Journal of Coastal Life Medicine
www.jclmm.com
ISSN: 2309-5288(Print)/2309-6152(Online)
Volume 10 No.1 (2022), Page No. 312 – 323
Article History: Received: 02 January 2022, Revised: 10 February 2022, Accepted: 21 February 2022, Publication: 31 March 2022

Effect of Thermocycling Aging on Denture Base Resin - A Comparative Analysis

Type of manuscript : original manuscript

Running Title: Effect of thermocycling on denture base resin.

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INTRODUCTION

Acrylic prosthetic resins are used in a number of types of dental prostheses, including complete or removable partial dentures, transitional prostheses, and implant-supported prostheses and polymethyl methacrylate (PMMA) resin is the

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most commonly used material for denture fabrication. There are various denture base resins commercially for manufacturing of it and it has its own mechanical limitations. Among which fracture of the denture base is the most common one, Various reinforcement methods have been used to prevent recurrent fracture, however repeated fractures frequently occur (1),(2). Those failures are attributed to insufficient flexural strengths of denture bases and it is considered as a primary mode of clinical failure(3),(4). Various methods to strengthen acrylic resin have been suggested. These include chemical modification to prepare high impact resin(5), mechanical reinforcement glass fibers(6),(7), sapphire whiskers,(8) aramid fibers, carbon fibers(9) metal wires,(10) nylon,(11) polyethylene fibers,(12) and zirconia (13).

There are various methods to fabricate denture base prostheses. The conventional 'flask-pack-press' technique for the fabrication of Prosthesis has been employed for more than half-a-century and can be considered as a time-tested "gold standard" procedure. Traditionally, they are manufactured with polymethyl methacrylate (PMMA) resin and involve a heat polymerization process . This procedure has evolved over time as the qualities of PMMA resin have improved, as has the associated processing methodology, such as the usage of auto-polymerizing, microwave-processing or injection-molding techniques (14),(15).

Recent improvements in science and technology have provided digital methods for denture base production, including computer-aided design/computer-aided manufacturing (CAD/CAM) and three- dimensional (3D) printing (16),(17),(18). Digital methods allow the production of a denture base in one block and provide the ability to attach prefabricated teeth with an appropriate adhesive. Digital technologies have the benefit of faster denture manufacture and fewer phases in the work process(26), which can lower the risk of errors. With the further development of digital technology, there are now new 3D-printed materials from various dental manufacturers and more CAD/CAM materials for denture base fabrication.

A material's ultimate flexural strength represents its ability to withstand catastrophic failure under a flexural load. Because alveolar resorption is a progressive, irregular process that leaves tissue-borne prosthesis unevenly supported, high flexural strength is critical to denture wearing success. As a foundation, the acrylic resin materials should exhibit a high proportional limit to resist plastic deformation and also exhibit fatigue resistance to endure repeated masticatory loads (19),(20–22). An acrylic resin capable of sustaining higher flexure in combination with high resistance to cyclic loading may be less prone to clinical failure. This study measured and compared the flexure strength and surface roughness of 3 different denture base resins - BPS (Biofunctional Prosthetic System), 3D printed and thermoplastic resin.

Our research and knowledge have resulted in high-quality publications from our team (23–33) .The aim of this study was to examining the mechanical properties (flexural strength and surface hardness) of different materials for denture base fabrication, as flexural strength of denture base resin is considered primary mode of clinical failure with an emphasis on digital technologies (3D printing), and compare them with heat-polymerized acrylics (BPS) and thermoplastic material (Polyon) for the production of complete denture bases before and after thermocycling.

MATERIALS AND METHODOLOGY

Sample preparation -

For each acrylic resin, an ADA-specified rectangular metal die specimen measuring 65 mm in length, 10 mm in height, and 2.5 mm in thickness was created in Google Sketchup.The design is then exported as an STL or OBJ file readable by print preparation software. 3D printers create parts from three-dimensional models, the mathematical representations of any three-dimensional surface created using computer-aided design (CAD) software or developed from 3D scan data and it include software to specify print settings and slice the digital model into layers that represent horizontal cross-sections. Adjustable printing settings include orientation, support structures (if needed), layer height, and material. Once setup is complete, the software sends the instructions to the printer via a wireless or cable connection.

