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Assessment of Some Physical Properties of 3D-Printed Temporary Crown and Bridge Material Modified with Styrene Butadiene Monomer: An in Vitro Study

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Abstract

Background and objectives: Since three-dimensional printing utilizable for dental manufacturing; questions were raised about previous research of their use, effectiveness and mechanical properties in temporary crown and bridge material. Shortcomings were present in this respect therefore, this study added styrene butadiene monomer to aforementioned material to develop an experimental material and compare its physical properties to conventional and computer-aided design-manufacturing materials.

Methods: An in vitro study done in College of Mechanical Engineering from September 2022 to March 2023, four types of temporary crown and bridge materials were utilized, group 1: GC Temp PRINT, group 2: GC Temp PRINTTM with the addition of styrene butadiene monomer (experimental material), group 3: TEMPSMART® GC, group 4: ERAYLAR (poly methyl methacrylate) bloc, 20 samples were produced per group, and tested for flexural strength and fracture toughness to evaluate the physical properties of the materials objectively.

Results: Higher flexural strength values were for group 4 (154+- 20.37) Mpa, the least value was for group 1 (91+-19.86) Mpa. Regarding Fracture toughness, group 4 showed higher mean value (69.93+- 4.28) Mpa, the least value was for group 3 (47.59+-5.58) Mpa, which means poly methyl methacrylate material have more flexural strength and fracture toughness. Statistical analysis using Kruskal Wallis and by Dunn-Bonferroni tests showed a highly significant difference among the groups ($p<0.01$).

Conclusion: Comparing all group samples' mechanical properties. GC temp print added with styrene butadiene improves the material's physical characteristics, giving poly methyl methacrylate better flexural strength and fracture toughness.

Keywords: CAD-CAM, Flexural strength, FTIR, PMMA

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Introduction

Patients will necessitate a provisional crown or bridge to cover up their prepared teeth till their final restoration will be cemented.[1] Temporary restorations are necessary for patients during the preparation of permanent ones as they fulfil important functions such as protecting teeth, preventing teeth from moving, and offering aesthetic benefits until the cementation of the final restoration.[2] A wide range of 3D printing applications are currently possible in both industry and medicine thanks to the availability of various printing technologies and equipment.[3] However, fused deposition modeling (FDM), stereolithography (SLA), digital light processing (DLP), and selective laser sintering (SLS), are the 3D printing techniques most frequently used in dentistry. SLA and DLP 3D printers are ideal for making prosthetics due to their excellent precision and rapid processing times.[4] By comparing to different digital manufacturing techniques, additive technology has many advantages, involving the flexibility to use different machines and obtainable materials. This makes additive technology an alluring field of research and opens up completely new application possibilities in dentistry.[5] The performance of the 3D printing process and the products created depends on the materials used. In order to enhance printed materials, many researchers have investigated how different additives affect material conversion and properties. Styrene-butadiene or styrene-butadiene rubber (SBR) refers to families of synthetic rubbers made from styrene and butadiene, Abrasion resistance, ideal impact strength, good resilience, and high tensile strength are just a few of the key advantages of SBR.[6] The build parameters, like layer thickness and print orientation, as well as post-processing, all have an impact on the mechanical properties of the printed objects.[7, 8] The impact of printing orientation, layer thickness, and various post-polymerization units have already been researched in earlier studies.[9,10] The use of styrene butadiene in 3D printing temporary crown and bridge material is a first, to the best of the researcher's knowledge.The aim and objective of this study is to add styrene butadiene monomer to 3D printing temporary crown and bridge material to produce new experimental material and compare its flexural strength and fracture toughness to CAD-CAM and conventional materials and to see if this material will improve the physical properties of the original 3D material.

Material and methods:

For 3D printing sample preparation, the GC Temp PRINT™ (GC, Tokyo, Japan) medium color (control group) will be altered by the addition of styrene butadiene rubber (Sika, Baar, Switzerland) in a percentage range of 1% to 5%. To identify the homogeneity of different constituents of the experimental material with varying concentrations, Fourier Transform Infrared Spectroscopy (FTIR) Analysis was used. X-ray diffraction analysis (XRD) later verified the FTIR results. The percentage of addition was 3% according to previous research.[9,10] Before 3D printing, samples were designed using Autodesk 3ds Max (2022). The 3D printing samples were prepared using the Asiga max Uv machine, which is capable of precise layer curing at 385 nm wavelength and can process water clear material. The 3D printing process involved shaking the bottle of 3D printed resin and then placing it inside the 3D printing tray.The resin was mixed with semi-hard paper inside the tray after placement. The layer thickness was set at 100 µm with 0-degree orientation, and the printing time ranged from 25 to 30 minutes. Once the process was complete, the samples were removed from the 3D print platforms using a sharp blade cutter. To wash the samples, they were placed inside a glass jar filled with a 75% isopropanol solution and then subjected

