMA using the hydrogen plasma treated polypropylene fibers. The study considered 10 different control groups for investigation. In the first control group, samples prepared without fiber reinforcement was considered. In the remaining 9 control groups, polymer composites prepared with different fiber weights in percentage were considered. Weight percentages such as, 2.5%, 5%, and 10% were considered. Similarly, the aspect ratios of 3 mm/220 µm, 6 mm/220 µm, and 12 mm/220 µm were used to prepare the samples. It was observed from their study that the polypropylene fiber treated using the hydrogen plasma for reinforcement showed better flexural strength. Compared to other control groups, the control group in which 6 mm long fiber included with 10% weight showed really excellent flexural strength.

**Gad et al. (2019)** [53] carried out the process of addition of titanium dioxide (TiO2NP) nanoparticle into the PMMA resin. But it was reported that there was no evidence to consolidate the effect of adding TiO2NP in PMMA resin. So the study done by **Gad et al. (2019)** [53] aimed at the work related to the properties of TiO2NP particles on PMMA/TiO2NP nanocomposite, method of addition of TiO2NP, interaction between TiO2NP and PMMA resin, and the properties of the final PMMA nanocomposite. In that study, the conclusions which connect the nanoparticle size or method of addition with the properties of the resulted nanocomposite could not be established.

# METHODOLOGY

# METHODOLOGY

In this work, comprehensive study was carried out to evaluate and compare the flexural strength of unreinforced heat polymerized PMMA resin, glass fibre reinforced PMMA resin, carbon fibers reinforced PMMA resin and polypropylene fibers reinforced PMMA resin.

**Materials and Methods:**

The materials used for the proposed thesis work is listed below:

1. Conventional heat cure poly methyl methacrylate denture base resin in powder and liquid form manufactured by DPI limited, Mumbai, India

3. Polypropylene fibers manufactured by Ceat Ltd, Calcutta, India

4. Glass fibers manufactured by Ceat Ltd, Calcutta, India

5. Carbon fibers manufactured by Ceat Ltd, Calcutta, India

7. Dental plaster - Type II manufactured by DPI limited, Mumbai, India

8. Modeling wax manufactured by DPI limited, Mumbai, India

10. Elastomeric impression material manufactured by Aquasil ultra DENTSPLY

11. Alginate separating media manufactured by cold-mold seal DPI limited, Mumbai, India

12. Acrylizer manufactured by Confident, India

**Equipment:**

In this study, dental flasks and clamp (Kavo® EWL, Leutkirch , Germany), universal testing machine (Instron® 3365 ; Buckinghamshire, England), and hydraulic press (Kavo® EWL, Leutkirch , Germany) were used to make the specimens and experimental tests under standard laboratory conditions.

**Grouping of Samples:**

There are four different groups of samples were used for the thesis work. These groups and the corresponding number of specimens used are listed below:

| | | |
|---|---|---|
| Group 1 | Control [unreinforced] specimens | 20 |
| Group 2 | PMMA resin reinforced with glass fibers specimens | 20 |
| Group 3 | PMMA resin reinforced with polypropylene fibers specimens | 20 |
| Group 4 | PMMA resin reinforced with carbon fibers specimens | 20 |

No. of samples per group - 20

Total no. of samples - 80

**Die Specifications and Standard:**

The stainless steel die was used to make the test samples to investigate the flexural strength of the heat activated resins is shown in (Figures 2 and 3). All these samples were manufactured in the dimension 3.0 mm X 10 mm X 65 mm (width X thickness X length) in reference to the ISO 1567 standard. [24,54]

**Fabrication of wax patterns:**

Polyvinylsiloxane was used to create a mold space and then the wax pattern was fabricated. In this study, the base and catalyst form of the putty were dispensed in equal proportions and then mixed thoroughly into a uniform streak free mixture.

Then the mixed material was spread on the surface of the rectangular glass slab of 20 mm thickness. As a next step, the rectangular die created using the stainless steel material was placed onto this duplicating material to make the impression.

After allowing sufficient period of time for the duplicating material to polymerize, the die was removed slowly without distortion. It was also confirmed that there were no presence of any bubbles on the mold surface (Figure 4).

The wax pattern used in this work was prepared using the base plate wax no. 2. The wax was melted and poured into the prepared mold (Figure 5).

Totally, eighty wax patterns were prepared in this manner to create the heat activated PMMA resin samples. Then wax pattern was removed from the duplicating mold (Figure 6).

**Preparation of mold space**:

Flasking of wax pattern was done and conventional dewaxing procedure was followed as in earlier research work to create mold pace.[55] The wax pattern was made to flush with surface in the lower portion of the flask at its middle half. So, it was possible to create two equal mold spaces after following the dewaxing procedure that facilitated the fiber reinforcement in the center (Figure 7).

**Fabrication of heat activated acrylic resin samples:**

The acrylic resin samples were fabricated from this waxes using compression molding technique. It was found from the manufacturer that the ratio of heat activated poly methyl methacrylate powder and monomer should be 2:1(Figure 11). So this prescribed ratio was followed in this work, and then packed into the mold space. After some trials, the dental flask used was closed. Then it was allowed for bench curing at room temperature. Finally, heat polymerization was done.

**Curing cycle:**

Here, considerably long time was taken to complete the curing cycle. According to the specimens and their standard followed, bench curing was done and then the process of "acrylization" was carried out. First the flask and mold used were cooled to bring the temperature into room temperature and then de-flasking procedure was followed. Then the samples were carefully removed, and deburring and finishing were carried out using a 600 grit size silicon carbide paper. In this way all the heat activated PMMA samples were fabricated and considered in different groups.