(Formlabs The impression of the metal die was made using polyvinyl siloxane material. 40 wax samples were prepared. 20 wax samples were invested in metal flasks for water bath technique and 20 were invested in plastic flasks for microwave curing. Table I lists the samples and their curing methods. Type III dental stone was used to invest wax samples in metal flasks for the conventional water bath procedure. The flask was preserved for dewaxing for 5 minutes

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in boiling water after the final set of the dental stone. The flasks were then opened and cleaned to eliminate any remaining wax and make the application of the separating medium. The mold cavities obtained were used for the preparation of acrylic resin test specimens. The control group test specimens were made with conventional heat-polymerized acrylic resin. A mixture of monomer and polymer mixed according to the manufacturer's instructions was allowed to reach the dough stage, then kneaded and placed in the mold. Trial closure was performed with a hydraulic press. The flask was preserved for processing by immersing it in water in an acrylizer at room temperature. Before deflasking, the flask was allowed to cool to room temperature in the water bath once the polymerization cycle was completed. The acrylic specimens then were retrieved, finished, and polished.

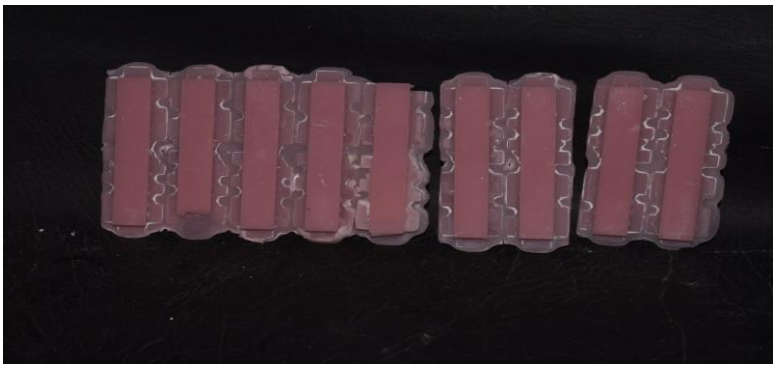

Figure 1- Printed samples

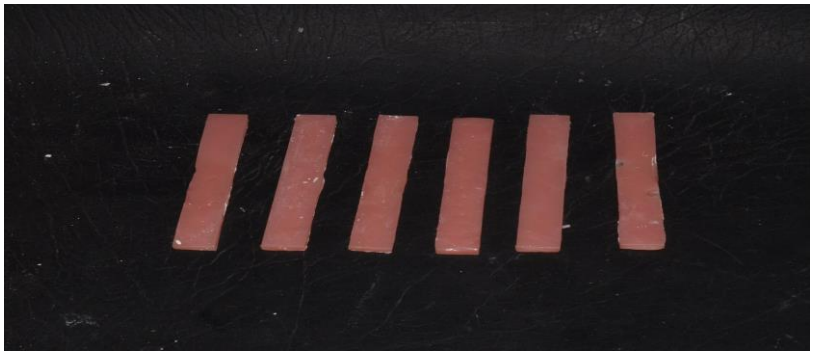

Figure 2- BPS samples

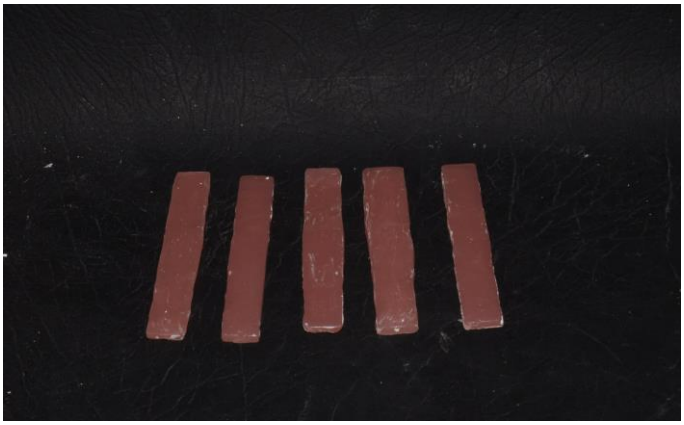

Figure 3- Polyon samples

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Test for flexural strength -

