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ORIGINAL ARTICLE

Comparative Evaluation of Impact and Flexural Strength of Four Commercially Available Flexible Denture Base Materials: An In Vitro Study

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Abstract Poly-methyl methacrylate is a rigid material. It is generally observed that the impact and flexural strength of this material is not satisfactory and that is reflected in the continuous efforts to improve these mechanical properties. Hence there was a serious need to make another material which could overcome the limitations of the existing materials and could have better properties, like thermoplastic materials. The study was aimed to evaluate and compare the impact strength and the flexural strength of four different flexible denture base materials (thermoplastic denture base resins) with the conventional denture base material (high impact polymethyl-methacrylate). Two, machine made master moulds of metal blocks according to the size of sample holder of the equipment were prepared to test the impact and flexural strength. Total 40 samples, 10 for each group of flexible denture base materials namely: De-flex (Deflex, United Kingdom), Lucitone FRS (Densply, Germany), Valplast (Novoblast, USA), and Breflex (Bredent, Germany) in specially designed flask by injection molded process. For different flexible materials, the time, temperature and pressure for injecting the materials were followed as per the manufacturer's instructions. Total 20 samples for control (Trevelon denture base materials) were prepared by compression moulded process, for each test. ANOVA test was applied to calculate p value. Unpaired t test was applied to calculate t-value. Tukey–Kramer multiple test was provided for comparison between the groups for flexural and impact strength. From the statistical analysis, it was found that, the impact strength of Group III (Valplast) was found to be the highest than all other groups and nearer to the control group. Whereas Group IV (Bre-flex) had the maximum flexural strength. The flexural strength of Group I (De-flex) was lowest than all other groups and nearer to control group. The values were found to be statistically significant but clinically non-significant with the control ($p < 0.001$). The overall results of the study showed that, Group III (Valplast) had the maximum impact strength and Group I (De-flex) had the lowest flexural strength, whereas Group IV (Bre-flex) had the maximum flexural strength and lowest impact strength.

Keywords Denture base materials · Flexible · Conventional · Flexural strength · Impact strength

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Introduction

Over the centuries, a variety of materials have been used for denture construction. The historic developments of these materials have lead it to the times, when the dentures were carved from stone, ivory, bone and wood to the latest polymers. The ideal denture base material should possess several key attributes, like biocompatibility, good esthetics, high bond strength with available denture teeth, radiopacity, ease of repair, and should possess adequate physical and mechanical properties [1, 3, 4]. The application of nylon-like materials to the fabrication of dental appliances has been seen as an advance in dental materials. Thermoplastic materials for dental prostheses were first introduced in dentistry in the 1950s. These materials were similar grades of polyamides (nylon plastics). Rapid injection systems were originated in 1962 [2].

Advantages of thermoplastic materials are that they tend to have predictable long-term performance, stability and resistance to the thermal polymer unzipping. They also exhibit high creep resistance, solvent resistance, high fatigue endurance as well as excellent wear characteristics. Thermoplastic resins typically have very little or almost no free monomer in the material. A significant percentage of the population is allergic to free monomer and these materials offer anew safe treatment alternative for these individuals. In addition, thermoplastic materials have almost no porosity, which reduces biologic material build up, odors, and stains and exhibit higher dimension and color stability as well as biocompatibility [5].

Thermoplastic resins are used for a broad variety of applications from removable flexible partial dentures, preformed partial denture clasps, fibre reinforced fixed partial dentures temporary crowns and bridges, provisional crowns and bridges, obturators and speech therapy appliances, orthodontic retainers and brackets, impression tray and border moulding materials, occlusal splints, sleep apnoea appliances, and implant abutments.

Today dentists are prescribing flexible material for removable partial dentures because it makes a better, stronger appliance faster. Being flexible allows the denture to avoid transferring stresses on to the adjacent teeth and tissues thus minimizing the trauma of having a partial denture. The colour of the denture base matches with the oral tissues to perfection and eliminates the use of metal clasps as in other partial dentures. Metal-based RPD design is complex because it has to adapt rigid materials to a flexible environment. This leaves room for error particularly under conditions where ideal designs and clinical preparations are challenged [2, 14].

A variety of mechanical properties can be used to assess the strength of denture materials. The most common tests are impact strength; the ability of a material to resist a sudden high level force or shock and flexural strength, i.e. force needed to deform the material to fracture or irreversible yield. Because of the risk of denture fracture, high impact strength, a desirable property is the main requirement. At the same time, high flexural strength would help to resist the torsional forces in function, leading to a longer clinical service for the prosthesis [8].