**Fabrication of Different PMMA Samples:**

In this study, finely gritted glass fibers, polypropylene fibers, and carbon fibers were used for investigation. Samples of 6 mm length with thickness ranging from 10 to 15 µm were supplied by manufacturer (Figures 8, 9 and 10). Then these fibers were kept in monomer and soaked for 10 minutes to enable better bonding of the fibers with acrylic resins.[56,57] Finally, after removing the fibers from the monomer, the excessive liquid was completely removed from the monomer.

The polymers and fibers used were thoroughly mixed to uniformly distribute in the samples. As described in **Vallitu**[58], the ratio of 2:1 was maintained between monomer and polymer that contained the fibers ( 2 % by weight). In this work, the mixing of monomer and polymer with fiber was continuously done until achieving the dough stage. Then the mixing at the dough stage was filled into the mold prepared. Then the specimen was allowed for polymerization and then retrieved as followed in the control groups.

After deflasking, the fibers exposed in the peripheral border were removed by trimming using the diamond burs in order to avoid delamination of the reinforcement. Before carrying out the experimental tests, the samples (Figure. 12) prepared were stored in water at room temperature.

**Experimental Test:**

Flexural strength (Transverse strength or Modulus of Rupture) is essentially a material property, defined as a stress in a material just before it yields in flexure test.

In this study, flexural strength of the samples to investigate the transverse strength or modulus of rupture was conducted. So, the specimen was used like a bar supported at the ends and then the experimental investigation was made.

**Three Point Bending Test:**

It is obtained when one loads a simple beam, supported at each end, with a load applied in the middle. Such a test is called three- point bending test.

The flexural strength of each specimen was determined by applying increasing load until fracture at the center of a test specimen.

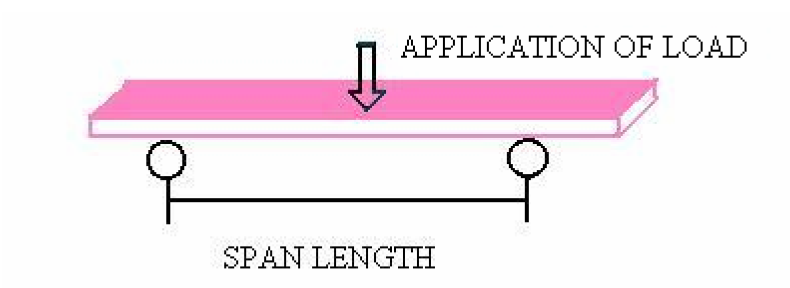



Figure 1. Schematic representation of the three-point bending test set up

Flexural strength test is especially useful in comparing denture base materials in which a stress of this type is applied to the denture under functional load.

The flexural strength of the samples was calculated as follows,

$$\sigma_f = \frac{3FL}{2WD^2}$$

where,

$\sigma_f$ - flexural strength in MPa

F - fracture load in Newton

L - span length in mm

W- specimen width in mm

D – specimen thickness in mm

**Equipment:**

In this study, Instron® (Figure 13) was used to conduct the experimental tests. The test was conducted at a crosshead speed of 2 mm/min. The span of this 3-point deflection test was 50mm.The peak load at fracture (F) (Figure 14) was noted and then the flexural strength was calculated using,

$$\sigma_f = \frac{3FL}{2WD^2}$$ relation.

The mean value of flexural strength of each group was calculated, and analyzed statistically using one sample test (Normality test) and t test.