Three-Point Flexural Test

Ten specimens were fabricated for each of the 10 groups, and stored in 37◦C distilled water for 24 hours. Three-point flexural tests were performed for 5 of 10 specimens in each group to determine the load to fracture 24 hours after fabrication. The loads of the remaining 5 specimens were determined after subjecting them to 50,000 thermocycles. Thermocycling was carried out by soaking the specimens alternatively into 4◦C and 60◦C water baths with a 1-minute dwell time at each temperature. The flexural test was carried out using a universal testing machine (Instron®) at a 5.0 mm/minute crosshead speed. The specimens were supported on the jigs with a 50 mm span. Load was applied to the center of the repaired site. Linear contact was obtained between the specimen and both supporting and loading levers Stress–strain curves were recorded on a chart throughout the flexural tests. The maximum flexural load during fracture was determined from the chart and recorded as a fracture load in N (Newton). Specimen size was strictly maintained with 0.05 mm accuracy. Deflections during fracture were calculated with the following equation: deflection = a ∗ l/b, where a is the crosshead speed (5 mm/minute), b is the chart speed (100 mm/minute), and l is the actual traveling distance of a loading lever (mm), as determined from the chart.

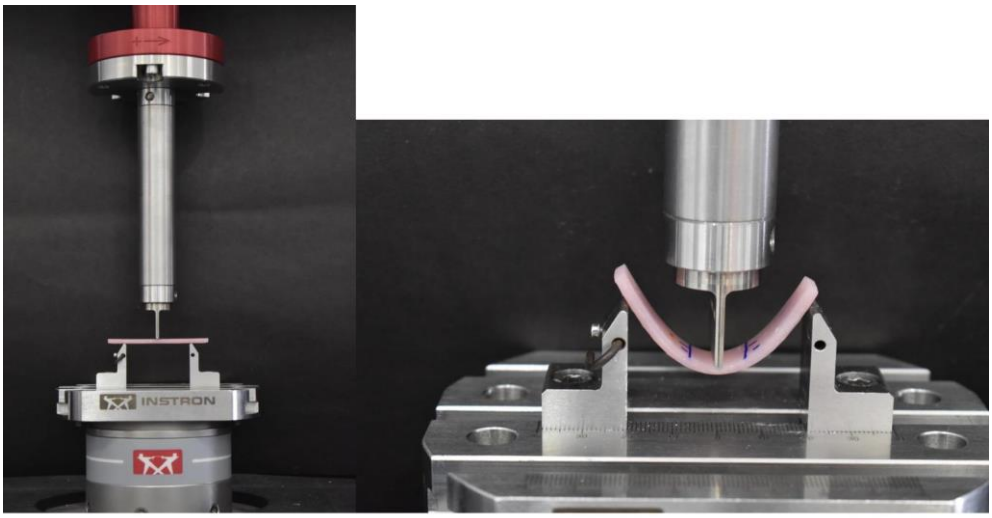

Figure 4- Sample placed in Instron® high force universal testing machine and checking for flexural strength.

Test for measuring surface roughness (Ra) -

The surface roughness (Ra) values were measured using a profilometer which can measure small surface variations by moving a diamond stylus in contact with the surface while moving laterally across the sample. The vertical displacement of the stylus is measured as the surface variations, usually measuring from 10 nm to 1 mm. The diamond stylus' height position is transformed to a digital signal, which is then saved and displayed. The machine's stylus tip radius was 2.5 m, and the scan length range was 0.5 mm. After manually approximating the center point of each study sample, three 0.5 mm scans were done. Each reading was separated by 2 mm. Over a 100 m range, the stylus was configured to read at 0.20 mm per second with a force of 0.5 mg. To get a level reading, the stage of the instrument on which the specimens were attached was manually inclined. The scan's length was used to determine the measurements. The zero line was used as a baseline using the ‘Least Squares Fit' approach. The Ra values for the specified areas of samples were generated by the profilometer in angstroms, which were then translated to the SI unit m.