The two most commonly used molding techniques for denture base acrylic resins are injection molding and compression molding. The injection molding processing method for the denture fabrication leads to less Polymerization shrinkage and produces a more accurate denture than the compression molding process. Many studies in the past have been conducted on the properties of denture base material in order to find the best material for denture [6, 11–13].

This study was aimed to evaluate the impact strength and the flexural strength of four commercially available flexible denture base materials. The objectives of the study were to evaluate and compare the flexural and the impact strength of flexible denture base materials and compare these materials with the high impact polymethylmethacrylate (control group).

Materials and Method

Materials Used in the Study

The flexible denture base materials (thermoplastic denture base resins): DE flex (DEFLEX, United Kingdom), Lucitone FRS (DENTSPLY, Germany), Valplast (NOVO-BLAST, U.S.A.) Bre-flex (BREDENT, Germany).These were grouped as Group I, II, III and IV respectively. For control, Group, high impact poly-methyl methacrylate, Trevlon (DENTSPLY, India) was used. (Fig. 1).

Preparation of the Die

For Impact Strength

Machine made master mold of stainless steel block with the dimensions 55 × 10 × 10 mm was prepared for testing the impact strength. A "v"-shaped notch was prepared at a distance of 35 mm and a depthof 2 mm with an angle of 90°. These dimension were standardized according to the size of the sample holder of the equipment used to test the impact strength. (Figs. 2, 3).

Two types of impact tests are available. In the Charpy tester,the specimen is supported horizontally and in an Izod instrument, the specimen is clamped at one end and held vertically. A problem of impact testing is that inconsistent