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to a 15-minute ultrasonic bath using a Renfent ultra sonic bath. After drying the samples with compressed air, they underwent post-curing using a post-curing equipment (Schutz, Rosbach, Germany). The samples were placed inside a curing chamber for 6 minutes with a UV intensity of 220 μW·cm−2. The finishing and polishing process involved sprue removal using a silicon carbide disc (gross) and then three steps of polishing with silicone carbide paper, as presented in Table (1), the all groups finished samples presented in Figure (1).

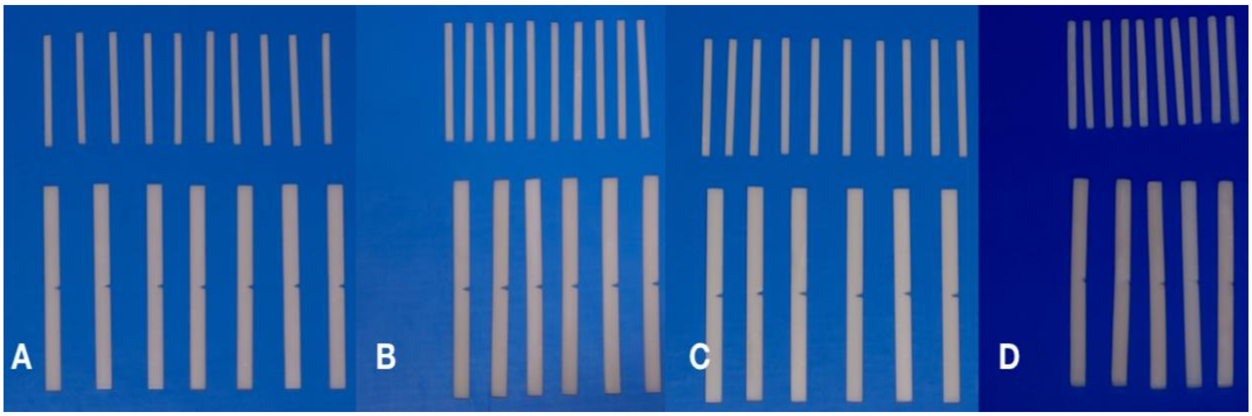

Figure (1): shows finished and polished samples a) GC TEMP PRINT prepared with 3D printing, b) GC TEMP PRINT added with styrene butadiene prepared with 3D printing, c) PMMA samples preparation, d) PMMA block prepared with milling.

For TEMPSMART (PMMA) samples were also designed by using Autodesk 3ds Max (2022), then ERAYLAR PMMA block (ERAYLARCORP., Ankara, Turkey) prepared with CORITIEC 350i pro (Imes-icore, Eiterfeld, Germany) with radius milling tool (conical) diameter 0.3 mm, and shaft 6mm. Two metal samples were created using a 3D printing design and the lost wax technique for notch final preparation, and a PMMA sample was sandwiched between them before the notch was cut with a sharp blade no. 11. The length of the V-notch was calculated via utilizing an optical microscope. The diameter of the tip was also recorded as shown in Figure (2), then 3 steps of polishing with silicone carbide paper have been done, presented in the Table (1).

Figure (2): An optical microscope image of a fracture toughness sample.

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Table (1): PMMA Samples Preparation

Step Number	Surface	Abrasive	Lubricant	Force per specimen	Time min:sec	Platen speed	Head speed	Rotation
1	Silicone carbide	Gross	Water	20N	1 min	250	60	>>
2	Silicone carbide	Medium	Water	20N	1 min	250		>>
3	Silicone carbide paper	Soft	Water	20N	1 min	250		>>

*clockwise >>

For Tempsmart (GC,Tokyo,Japan) samples preparation, the injectable provisional crown and bridge material began with the design of a mold in Autodesk 3ds Max, followed by 3D printing mold preparation in Asiga max Uv, using 3D printed resin material (IMPRIMO LC Model, SCHEU GROUP, Germany), with three molds prepared for each test. Before starting to inject the material a thin layer of handpiece oil spray universal (d line, Kaisiadorys, Lithuania) was applied with a small soft brush on both inner surfaces of the mold then uses compressed air to remove the excess oil leaving a very thin layer, it was used to avoid adhesion of the material to the surface and difficulty in removing it after setting. The properties of the different materials that will be used are shown in Table (2).