Stylus profilometers detect the surface with a probe that is physically moved along the surface to obtain the surface height. This is accomplished mechanically by a feedback loop that measures the force exerted by the sample against the probe as

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it scans across the surface. To maintain a precise level of torque on the arm, known as the 'setpoint' a feedback mechanism is used. The surface can then be reconstructed using the changes in the Z position of the arm holder.

While stylus profilometry is extremely sensitive and gives high Z resolution, it is sensitive to soft surfaces and the probe can become contaminated by the surface. Some surfaces may be damaged as a result of this approach.

A stylus profilometer is slower than non-contact approaches because it requires physical motions in X, Y, and Z while keeping contact with the surface. The size and form of the stylus tip might affect measurements and limit lateral resolution (34).

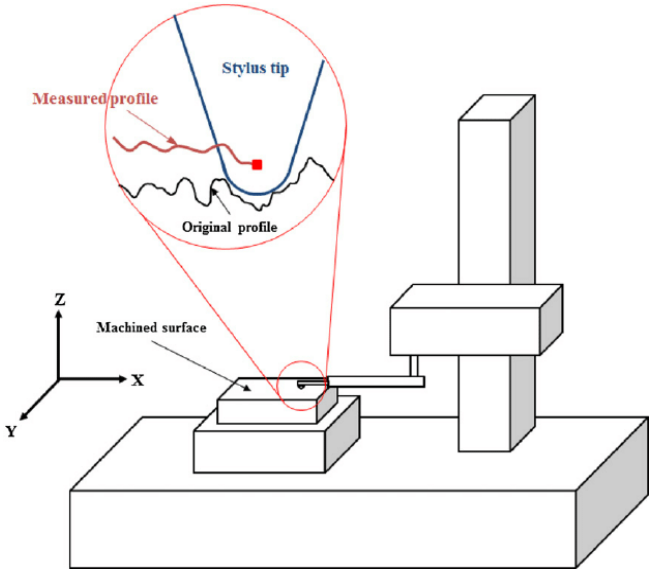

Figure 5 - Schematic of a stylus profilometer

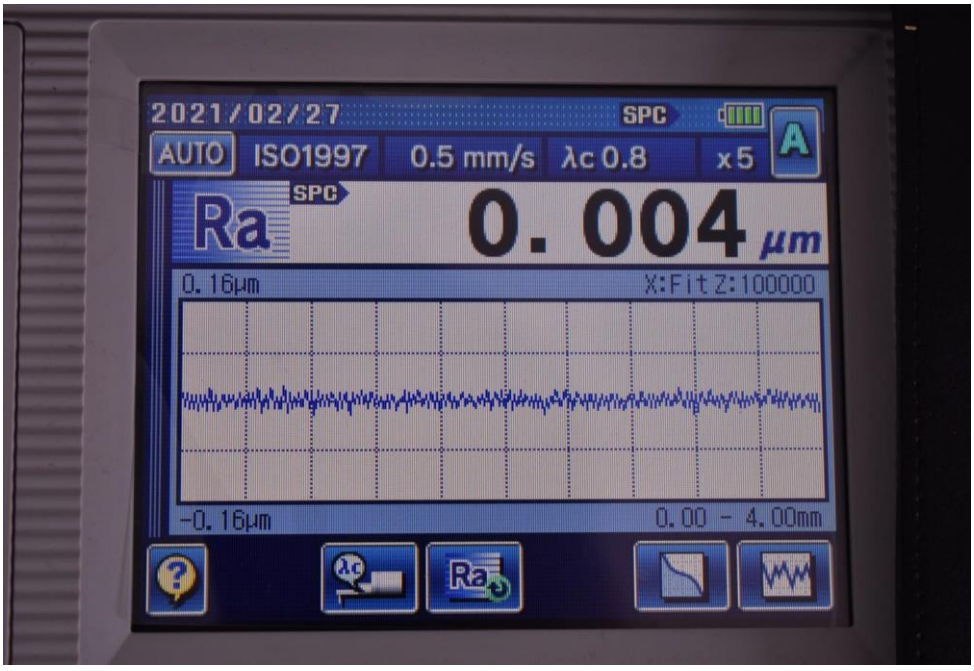

Figure 6 - Profilometer showing the Ra value

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RESULTS -

Flexural strength					
Before Aging			**After Aging**		
Printed	**BPS**	**Polyon**	**Printed**	**BPS**	**Polyon**
66.62	91.80	250.87	92.08	119.20	177.43
65.50	88.06	254	92	118.25	175.46
70.05	92.95	255.96	90	115.50	170.50
65.52	90.80	254.84	91	121.50	178
67.62	92	260.80	87.66	121	176.44
64.60	89.95	240.70	91.25	120.07	178.32

Table 1 - Deflection at maximum Flexural Load before and after aging.