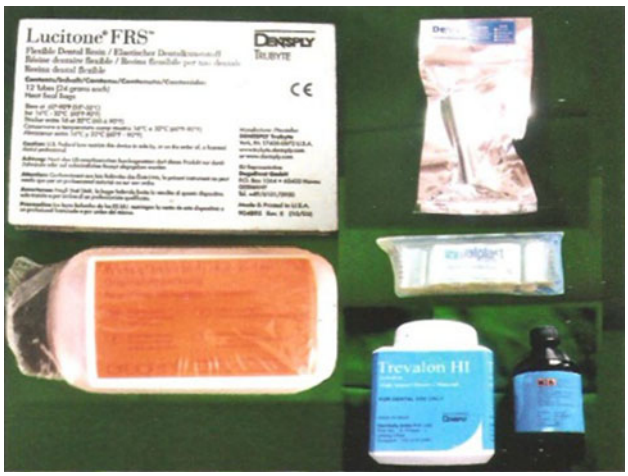


Fig. 1 Materials used in this study

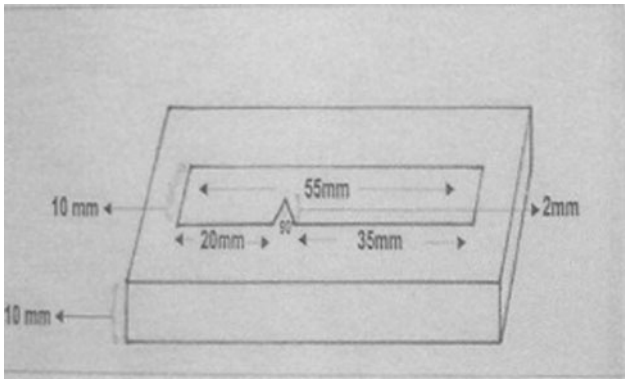


Fig. 2 Linear diagram of metal block of impact sample

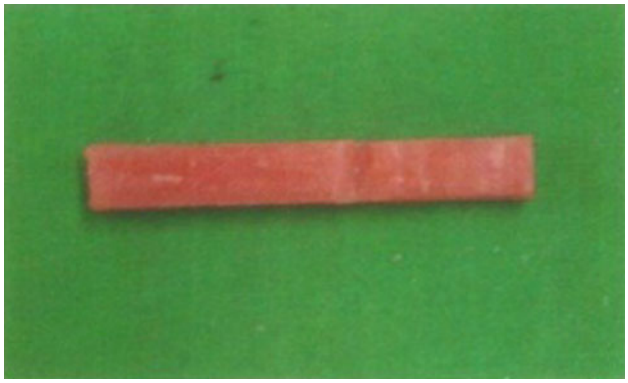


Fig. 4 Wax pattern for impact sample

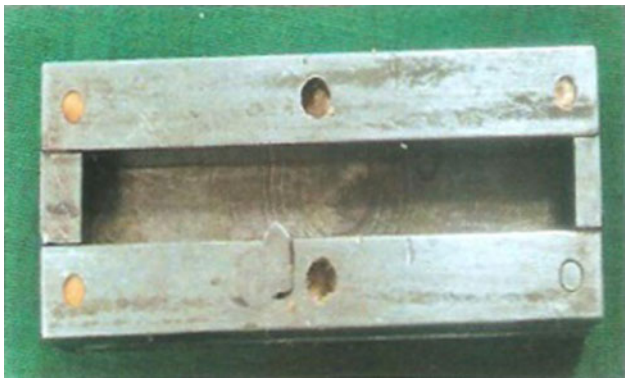


Fig. 3 Metal mold for impact sample

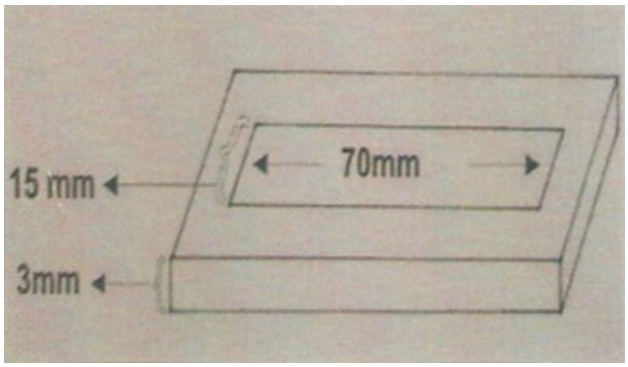


Fig. 5 Linear diagram of metal block of flexural sample

results can be obtained because of specimens breaking indifferent planes. In order to ensure more consistent results, specimens are notched. The material fractures at the notch, since this is its weakest part. A notch also makes the material more brittle, hence this is a severe test of the toughness of the material. In the present study the samples are notched, off centered, as the larger end of the sample gets embedded vertically in the sample holder [3, 4].

For Flexural Strength

Machine made master mold of stainless steel block with the dimensions 70 × 15 × 3 mm was prepared for testing the flexural strength.(Figs. 4, 5) These dimensions were standardized according to the size of the sample holder of the equipment used to test the flexural strength. (Figs. 6, 7).

Preparation of the Sample

All the samples of flexible denture base materials were prepared in specially designed flask by injection moulding process. To inject flexible dental resin, regular sized metal flasks were used. These are numbered as specifically matched halves. For best results, always match the top and bottom halves of each flask via their matching numbers. For preparation of the sample, softened modeling wax was used in the metal mold and allowed to become hard. This wax block was flasked in the die stone. It was allowed to set for 45 min. The detail injection molded procedure was as follows: [19].

Fig. 6 Metal mold for flexural sample

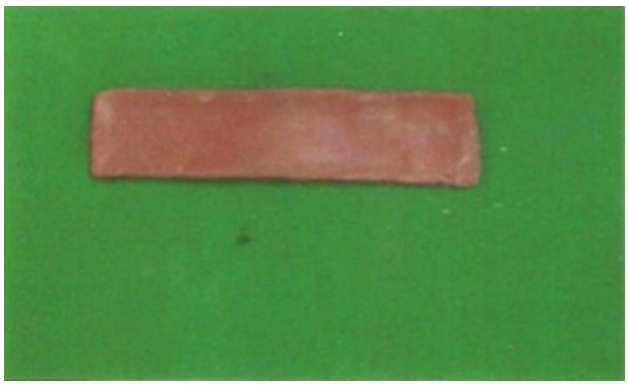


Fig. 7 Wax pattern for flexural samples

(i) Embed the bottom half of the flask: After application of petrolatum to the inner side of the metal flask, and the flask was placed on the leveler (side "1" up). The deflasking hole was covered with two pieces of moist paper towel or with wax. The "pin half" of the Space maintainer was positioned in the injection cavity. Pour1: die stone was mixed, and the wax block was embedded in the flask. All excess investment was removed. Then, the top half of the Space Maintainer was fixed securely on the bottom half

(ii) Position the injection sprues: D-shaped sprue wax sticks (7 × 180 mm,) were used to build the injection sprues

(iii) Embed the top half of the flask: Separator was applied to the investment, and the top half of the Flask was placed on the bottom half, ensuring complete, intimate metal contact and closure of the halves. Metal Flask Brackets were secured to the flask and tightened. Pour 2: The flask was placed on the Leveler (side "2" up), the investment was mixed, and poured into the flask. Separator (such as sodium silicate or another alginate or petrolatum separator) was applied over pour #2 once set. Pour 3: Additional investment was poured on top of separator, filling the Flask. Excess investment was removed, leveled, and allowed to set completely

(iv) Boil out: the bolts of the metal Flask Brackets were loosened and removed. The flask was kept in boiling water 4–6 min. Then it was opened and the Space Maintainer was removed. All wax was discarded, flushed and cleaned thoroughly. Flask margin was checked, ensuring that both flask halves make intimate metal contact