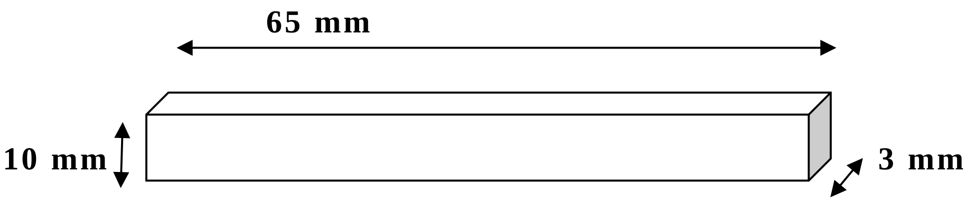



Figure 2. Line diagram of the master die

Figure 3. Master die

Figure 4. Putty index

Figure 5. Wax pattern

Figure 6. Wax pattern samples

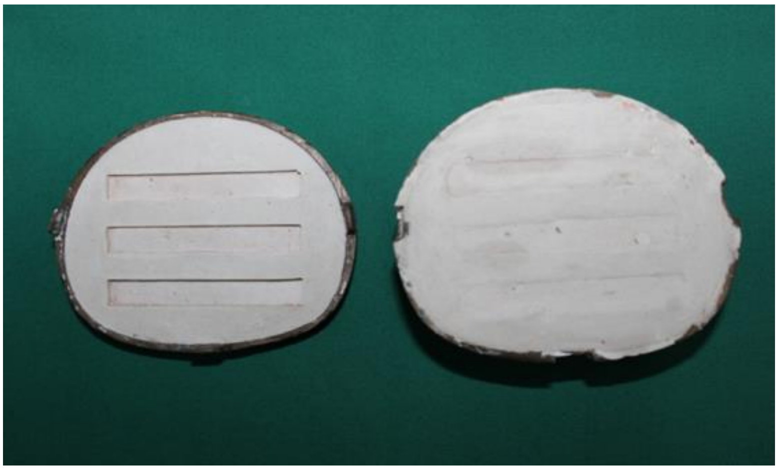


Figure 7. Mould space

Figure 8. Gritted  carbon fibres

Figure 9. Gritted glass fibres

Figure 10. Gritted polypropylene fibres


Figure 11. Heat cure materials

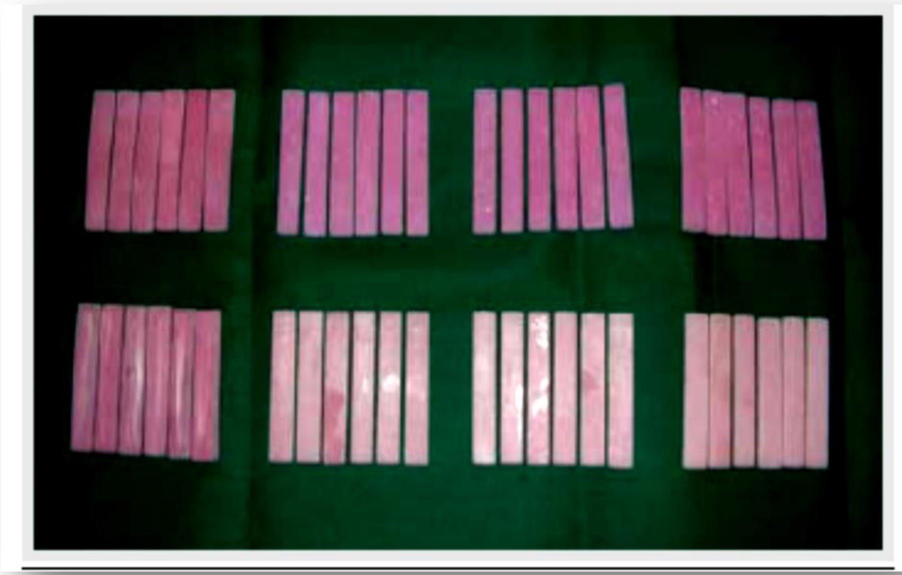


Figure 12. Polymerised acrylic Samples


Figure 13. Universal Testing Machine

Figure 14. Fractured sample

# RESULTS

# RESULTS

## Statistical Analysis

After data collection, the mean and the standard deviation (SD) values of transverse strength of each group were analyzed.

Total number of groups – 4

Total number of samples - 80

In group 1, (control) the transverse strength ranged from 55.73 to 69.83 (MPa) with a mean value of 63.59 and a standard deviation of 3.75 (Table 1).

In group 2, the transverse strength ranged from 65.59 to 74.96 (MPa) with a mean value of 70.01 and a standard deviation of 2.41. Only one value (i.e., value no. 14) is shown as outlying value. Leaving this value apart, the range of distribution was 55.06 to 63.74 (MPa) (Table 1).

In group 3, the transverse strength ranged from 60.18 to 70.08 (MPa) with a mean value of 66.90 and a standard deviation of 3.03 (Table 1).

In group 4, the transverse strength ranged from 69.89 to 74.96 (MPa) with a mean value of 72.17 and a standard deviation of 1.62 (MPa). None of the values were outliers (Table 1).

One-way ANOVA analysis showed the F value of 35.293 and P value of 0.001. Since $P < 0.05$ there is a significant difference in the flexural strength among different groups (Table 2). Hence a Post Hoc analysis was done to analyze the flexural strength among different groups

- When Group 1 was compared with other groups there is statistically significant difference between Group 1 and group 2 with a P value of 0.001. Group 1 and group 3 with a P value of 0.002 and Group 1 and Group 4 with P value of 0.001 (Table 3).

- When Group 2 was compared with other groups there is statistically significant difference between Group 2 and group 1 with a P value of 0.001. Group 2 and group 3 with a P value of 0.004 but no significant difference was found between Group 2 and Group 4 with P value of 0.080 (Table 4).

- When Group 3 was compared with other groups there is statistically significant difference between Group 3 and group 1 with a P value of 0.002. Group 3 and group 2 with a P value of 0.004 and Group 3 and Group 4 with P value of 0.001 (Table 5).

- When Group 4 was compared with other groups there is statistically significant difference between Group 4 and group 1 with a P value of 0.001. Group 4 and group 3 with a P value of 0.001 but no significant difference was found between Group 4 and Group 2 with P value of 0.080 (Table 6).

- In graph 1 , transverse strength of group 1 (control ) samples were analyzed in which 3 samples were ranged from 55.73 (MPa) to 59.85

(MPa ), 9 samples were ranged from 60.41 (MPa ) to 63.17 (MPa) and 7 samples were ranged from 65.14 (MPa) to 69.83 ( MPa).

- In graph 2, transverse strength of group 2 samples were analyzed in which 5 samples were ranged from 65.59 (MPa) to 68.43 (MPa,) 5 samples were ranged from 68.8 (MPa) to 70.28 (MPa) and 9 samples were ranged from 70.34 (MPa) to 72.58 (MPa).

- In graph 3, transverse strength of group 3 samples were analyzed in which 5 samples were ranged from 60.18 (MPa) to 64.13 (MPa), 6 samples were ranged from 65.2 (MP a) to 68.43 (MPa) and 8 samples were ranged from 68.67 (MPa) to 70.06 (MPa).

- In graph 4, transverse strength of group 4 samples were analyzed in which 6 samples were ranged from 69.89 (MPa) to 70.8 (MPa), 6 samples were ranged from 70.85 (MPa) to 72.18 (MPa) and 7 samples were ranged from 72.22 (MPa) to 74.96 (MPa).