Table (2): Properties of the different materials

Materials	Composition	Classification	Company
GC Temp PRINT™	Silica fillers Surface coating Resin Pigments Anti-sedimentation additive	Biocompatible Class II a material Free of methyl methacrylate (MMA)	GC Corporation, Japan
Styrene butadiene monomer	Styrene monomer and butadiene monomer	Families of synthetic rubbers derived from styrene and butadiene	Sika Switzerland
TEMPSMART® GC	Dual-cured, bis acrylic composite temporary crown and bridge material	Microfilled resin (MFR) and nano filler technologies	GC Corporation, Japan
ERAYLAR PMMA block	Acrylic glass PMMA	Polymethyl methacrylate cuttable disc (PMMA), monochrome	ERAYLAR CORP. Turkey

For the three-point bending test (Flexural Strength) which was carried out using a universal testing machine outfitted with a 5-kN load cell and at a crosshead speed of 0.75 mm per minute in accordance with DIN EN ISO 4049. Ten samples were produced for each group, these samples were designed using Autodesk 3Ds Max (2022) as shown in Figure (3), and shaped into a bar-like structure with a width and thickness of 2 mm, as well as a length of 25 mm.[11]

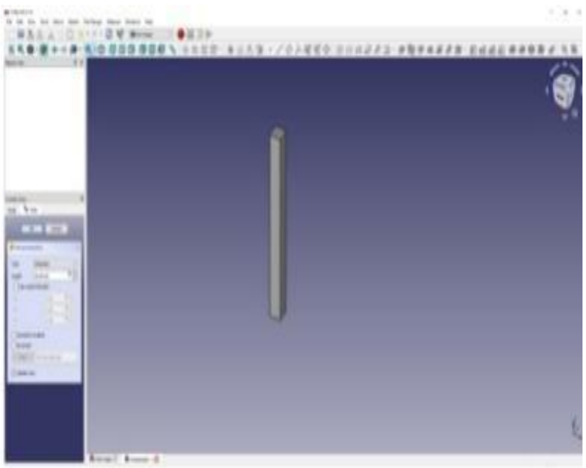

Figure (3): Flexural Strength test sample designed using Autodesk 3Ds Max (2022).

A high precision digital caliper with an accuracy of 0.001 mm was used to measure the dimensions of the specimen before each flexural test. Figure (4) shows flexural strength sample for 3-point bending test with using universal testing machine. The span of the flexural test was 20 mm, and two rounded supports (2 mm) were used. The following equation was utilized to detect the flexural strength (MPa) using the fracture load (N) that was measured:

$FS = 3Fl/2bh^2$, where “F” is the maximum load (N), “l” is the length of the support span (mm), b” is the width (mm) of the specimen, and “h” is the height (mm) of the specimen.

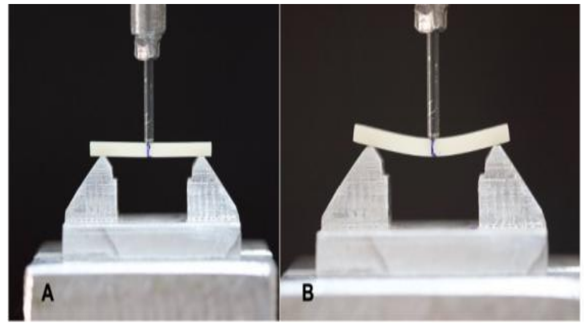

Figure (4): flexural strength sample for 3-point bending test using universal testing machine a) before bending, b) after force application 5-kn (before sample fracture).