(v) Apply separator: a thin coat of separating agent was applied to mold space and allowed to dry completely

(vi) Begin heat cycle: Pre-heated the furnace with Cartridge Sleeve in place for at least 15 min prior to processing

(vii) Heat cartridge: DENTSPLY® Silicone Spray was sprayed on a Lucitone FRS cartridge. Using heat resistant gloves, the cartridge was inserted into the cartridge sleeve, this must remained in the furnace during the injection process

(viii) Heat flask: Injection Insert was positioned on bolt side of the flask and flask halves were placed directly under heat lamps. The heat lamps were turned on. Timer was set for 17 min. Cartridges removed prior to 17 min will not be properly injected

(ix) Inject case. After heating for 17 min, heat lamps get turned off and then assemble the warm flask halves. The Cartridge Sleeve and cartridge assembly was removed from the furnace. The cartridge assembly was positioned on top of the flask assembly. The combined assemblies were slide into the Injection System. At this time it was made sure that the piston head was properly aligned with the Cartridge Sleeve. The piston was engaged by depressing the activation switch

(x) Remove cartridge: the injection piston should remain engaged for 1 min. After Injection, the flask assembly was immediately removed from the system. The cartridge assembly was also immediately disengaged from the flask assembly. If the cartridge walls remain uncrushed after injection, use a knife to bend them down. The used cartridge was expelled using the Knock out Base and Knock out Rod and the Cartridge Sleeve was returned to the furnace. The Cartridge Sleeve must remain in the furnace when not in use

(xi) Divest case: the flask assembly kept to bench cool for 5 min before deflasking. Caution should be taken while handling the hot parts. The investment from the bottom half of the flask was removed by blowing compressed air through the deflasking hole. The investment from the top half of the flask was also removed and cleaned. The sample from the bulk of the investment was divested

(xii) Finish and polish: the injection sprue(s) were cut off. Samples of flexible denture base materials should be finished and polished using normal procedures used for acrylics. A bur was used followed by coarse pumice for finishing. The samples were polished with Tripoli and high shine

The injection molding procedure for all other flexible materials was followed in the similar manner. Length of the sprue, temperature, pressure and time for each of the flexible denture base material is mentioned in the following table as per the manufacturer's instructions:

Group	Length of Sprue wax (mm)	Temperature (°C)	Pressure (psi)	Time (min)
Group I De flex	5	280	3.5	15
Group II Lucitone FRS	7	300	75	17
Group III Valplast	5	300	77.25	17
Group IV Bre-flex	3	280	110	20

After completion of process, finishing and polishing of all the samples was done. The dimensions of samples were verified using electronic vernier calliper. In this way, total 40 samples for impact strength and 40 samples for flexural strength, 10 for each group were fabricated. All the samples were kept in distilled water at room temperature for 7 days until the test was performed (Fig. 8, 9).

For control group (high impact poly-methyl methacrylate), samples were prepared with a long curing at a temperature of 70–75 °C for 8 h. For this group also, total 10 samples for impact strength and 10 samples for flexural strength were fabricated. These samples were also kept in distilled water at room temperature for 7 days until the test was performed (Figs. 8, 9 Group V).

Impact Test Procedure

10 samples of each group were tested on Izod impact tester (pendulum type impact tester, FEM. Miraj) on the notched samples. The samples were kept in a sample holder in a vertical direction with the "v" notch facingthe pendulum, in which the energy stored was 16 kg (f) m. The pendulum was released from its rest position, and the reduction swing immediately after breaking the specimen was indicated by the position of the pointer attached on the dial scale and