- In graph 5 , mean flexural strength of all group samples were analyzed in which group 4 showed higher flexural strength 75.12 (MPa)when compared among all other groups such as group 1 63.59 (MPa), group 2 70.01( MPa), group 3 66.90 (MPa)

The results obtained in this study revealed that all the reinforcement groups namely glass fiber, polypropylene fiber, and carbon fiber improves flexural strength of heat cured acrylic resin samples and carbon fiber reinforced samples had the greatest flexural strength when compared with all other groups.

Table 1: Flexural strength (MPa) of different groups with mean and standard deviation

| S. No. | Flexural Strength ( MPa) | | | |
|---|---|---|---|---|
| | Group 1 | Group 2 | Group 3 | Group 4 |
| 1 | 60.41 | 74.96 | 66.12 | 74.96 |
| 2 | 55.73 | 66.37 | 66.37 | 72.13 |
| 3 | 58.23 | 69.6 | 62.03 | 70.66 |
| 4 | 63.16 | 69.18 | 60.18 | 75.12 |
| 5 | 69.83 | 71.72 | 68.4 | 71.72 |
| 6 | 65.21 | 71.66 | 69.31 | 71.66 |
| 7 | 63.17 | 68.1 | 65.2 | 72.18 |
| 8 | 69.82 | 72.58 | 69.36 | 72.58 |
| 9 | 66.25 | 65.59 | 65.59 | 74.13 |
| 10 | 63.11 | 70.34 | 70.08 | 70.34 |
| 11 | 68.54 | 71.8 | 69.93 | 72.88 |
| 12 | 61.72 | 68.8 | 68.8 | 74.65 |
| 13 | 67.66 | 70.8 | 69.06 | 70.8 |
| 14 | 66.03 | 72.22 | 68.67 | 72.22 |
| 15 | 61.65 | 65.89 | 63.15 | 70.66 |
| 16 | 61.22 | 72.18 | 69.85 | 72.18 |
| 17 | 59.85 | 70.85 | 70.06 | 70.85 |
| 18 | 62.08 | 68.43 | 68.43 | 69.89 |
| 19 | 65.14 | 68.95 | 63.31 | 73.67 |
| 20 | 63.12 | 70.28 | 64.13 | 70.28 |
| **Mean ± SD** | **63.59 ±3.75** | **70.01±2.41** | **66.90±3.03** | **72.17±1.62** |

Table 2: The ANOVA one- way test for flexural strength (MPa) of all groups

| Group | Mean Flexural Strength (MPa) | F -Value | P -Value |
|---|---|---|---|
| Group 1 | 63.59 | 35.293 | 0.001 |
| Group 2 | 70.01 | | |
| Group 3 | 66.90 | | |
| Group 4 | 72.17 | | |

Table 3: Comparison of mean difference and P value of group 1 with other groups

| Group | Groups | Mean Difference | P -value |
|---|---|---|---|
| 1 | 2 | -6.41850* | **0.001** |
| | 3 | -3.30500* | **0.002** |
| | 4 | -8.58150* | **0.001** |

Table 4: Comparison of mean difference and P value of group 2 with other groups

| Group | Groups | Mean Difference | P-value |
|---|---|---|---|
| 2 | 1 | 6.41850* | **0.001** |
| | 3 | 3.11350* | **0.004** |
| | 4 | -2.16300 | 0.080 |

Table 5: Comparison of mean difference and P value of group 3 with other groups

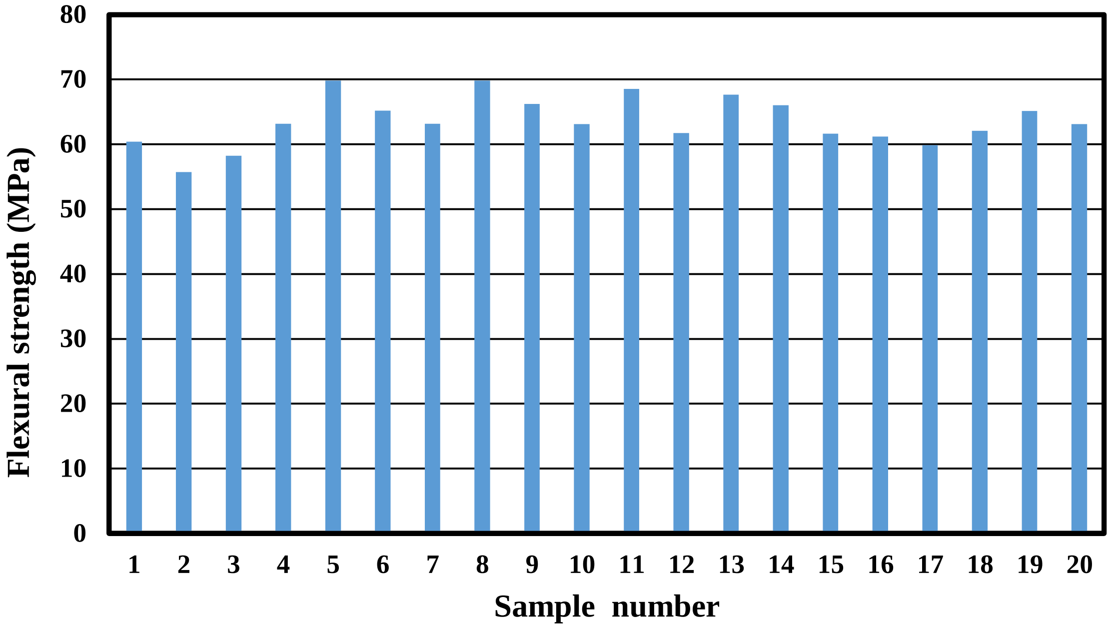
| **Group** | **Groups** | **Mean Difference** | **P-value** |
|---|---|---|---|
| 3 | 1 | 3.30500* | **0.002** |
| | 2 | -3.11350* | **0.004** |
| | 4 | -5.27650* | **0.001** |