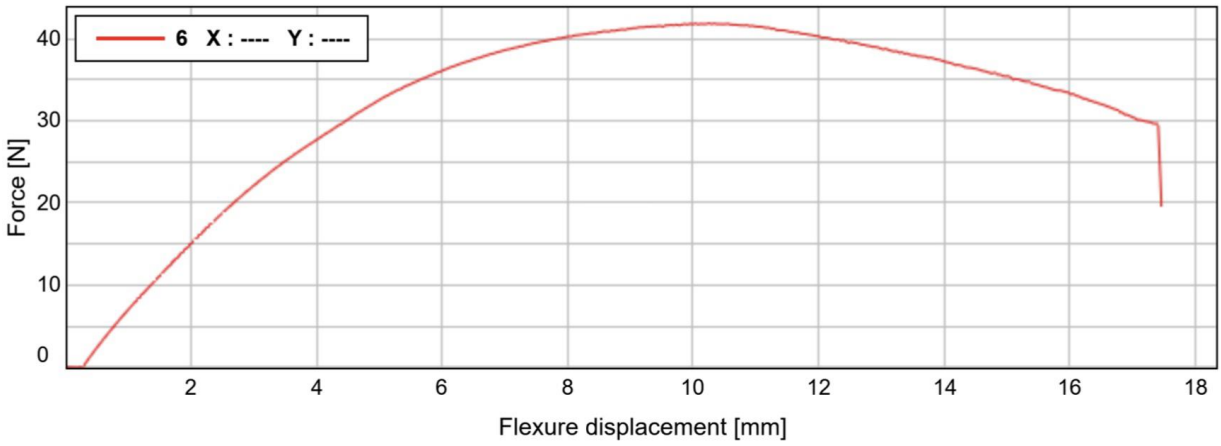

Figure 7 - flexural displacement of Printed sample

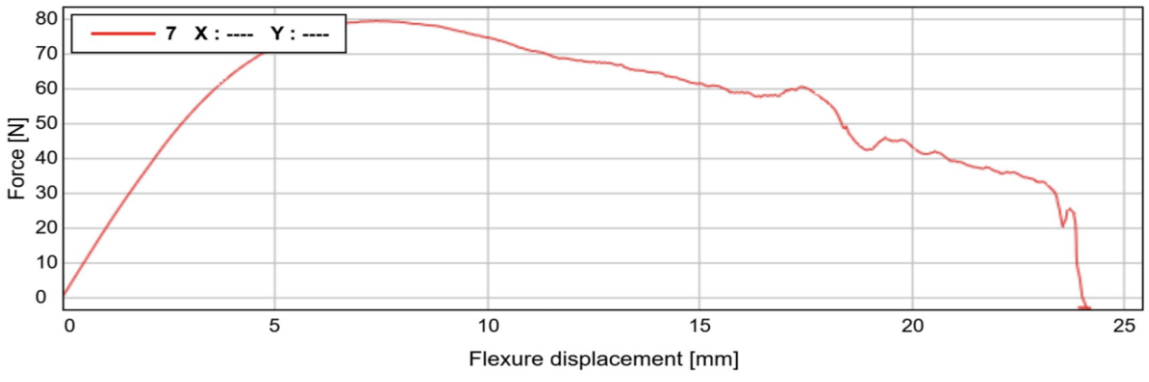

Figure 8 - flexural displacement of BPS sample

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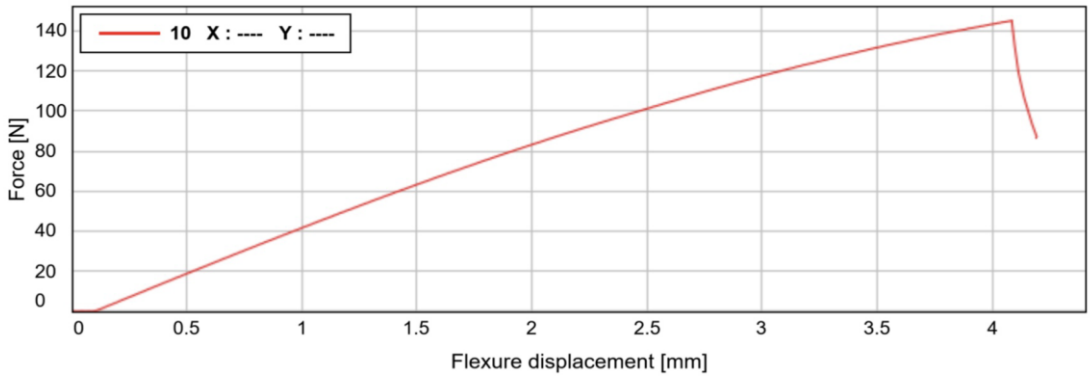

Figure 9 - flexural displacement of Polyon sample

Paired Sample Test

Paired Differences							
Groups	Mean ± SD	SE	95% CI Lower	Upper	df	t	P-value
printed	-24.096 ± 3.236	1.321	-27.49	-20.70	5	-18.239	0.001
BPS	-28.326 ± 3.006	1.251	-31.54	-25.10	5	-22.631	0.001
Polyon	76.836 ± 8.418	3.437	68.00	85.67	5	22.356	0.001

Table 2 - mean difference between groups before and after aging

	Groups	Mean ± SD	SE	95% CI Lower	Upper	F value	P-value
	printed	66.65 ± 1.96	0.80	64.58	68.71		

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Before Thermocycling	BPS	90.92 ± 1.74	0.71	89.09	92.75	3490.90	0.001
	Polyon	252.86 ± 6.77	2.76	245.74	259.97		
After Thermocycling	printed	90.74 ± 1.70	0.69	88.96	92.53	2107.29	0.000
	BPS	119.25 ± 2.18	0.89	116.96	121.54		
	Polyon	176.02 ± 2.90	1.18	172.97	179.07		