The Fracture toughness test used ten samples per group and was identified by the applied force, sample size, and the size and form of the notch, as shown in Figure (5). The fracture toughness test samples were constructed using ISO 14704 dimensions. L: 45 mm (1/4-point flexure), W: 4,0 mm ± 0,2 mm, B: 3,0 mm ± 0,2 mm. 3D printing samples were created in Autodesk 3ds Max (2022), and 3D printing samples were prepared in Asiga Max Uv. Fracture toughness samples were examined with universal testing equipment at four different places, as illustrated in Figure (6). The ISO/FDIS 23146:2008 (E) standard was used to determine the results of KIC testing. The force was subjected to the beam specimen with the average initial crack size α until the fracture of the sample. The KIC equation for the fracture toughness test is presented below:

$$K_{IC} = \frac{F}{B\sqrt{W}} \cdot \frac{S_1 - S_2}{W} \cdot \frac{3\sqrt{\alpha}}{2(1-\alpha)^{1.5}} \cdot Y^*$$

$$Y^* = 1.9887 - 1.326\alpha - \frac{(3.48 - 0.68\alpha + 1.35\alpha^2)\alpha(1-\alpha)}{(1+\alpha)^2}$$

Where: Fc: fracture load, Sx: span (x=1: outer span; x=2 inner span), B: specimen width, W: specimen height, a: notch depth, α: a/W , Y: stress intensity shape factor.

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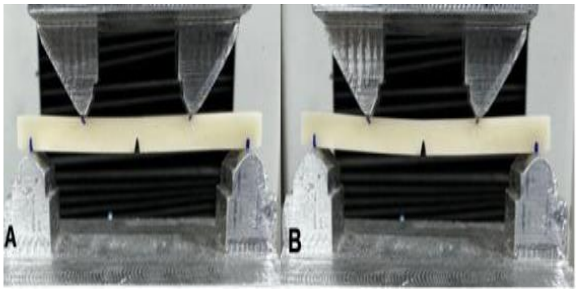

Figure (5): the shape and size of the sample for fracture toughness test

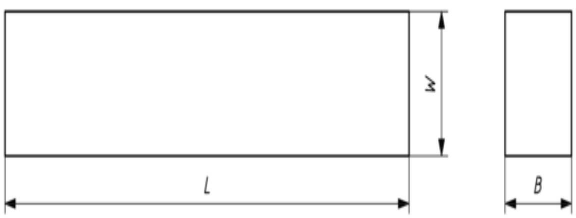

Figure (6): Fracture toughness sample testing with a universal testing machine with 4-point a) before force application b) after force application (slightly bent before sample fracture).

Statistic evaluation Statistical Package for Social Sciences (SPSS) version 23 and Microsoft Office Excel 2010 were used to compile, analyze, and present the data. While categorical variables were expressed as numbers and percentages, quantitative variables were expressed as mean and standard deviation (SD). The significance threshold was set at P 0.05. The ethical approval No. 608 in 17 February 2022 in KHCMs, Erbil, Iraq.

Results

The mean and standard deviation of the Flexural strength values in Mpa had been presented in the Table (3), the results showed that the higher mean value was for G4 (154+-20.37) Mpa, while the least value was for G1(91+-19.86) Mpa, that's mean PMMA material have higher Flexural strength compared to other materials by using Kruskal Wallis test and By Dunn-Bonferroni test the difference was significant $p<0.0$ presented in Table (4).

Table (3): Descriptive statistics of flexural strength and fracture toughness of the four groups.

Flexural strength				
	G1	G2	G3	G4
N	10	10	10	10
Mean	91.88	117.75	107.81	154.50
SD	19.86	23.86	4.84	20.37
SE	6.28	7.55	1.53	6.44
Median	97.50	125.63	106.03	157.50
Variance	394.53	569.38	23.40	415.00
Minimum	56.25	78.75	103.05	123.75
Maximum	112.50	146.25	118.50	180.00
Fracture toughness				
N	10	10	10	10

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Mean	55.95	48.49	47.59	69.93
SD	2.80	3.13	5.85	4.28
SE	0.89	0.99	1.85	1.35
Median	55.55	47.69	47.29	70.43
+Variance	7.86	9.77	34.18	18.35
Minimum	51.46	43.99	38.59	63.77
Maximum	59.72	52.95	55.58	75.70

N: number. SD: standard deviation. SE: standard error

Table (4): Comparing the mean ranks of flexural strength, and fracture toughness of the four study groups.