Table 6: Comparison of mean difference and P value of group 4 with other groups

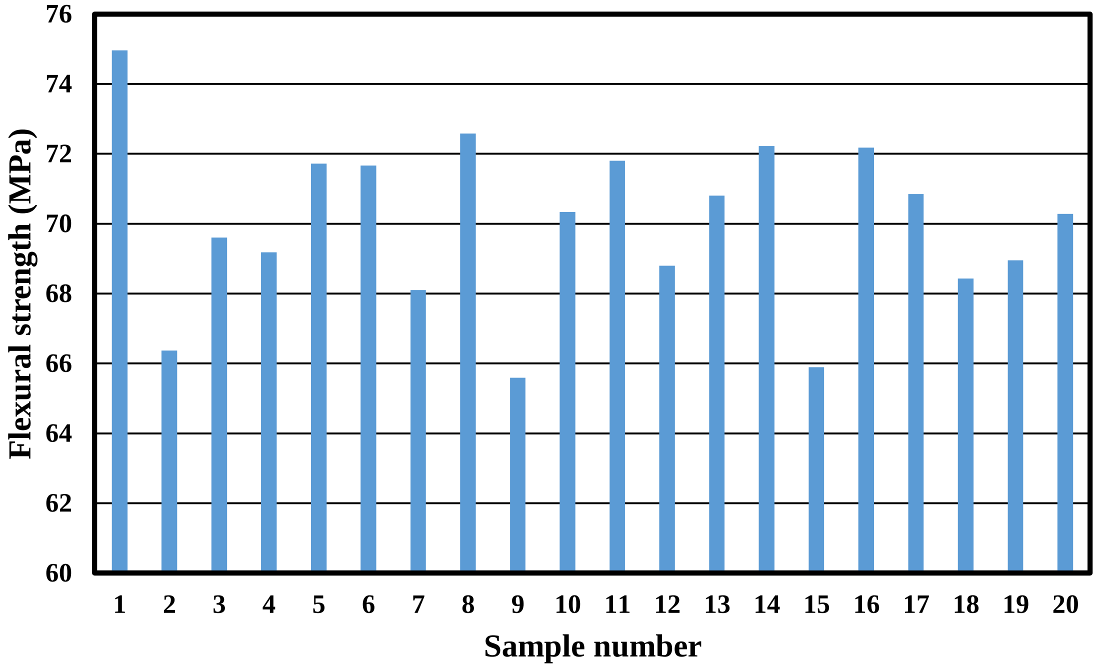
| **Group** | **Groups** | **Mean Difference** | **P-value** |
|---|---|---|---|
| 4 | 1 | 8.58150* | **0.001** |
| | 2 | 2.16300 | 0.080 |
| | 3 | 5.27650* | **0.001** |

* The mean difference is significant at the 0.05 level.

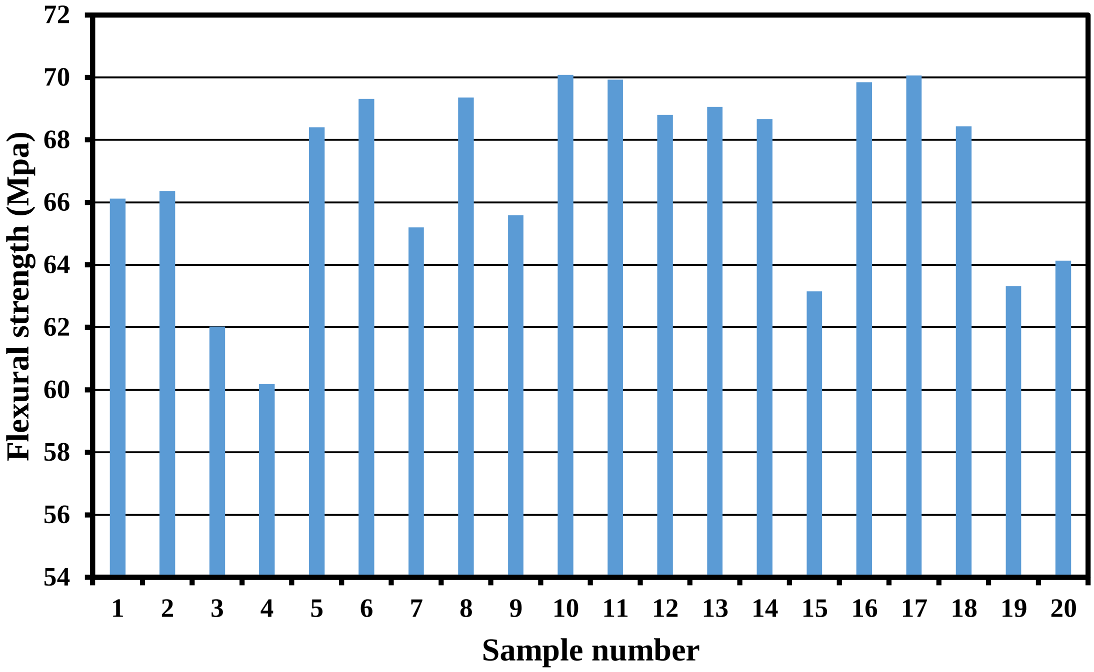
Graph 1 showing the flexural strength (MPa) of group 1 samples