Table 3 - comparison among all groups before and after thermocycling. P value derived from one way ANOVA test. Significant at $P < 0.05$

	Groups	MD	SE	95% CI Lower	Upper	P-value
Before Thermocycling	Printed vs BPS	24.275	2.423	-30.56	-17.98	0.000
	Printed vs polyon	-186.210	2.423	-192.50	-179.91	0.000
	BPS vs Polyon	-161.935	2.423	-168.22	-155.64	0.000
After Thermocycling	Printed vs BPS	-28.505	1.337	-31.97	-25.03	0.000
	Printed vs polyon	-85.277	1.337	-88.75	-81.80	0.000
	BPS vs Polyon	-56.771	1.337	-60.24	-53.29	0.000

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Table 4 - Pairwise comparison between groups before and after thermocycling. P value derived from Tukey HSD post hoc test. Significant at P<0.05

Bonferroni Test						
Groups	Groups	MD	SE	95% CI Lower	Upper	P-value
Printed	BPS	-26.3902*	1.14411	-29.4721	-23.3082	0.000
Printed	Polyon	-135.7435*	1.14411	-138.8254	-132.6616	0.000
BPS	Polyon	-109.3533*	1.14411	-112.4353	-106.2714	0.000

Table 5 - comparison(mean difference) of printed, BPS and polygon resin based materials on flexural strength before and after thermocycling.