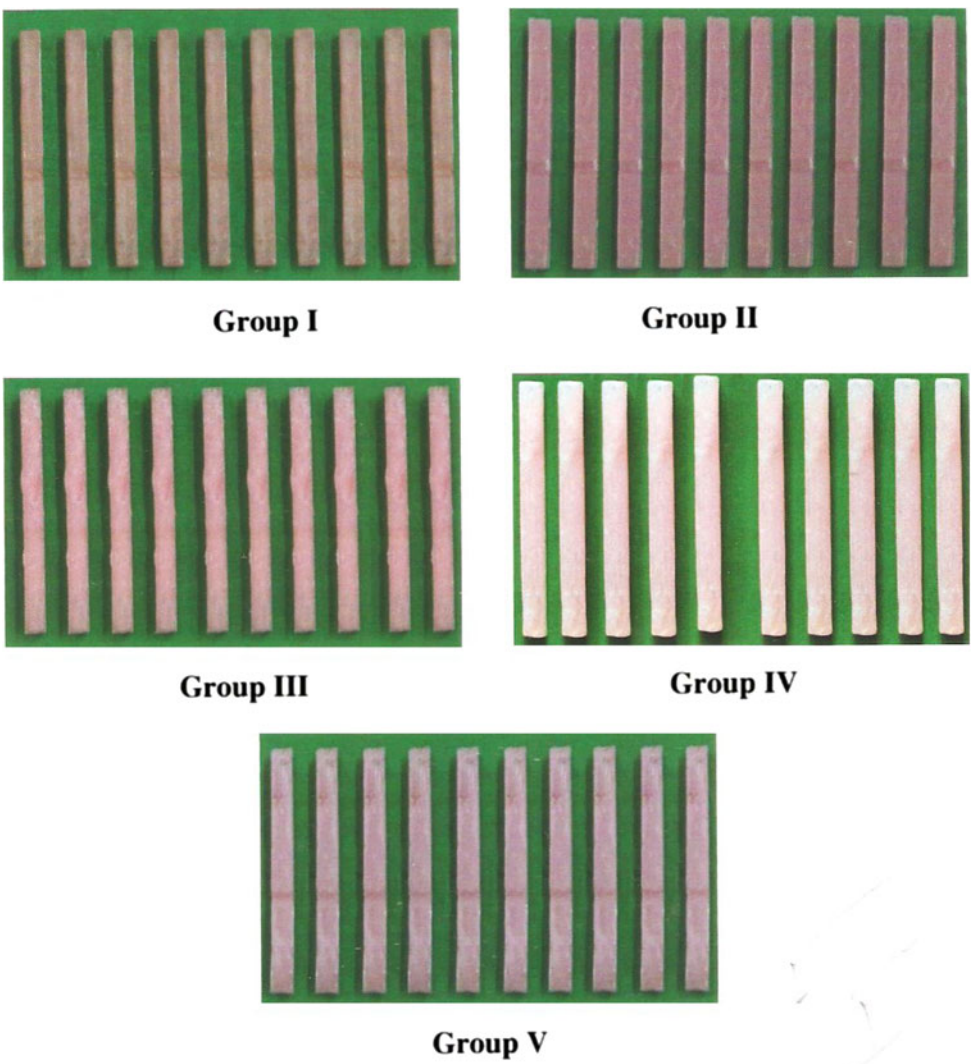


Fig. 8 Samples for impact strength

impact energy was achieved. The impact strength was calculated by the formula:

$$\text{Impact strength} = \frac{\text{Impact energy}}{\text{Area of the sample}}$$

Flexural Strength Procedure

The flexural strength was carried out on the universal testing machine (Instron, USA.) All the samples were tested using three-point bending test. The maximum distance moved by the samples on applying load was measured. For calculating the flexural strength, following formula was used:

$$\text{Flexural strength} = \frac{3PL}{2BH_2}$$

where P is the maximum load at the point of fracture, L is the distance between the supports, B is width of sample and H is the depth or thickness of the sample. Anova test and unpaired t test was used to test the differences of mean values of more than two groups. Tukey–Kramer multiple test was provided for comparison between the groups for flexural and impact strength. The level of statistical significance was taken as p value < 0.05.

Results

On application of ANOVA test, to the impact strength, it was concluded that the p value was significant (<0.001) (Table 1).Tukey–Kramer test, was applied for comparison of different groups of samples of impact strength (Table 2). Their mean values and standard deviation of each group are shown in (Table 3, 4 and Graph 1). Similarly, ANOVA test was applied to the flexural strength performed and the p value was found to be statistically significant (<0.001) (Table 5). Tukey- Kramer test was applied for comparison