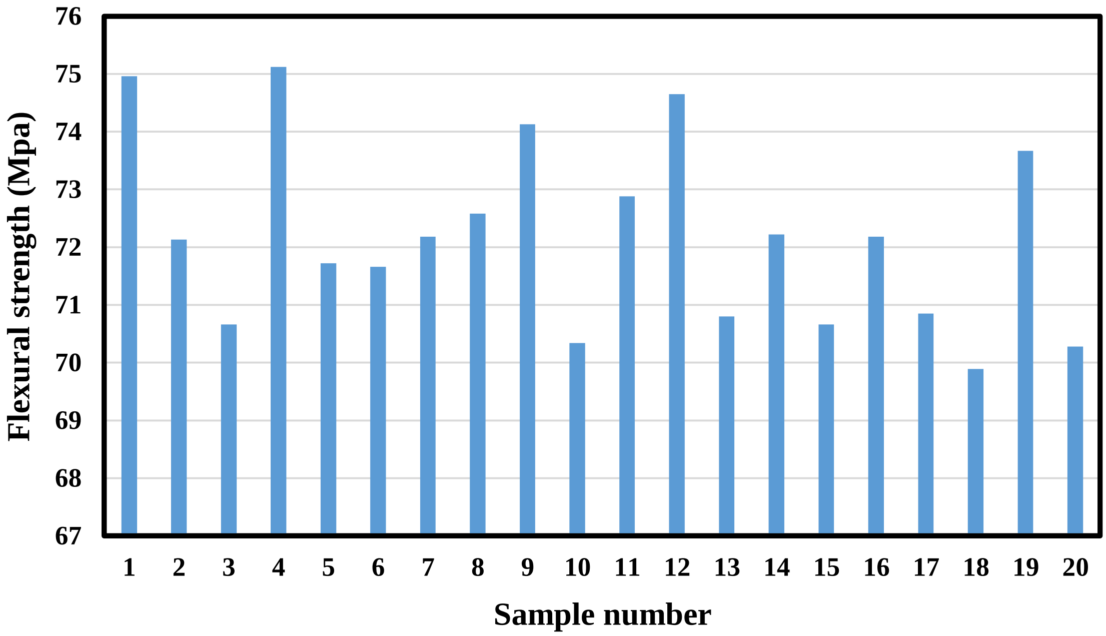
Graph 2 showing the flexural strength (MPa) of group 2 samples



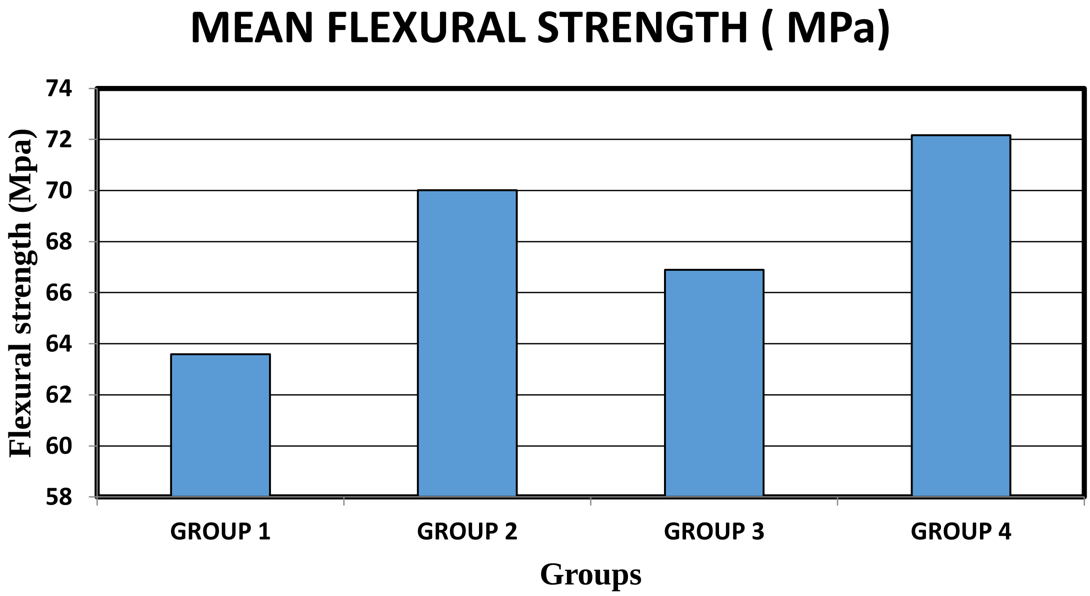
Graph 3 showing the flexural strength (MPa) of group 3 samples



Graph 4 showing the flexural strength (MPa) of group 4 samples



Graph 5 showing the Mean flexural strength (MPa)among the four groups



# DISCUSSION

# DISCUSSION

The continuous improvement in the technologies used in medical sciences pose major contribution in specialization and advanced treatments which could improve the patient's life regardless of whether the patient is young or old. In dentistry, the loss of tooth is the important problem which should be controlled, otherwise treated successfully for healthy living of the patients.

Dental implants and dentures are the artificial devices commonly used to treat the tooth loss of the patients. In general, these devices are used to restore the physiological functions with good esthetic appearance. So, the physiological and esthetic functions of oral tissues of the patient are partially or fully restored by using appropriate denture or implant.

As the cost of dental implants and other metallic denture bases are comparatively much higher, the denture base made up of acrylic resin is the most popularly used one in dentistry. Now days, a denture made up of poly methyl methacrylate resin is commonly used to treat the patients. But, fracture in the denture base is the major problem in the poly methyl methacrylate resin based denture which is to be addressed.