Flexural strength				
	Mean Rank	P*	Groups	Adjusted p**
G1_GC Temp PRINT medium color	10.70		G1 X G2	0.348
G2_GC TEMP with styrene butadiene	20.60	< 0.001	G1 X G3	> 0.999
G3_TEMPSMART	16.55		G1 X G4	< 0.001
G4_ERAYLAR PMMA bloc	34.15		G2 X G3	> 0.999
			G2 X G4	0.057
			G 3 X G4	0.005
Fracture toughness				
	Mean Rank	P*	Groups	Adjusted p**
G1. GC Temp PRINT medium color	24.20		G1 X G2	0.068
G2. GC TEMP with styrene butadiene	10.95	< 0.001	G1 X G3	0.084
G3. TEMPSMART	11.35		G1 X G4	0.184
G4. ERAYLAR PMMA bloc	35.50		G2 X G3	> 0.999
			G2 X G4	< 0.001
			G 3 X G4	< 0.001

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The mean and standard deviation of the fracture toughness values in Mpa had been presented in the (Table 3), the results showed that the higher mean value was for G4 (69.93+- 4.28) Mpa, while the least value was for G3(47.59+-5.58) Mpa, that's mean PMMA material have higher fracture toughness compared to other materials by using Kruskal Wallis test. **By Dunn-Bonferroni test the difference was significant p<0.01 presented in Table (4).

Discussion

Mechanical and physical qualities of three-dimensional printed temporary materials differ noticeably. There have been numerous studies that compare the mechanical and physical properties of materials used in 3D-printed fixed partial dentures (FPDs) and provisional crowns with those used in CAD/CAM milled or traditional provisional restorations and the capacity of a material to change its crystalline phase at stresses in order to halt the spread of a crack and seal it is the foundation for the optimal combination of flexural strength and fracture toughness and this is the importance of using these two tests.[12-16] The studies have revealed that the production process and material composition have an effect on the physical and mechanical qualities of temporary crowns and FDP materials.[17] Flexural strength and fracture toughness were shown to be better for G4 (ERAYLAR PMMA bloc) when compared to new and original materials such as GC Temp PRINT medium color, GC Temp with Styrene Butadiene, and TEMPSMART. According to the conclusions of this study, CAD-CAM has superior qualities to 3D printing and traditional temporary crown and bridge technologies.Because of their extensive cross-linking and homogeneous structure, CAD/CAM milled PMMA resins are much more resistant to hydrolytic degradation than conventional and 3D-printed resins, making them a desirable alternative for usage in a number of applications.[18] A study in Florida (2019) indicated that the milled PMMA has greater flexural strength than resins used in 3D printing. Comparing urethane methacrylate resin to milled PMMA or acrylic ester resin, urethane methacrylate resin demonstrated noticeably better gloss and translucency. When contrasting clinically relevant characteristics, each method for fabricating provisional restorations showed benefits and drawbacks.[19] Despite the fact that PMMA had better mechanical characteristics than G2 (Styrene Butadiene added to GC Temp PRINT medium color), there were no appreciable differences in flexural strength between the two materials. Although, there were no statistically significant differences between G1 (GC Temp PRINT medium color) and G2 in terms of fracture toughness, G2 shows higher flexural strength and lower fracture toughness to G1, because the microstructure of the material like leucite contain, particle size will affect the correlation between fracture toughness and flexural strength, when defects or cracks spread unstably under imposed stresses and the addition of styrene butadiene have been altered the cross linking of the material .[20] This finding might suggest using Styrene Butadine as a new conventional material for temporary crown and bridge construction in 3D printing in the future. A study published in Russia in 2023 compared the mechanical properties of Acrylonitrile Butadiene Styrene (ABS) samples that were 3D printed from scratch to ABS samples reinforced with short carbon fibers, revealing that adding short carbon fibers to the ABS matrix increased the tensile strength of the printed samples by 29.8%. This, along with the material's high-performance properties, opens up a wide range of possibilities for using it to solve various engineering tasks. The SCF-reinforced ABS performed admirably in tests for bending and fracture. Models that fully take advantage of the short fiber reinforced

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polymer can be developed by carefully choosing the numerical simulation parameters.[21]

Conclusion

Comparing the mechanical characteristics of samples made of PMMA, Styrene Butadiene added to GC Temp PRINT medium color, TEMPSMART, and GC Temp PRINT medium color during 3D printing. However, Styrene Butadiene added to GC Temp PRINT medium color (G2) also differs significantly from GC Temp PRINT medium color (G1) in ways that improve the material's physical properties. PMMA has higher flexural strength, and fracture toughness.

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Conflict of Interest

No conflict of interest.

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