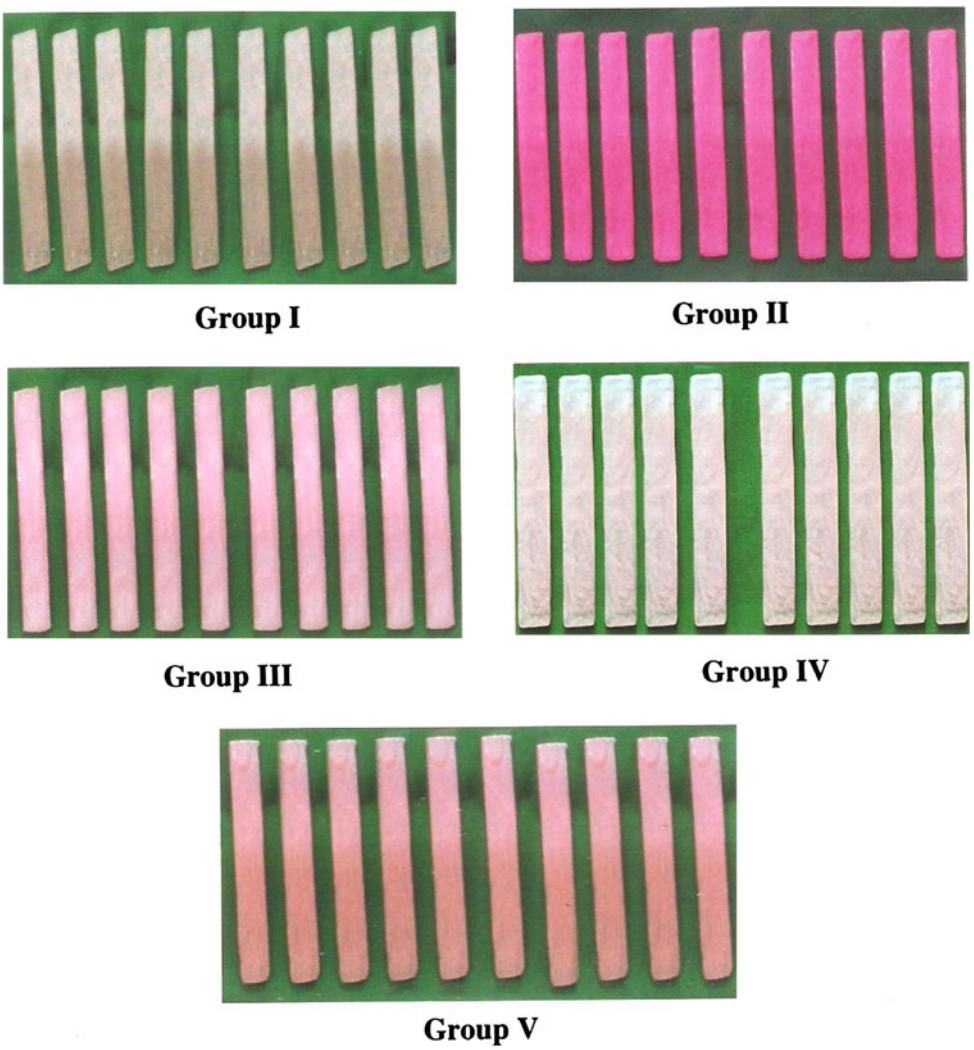


Fig. 9 Samples for flexural strength

of different groups (Table 6). Mean values of groups are shown in (Graph 2).

Discussion

Polymethyl-methacrylate is the rigid material. Studies have proved that, to increase the strength, with the incorporation of carbon fibres in this material, lead to increase porosity, minor surface imperfections and ultimately weak final prosthesis [20, 21].Polymethyl-methacrylate cannot be used in cases of severe undercuts due to its rigidity, which requires blocking the undercuts. Hence there was a need to introduce another material, having better properties and certain amount of flexibility, so that they can be used in undercut areas and could overcome the limitations of polymethyl-methacrylate [10, 17, 18, 27, 28].

Injection processing of polymethyl-methacrylate denture bases was introduced by Pryor in an attempt to reduce processing shrinkage.

Thermoplastic materials are polyacetal or polyamide nylon. Chemistry of thermoplastic material: principle difference between thermoset elastomers and thermoplastic elastomer is different in the type of cross linking in their structure. In fact cross linking is the critical structural factor which contributes to impart high elastic properties. The cross linking in the thermoset polymer is a covalent bond created during polymerization process.

$$\text{Poly (formaldehyde)} + \text{acetic acid} = \text{polyacetal}$$

$$\text{Adipic acid} + \text{hexamethylene diamine} = \text{polyamide nylon 66}$$

As discussed by Schmidt the process claims to deliver reduced processing error and increased resin density through layered curing of the resin and no processing flash. Trituration of the liquid: powder system is mechanically performed in pre-packaged capsules in an attempt to produce a more even mix resulting in a homogeneous denture base. The mixed resin is injected into the flask under continuous pressure during the processing [6].

The results of the present study allow a comparison of the mechanical properties between the latest flexible denture base materials and the existing PMMA-based denture base polymers.

Impact strength is a measure of the energy absorbed by the material before fracture. Notching is normally employed in this type of test. Kaush [7] and Yee [8] observed that energy loss during the impact test depends on four factors: (a) the energy to bend the specimen up to the point of crack initiation, (b) the energy to propagate the crack through the specimen, (c) the kinetic energy of the fractured specimen and (d) the vibrational or otherwise dissipated energy. Gianluca Zappini [29] compared the impact strength of notched and un-notched denture materials and observed the same ranking order regardless of the types of specimen preparations. However, in this study, the samples were prepared with the notch. The denture base material with high impact strength should withstand high masticatory loads or impact caused by accidental dropping.