It is very crucial to appropriately select the materials in order to construct the denture. Because of the right selection of denture material, the performance and life span of the prosthesis during its function in the oral cavity can be improved or extended.

Although poly methyl methacrylate denture material has been widely used by researchers, its inherent disadvantages such as fracture and crack are the important issues that have to be considered in fabricating the denture. Generally, the fracture of the denture occurs inside the mouth during its function.[60] Compressive stress, tensile stress, and shear stress are the different stresses experience by the denture.

It was found that stress intensification, high ridge resorption, deep incisal notching, sharp change in the contour of the denture base, deep scratches, and process induced stress are the important reason for denture fracture.[36]

In **Hargreaves** [61] work, the author reported that in 6 months survey about the prevalence of fracture of denture, about 68 % of the denture had broken in 3 year of their provision. It was found that the method used to make the denture should be improved to enhance the properties of the denture base acrylic resin.

Different stresses are involved on denture base acrylic resins. For instance, intra-orally, repeated masticatory forces can lead to fatigue phenomena. Similarly, extra-orally, high-impact forces occurred, when the prosthesis is dropped accidently. Consequently, the denture base experience fractures during these situations. It was observed, and reported that these fracture in dentures were caused by flexural fatigue phenomena.

So number of methods were tried to improve the properties of the denture base materials. Introduction of certain additives to the poly methyl methacrylate, chemical modification by adding rubber beads, and incorporation of fibers and inserts.[62] It was also reported in literature that, incorporation of fibers for various studies was also carried out by researchers at different period of time.

Over the years, researchers were also attempted to use metal wires and plates, carbon fibers, aramid fibers, polyethylene fibers, and glass fibers to reinforce with denture resins.[63] Because of the increase in strength and stiffness, particulate or fibrous inorganic fillers have significant effect on mechanical properties of polymer.[64] In the early1960s and 1970s, the first attempt was made to use fiber reinforcement using carbon fibers. But the main problem in using carbon fiber is its black color. So, materials such as polyethylene, aramid, kevlar fibers, and vitallium strengtheners were used to make the denture reinforcement with some difficulties.

In the last 30 years, polyethylene, carbon-graphite, and glass fibers were successfully used to reinforce with polymers to improve the mechanical properties. So, these materials were used in dentistry, aeronautical, civil, and automotive industry. It was observed that, in order to stiffen the denture base, the bonding between the reinforcement material and the acrylic resin is essential which is very crucial in nature. But the main problem in using reinforcement is the inability to impregnate the fibers in the polymer and mixture of monomer of high viscosity and this make the complexity in denture making procedure.[59]

In literature, various methods have been reported to improve the mechanical properties of the heat activated poly methyl methacrylate. The heat activated resin reinforced with different types of fibers such as polyethylene, glass, carbon, and aramid have been successfully investigated by researchers **(Stiphlo et al., Kanie, Vojvodic, Kamble)**.[3,5,28,38] It was found that the flexural strength of the denture base had increased by the glass fibers like aramid and polyethylene fibers. Compared to other fibers, carbon fibers showed highest flexural strength.

Because of the continuous improvement in material processing techniques, the use of polymers in industries had increased in terms of the improvement in making hard fillers which can increase the strength. Similarly, the mechanical properties of the poly methyl methacrylate denture base have been continuously improved.[65] Compared to the polymer matrix, the fibers used for reinforcement are stronger, and thus the inclusion of the fibers could improve the composite structure. In reinforcement, the reinforcing agent is used either unidirectional or multidirectional.[66]

The reinforcement used in the denture base making method depending upon the factors such as material, fiber quantity, fiber diameter, fiber shape, fiber orientation, adhesiveness of the fiber to the polymer matrix, and fiber impregnation with polymer matrix.[58] It was experimentally found that the reinforcement of fibers into the denture making resin can be easily processed, and can be adapted for routine use. By using gritted glass fiber, the reinforcement can be done easily as they are very easy to incorporate than the long fibers. In this study, only the short fibers have been incorporated in the polymer resin.

Although the use of ploy methyl methacrylate have lot of advantages, certain drawbacks found in that material such as reduced strength and stiffness pose restriction to the applications. Many research group have introduced the methods to strengthen the resin by embedding solid metal forms into the resin, incorporation of rubber phase into the polymer, and fiber reinforcement in the polymer matrix.[67,68,69] But, because of embedding the solid metal forms resulted in poor aesthetics.[67,70] The incorporation of rubber phase into the polymer incurred more cost as stated.[71,72,73] This drawback limited the use of fibers to reinforce with polymer.

Number of studies revealed significant increase to the physical and mechanical properties of reinforced acrylic resin. Carbon fiber, glass fiber, polyethylene, and Kevlar are some of the commonly used fibers in dentistry.[67,70,72, 74-79]

It was found from literature that, only for limited number of fibers have been investigated in the research to improve the mechanical properties.

The present study aimed at an *in-vitro* study to compare flexural strength of PMMA resin reinforced with different fibers. Carbon fibers, glass fibres and poly propylene fibers with that of plain unfilled resin were the different fibers considered for investigation.

Glass fibers are proved to be the good alternative to improve the mechanical properties of the denture base resin. Initially, glass fibers in long, parallel forms were tried. Then, woven and gritted fibers were investigated.[80-83] Prior to that, glass fiber in chopped form were tried to improve the transverse strength and impact strength of the denture base.[36,1] So, in this study, glass fibers have also been added for investigation.