Discussion -

The commonly used resin for denture base is PMMA. It has the advantage of low cost, ease of processing, easy repair and light weight. This material also has disadvantages of low strength, brittle and also exhibits large shrinkage during polymerization which leads to inaccuracy in the dimensions of hardened material. Several materials and methods have been used to improve the strength of the acrylic resin.

The mechanical properties of denture base materials created using various methods were studied in this in vitro study, with a focus on digital technologies (CAD/CAM and 3D printing). Flexural strength, also known as modulus of rupture, bend strength, or transverse rupture strength, is a material property defined as the stress in a material just before it yields in a flexure test. Because a denture base might break in real life due to many reasons, it's important that it's made of a material which has high flexural strength.

There is a significant difference before and after thermocycling aging for each group individually ($p<0.005$) (Table 1) and there is a significant difference among 3 different groups for both before and after thermocycling. Where the polyon was showing the maximum flexural strength followed by BPS and printed. The difference among the groups was significant ($P<0.05$)(Table 2) after thermocycling both printed and BPS acrylic resin increased its flexural strength. Increased flexural strength was anticipated, because further polymerization occurred at the 60°C water bath during thermocycling. Decrease in flexural strength of polygon material is seen after thermocycling. This might be due to diffusion of water inside the material, where the polymer swells and volumetric increase is seen. This leads to change in shape and decrease in shape. Studies done by Shah et al, Rejab et al. and Ristic et al, support this statement (35),(36),(37).

Findings related to the flexural strength of CAD/CAM materials for denture bases vary.(38),(39)(40). A study by Steinmassl et al5 obtained mixed results where different CAD/CAM denture base resins showed similar, lower or higher flexural strength values than the heat-polymerized group. Ayman (39) and Pacquet et al (38) determined higher values of flexural strength in heat-polymerized PMMA than in CAD/CAM denture base material.In contrast to the studies by Steinmassl et al, Ayman and Pacquet et al in their studies results agree with those of Aguirre et al, where CAD/CAM materials showed higher flexural strength values than compression- molded denture base materials.

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The 3D-printed material had the lowest flexural strength compared with the other study groups. Although the 3D- printed material (monomer based on acrylic esters) had the lowest values, it met ISO requirements for flexural strength (65 MPa) (41). It is safe to conclude that 3D-printed materials for denture bases are a new option for denture production, but for now, they have lower flexural strength values than most other denture base materials.

According to the results of the present study, clinicians should consider that, with the emergence of digitally pro- duced dentures, new denture base materials with different mechanical properties are available. Although it seems logical to compare materials based on manufacture type (e.g., 3D printing, CAD/CAM, or heat polymerization), the mechanical properties of the selected denture base material depend solely on the material itself, and not how it was made. However, 3D-printed materials for denture base fabrication do have lower mechanical property values than most CAD/CAM and heat-polymerized acrylics do.

The study had two major limitations. First, oral conditions were absent in the present research, and second, different testing conditions (dry vs. wet) and different testing media (air or water) were not included. Both may have affected the results. To obtain more comprehensive knowledge on new denture base materials, future studies considering flexural modulus, bonding to synthetic polymer teeth, and residual monomer testing are necessary.

CONCLUSION-

With the limitations of the study, we can conclude that after thermocycling aging of different denture base materials, the flexural strength of BPS and printed has increased and for polyon it has decreased. And the surface roughness has not changed when compa before and after aging.

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ISSN: 2309-5288(Print)/2309-6152(Online)
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ISSN: 2309-5288(Print)/2309-6152(Online)
Volume 10 No.1 (2022), Page No. 312 – 323
Article History: Received: 02 January 2022, Revised: 10 February 2022, Accepted: 21 February 2022, Publication: 31 March 2022

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