Impact strength data and fracture characteristics depend upon many factors including material selection, geometry of the specimen, fabrication variables, stress concentrations and position of specimen and temperature. Stress concentrations are the main contributors to impact failure in dentures which include notches, cuts, depressions, sharp corners, and grooves, rough or textured surfaces, sudden changes in thickness, foreign particles or gas inclusions. Surrounding temperature also has an effect on the impact

Table 1 Analysis of variance of impact strength

Source	Sum of square	df	Mean sum of square	F	Significance
Total	25,379.2	49			$p < 0.01$
Between	17,290.5	4	4,322.6	24.05	
Within	8,088.7	45	179.7		

Table 2 Table showing mean and SD of impact strength

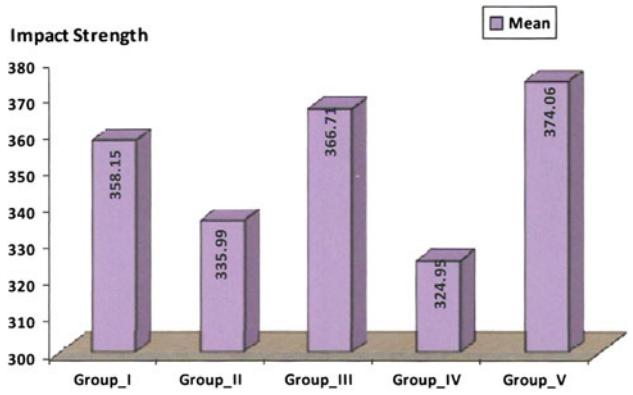
Group	Mean	SD
Group I	358.15	12.75
Group II	335.99	19.35
Group III	366.71	14.62
Group IV	324.95	8.67
Group V	374.06	8.51

Table 3 Tukey–Kramer multiple-comparison test for impact strength

Group	Count	Mean	Different from groups
Group I	10	324.95	Group I, Group III, Group V
Group II	10	335.99	Group I, Group III, Group V
Group III	10	358.15	Group IV, Group II
Group IV	10	366.71	Group IV, Group II
Group V	10	374.06	Group IV, Group II

Table 4 Table showing mean and SD of impact energy

Group	Mean	SD
Group I	2.95	0.082
Group II	2.96	0.082
Group III	3	0.053
Group IV	3	0.092
Group V	3.08	0.051



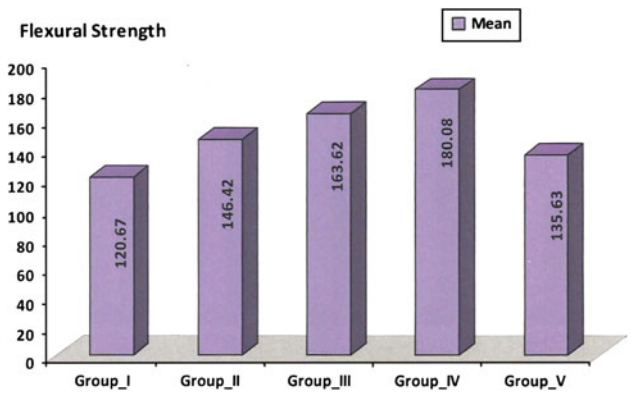
Graph 1 Showing mean values of impact strength of all groups

Table 5 Analysis of variance of flexural strength

Source	Sum of square	df	Mean sum of square	*F*	Significance
Total	25,6671.97	49			$p < 0.01$
Between	21,674.97	4	5,418.7	61.01	
Within	3,996.99	45	88.82		

Table 6 Tukey–Kramer multiple-comparison test for flexural strength

Group	Count	Mean	Different from groups
Group I	10	120.66	Group V, Group II, Group IV, Group_III
Group II	10	135.63	Group I, Group IV, Group III
Group III	10	146.42	Group I, Group IV, Group III
Group IV	10	163.61	Group I, Group V, Group II, Group IV
Group V	10	180.08	Group I, Group V, Group II, Group III



Graph 2 Showing mean values of flexural strength of all groups

strength of the material. As the temperature increases to the glass transition temperature or higher, the impact strength of amorphous polymers and most crystalline polymers increases because molecular motion in the backbone of the polymer chains is increased enough to relieve stress concentrations. Thus temperature can make a material fail either in a brittle manner or ductile manner. Plasticizers can increase the impact strength of a polymer because they lower the glass transition temperature of the polymer and increase the energy dissipation per unit volume. They also decrease notch sensitivity and impede crack propagation. Thus brittle polymer can be converted into high impact polymer by addition of rubber. [16].