Polypropylene is one of the most important polyolefin synthetic fibers. The use of polypropylene fibers in dentistry have increased due to its strength, straining, abrasion resistance, good surface finish and polish, low cost and excellent biocompatibility. Polypropylene fibers have natural color, good mechanical properties and provide good surface finish and polish. Owing to excellent biocompatibility, polypropylene fibers have been used in general surgery as a closure in abdominal wounds as well as in oral and maxillofacial surgery, where even multiple fragment fractures exist.[84] An American composite manufacturers recommended polypropylene as important reinforcement material for composite resin. So, in this study, polypropylene was also used for reinforcement in poly methyl methacrylate.

Carbon fibers were first made commercially by Edison in the later 19th century by carbonizing thin bamboo shoots and cotton fibers.[85] The bulk of carbon fiber is made from poly acrylonitrile by heating in air at 200º to 250º C. Then it was held in an inert atmosphere and maintained a temperature about 1200º C to remove HZ, N, and O, which then leave a chain of carbon atoms and thus forming carbon fibers.

The main drawback in using carbon was unaesthetic appearance due to its black color. A pre-pregs (impregnated fiber bundles) to mask the unaesthetic color of the carbon fibers was reported by Scriber.[5] It was also investigated in the study that, the incorporation of fibers in the unnoticeable region like palate, lingual regions of lower denture are important. Hence in the present thesis work, carbon fibers have also been used to reinforce with the polymer resin.

In general the fibers are wetted in the monomer in order to improve the bonding properties. Even though the addition of monomer could increase the adhesion of fibers to the polymer matrix, it will affect other properties because of the residual monomer. So appropriately the impregnation of fibers was made to bring contact with surface of each fiber of the denture base.

It was observed from the study that the addition of more than 3% by weight of fibers into the polymer resin affected dough flow. So during mixing large volume of material needed to wet by monomer and produce dry fribal dough. But this did not show a significant effect on the strength.  Hence in this study , 2 % concentration of fiber reinforcement was done, which is in accordance with the findings of Gutteridge [86] who used 1%, 3% concentration of ultrahigh molecular weight polyethylene fibers, and reported that if fiber concentration was greater than 4% by weight, manipulation becomes difficult. **Ladizesky et al.**[87] also found that more than 4% concentration of fiber increased impact strength, but had no effect on transverse strength.

In this study, the flexural strength of the samples was found in a universal testing machine, Instron®. A cross head speed of 1 mm/min was used and then a load of 2 kN was applied exactly to the midpoint of the specimen using a hardened steel cylinder. Then the flexural strength of the specimen was calculated by using the formula, $\sigma_f = \frac{3FL}{2BD^2}$

The results obtained in this study showed that among the fibers used for reinforcement, carbons fibers could provide maximum strengthening effect. In **Sciber**[75] work, the authors reported that the transverse strength of about 50% had increased in the acrylic resin while incorporating the surface treated carbon fibers. Similarly, **Viguie et al.**[76] reported about 60% increase in strength.

Numbers of studies have reported the amount of optimal volume of glass fibers from 5% to 25%. But the use of glass fibers into the polymer resin caused an irritation to the tissues when exposed to the outer surface. Study reported that the flexural strength of the polypropylene fibers is lesser than that of carbon fibers and glass fibers.[88] Hydrophobic is another important property of polypropylene fibers. Because of the hydrophobic and low surface energy its compatibility with poly methyl methacrylate is poor.

Mean flexural strength values of PMMA resin and PMMA resin reinforced with E- glass fibers, polypropylene fibers, carbon fibers were 63.59 MPa (Group 1), 70.01 MPa (Group 2), 66.90 MPa (Group 3), and 72.17 MPa (Group 4) respectively. Independent samples T-test analyzed these values and shows the P value which is less than 0.05. Hence it is statistically significant.

# SUMMARY

# SUMMARY

This study compared the flexural strength of conventional heat activated unreinforced poly methyl-methacrylate resin and heat activated poly methyl methacrylate reinforced with glass fibers, carbon fibers reinforced PMMA resin, polypropylene fibers reinforced PMMA resin. According to ISO 1567, the samples were prepared with the dimension of 3.0 mm width x 10 mm thickness x 65.0 mm length.

The samples prepared with heat activated denture base resin was considered as Group 1 (Control) .The heat activated denture base resin reinforced with E- glass fibers, polypropylene fibers, carbon fibers were considered as Group 2,Group 3, Group 4 for evaluating the flexural strength. There were 80 samples prepared for this study.

Using a three-point bending test in a universal testing machine, the flexural strength of all samples were evaluated and the values were calculated using the formula, $\sigma_f = \frac{3FL}{2WD^2}$.

The samples were tested and the results obtained were statistically analyzed. The results showed the mean flexural strength value were 63.59 MPa (Group 1), 70.01 MPa (Group 2), 66.90 MPa (Group 3), and 72.17 MPa (Group 4).

# CONCLUSIONS

# CONCLUSIONS

In this study, the flexural strength of the PMMA resin in different forms was considered. Experimental tests were conducted on unreinforced heat polymerized PMMA resin, glass fibers reinforced PMMA, carbon fibers reinforced PMMA and polypropylene fibers reinforced PMMA. Within the limitations of the study, the following conclusions could be made:

- All the reinforcement groups namely glass fiber, polypropylene fiber and carbon fiber improves the flexural strength of the heat-cured acrylic resin.

- The flexural strength of heat activated PMMA resin reinforced with fibers were statistically significant when compared to the control group.

- The carbon fiber reinforced samples had the greatest flexural strength than all other groups.

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# Annexure

# Annexure

## Urkund Analysis Result

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