Of the four materials tested, Group III (Valplast) exhibited statistically superior performance in Izod impact strength And flexural strength, when they were compared to the other three Groups ($p < 0.01$ significant). On comparison with the control Group (3.08), the values of impact of Group III (3) are comparable. Studies have shown that after introducing glass fibres, the mechanical properties were found to be higher than the compression moulded and this might be due to the molecular orientation of backbone chains caused by the injection moulding process [30–32]. The flexural strength of the material is the combination of compressive strength and shear strength. As the tensile strength and the compressive strengths increase, the force required to fracture the material also increases. If the material is deformed by stress to a point above the proportional limit before fracture, the removal of the applied force will reduce the stress to zero, but the strain does not decrease to zero, because of plastic deformation [3, 4, 15]. The flexural strength of the all flexible materials was found to higher than the control group (5.4642). Among the different flexible denture base materials Group IV was found to have the best flexural strength. The high flexural modulus of the injection-moulded polyurethane-based Micro base can be explained in terms of the highly cross-linked polymer structure. Again, this is in agreement with the previous study in which the flexural modulus of a urethane di-methacrylate polymer (Triad) was found to be higher than the conventional heat-polymerized PMMA. [26] It is undesirable to introduce any material into clinical practice whose mechanical properties are inferior to existing materials. The impact strength and the flexural properties are of some clinical relevance when evaluating denture base materials even though fatigue behavior is clinically more important.

An obvious advantage of using the new flexible material is that it eliminates mixing and direct handling, as it is available in a cartridge in the form of a single paste. Studies have shown that the compression-packed samples exhibited three times the shrinkage than that of the injection-processed samples. This is probably because of the continuous application of the pressure to the system and the subsequent layered processing of the base material. [6, 7] The results for the injection moulded specimens with the

incorporation of various lengths and concentrations of chopped E-glass fibre -reinforcement showed that when the concentration of fibres was increased approximately 35 %, the elastic modulus approximately 48 %, with the higher values for 5 % concentrations of fibres [22–25].The injection moulded specimens were reported to have higher impact strength values than compression-moulded specimens and this might be due to the molecular orientation of backbone chains caused by the injection-molding process [33–35].

The difference found in the values of the flexible denture base material may be due to the different percentage of nylon, incorporated in the individual material, by the manufacturers [34]. However in dentistry, because of its inherent flexibility, it is used primarily for removable partial dentures, as interim prosthesis. This material may have great potential for future development.

There are certain limitations of this study regarding different physical properties like masticatory load and accuracy of the material, effect of microorganisms, water sorption need to be explored and need to be clinically correlated, as the environment of the oral cavity cannot be optimally duplicated in vitro. For this, further "In-Vivo" studies should be carried to verify these results.

Summary and Conclusion

The therapeutic use of thermoplastic materials has increased drastically in the late decade. This new procedure, during which a fully polymerized basic material is softened by heat (without chemical changes) and injected afterwards, has opened up a new chapter in making dentures. Dentistry is a struggle with the limitations of the existing materials available for the denture base materials. Hence this study was planned to evaluate the impact strength using Izod tester and the flexural strength using Instron testing machine of four commercially available flexible denture base materials.

Considering the limitations of the current study it could be concluded that:

Group III (Valplast) had the maximum impact strength and Group I (De-flex)had the lowest flexural strength, whereas group IV(Bre-flex) had the maximum flexural strength and lowest impact strength.

1 The flexible strength of Group IV (Bre-flex) was found to be the highest 180.08 N/mm^2 and the lowest value got was 120.67 N/mm^2 for Group I (De-flex)
2 Group III was different from all other Groups for flexural strength. Result of Group III were found to be non-significant with the control Group for flexural strength
3 The impact strength of Group III (Valplast) was found to be highest 366.71 kJ/m^2 followed by Group I (De-flex) with mean value of 358.15 kJ/m^2 Group IV (Bre-flex) was found to be lowest for impact strength

The overall results of this studied showed that Group III and Group I had the highest Impact and lowest flexural strength, whereas Group IV had the maximum flexural strength and lowest impact strength. Further in-vitro and in-vivo studies using these materials are recommended to substantiate these results so that ideal and best material can be determined for clinical success.

Clinical significance of the study: In the present study, Group III (Valplast) had the maximum impact strength, so these materials should be used in less undercut areas for long term interim removable partial dentures, and Group I (De-flex) had the lowest flexural strength, therefore these should be used in severe undercut areas for short term duration. Group IV (Bre-flex) had the maximum flexural strength and lowest impact strength these materials are poorer for use in clinical applications.

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