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Flexural Strength and Surface Roughness of Milled Composite Resin Blocks versus 3D Printed Composite Resin with Different Orientations Using Two Thicknesses

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Abstract:

Background: to evaluate the flexural strength and surface roughness 3D printed composites with different orientations (0, 45and90 degrees orientations) and Composite modified blocks with two thicknesses 1mm and 1.5 mm.

Materials and Methods: 64 specimens were constructed divided into 4 groups then tested for flexural strength and surface roughness. The first group (C) n=16 was made of Crios, then divided into two subgroups according to thicknesses Subgroup (I) 1 mm n=8, Subgroup (II) 1.5 mm n=8. The other three groups (P) n=48 was printed using Flexcera and divided into three different groups with three different angles P0° n=16; P45° n=16; P90° n=16, then divided into two subgroups Subgroup (I) 1 mm n=8 Subgroup (II) 1.5 mm n=8

Results: The highest roughness was found in P45, while the lowest roughness was found in C.The highest strength was found in C, while the lowest strength was found in P90. According to the thickness the difference was not statistically significant.

Conclusion: Milled specimens showed lowest surface roughness and highest strength. Specimens printed at 45 degrees reported the highest surface roughness.Specimens printed at 0 degree had the highest strength. Layer thickness had no significant effect.

Key words: Milled, 3D printed, flexural strength, surface roughness.

Introduction

Ceramics and composites are some of the famous materials commonly used for manufacturing machined definitive restorations. Ceramics are famous for having superior mechanical and optical properties, as well as being biocompatible; but they are fragile, rigid, and difficult to repair. On the other side, composites are famous for being easily manipulated and repaired, more flexible, and less abrasive on the antagonist teeth, but their low wear resistance and difficult polishability put them in a disadvantage when compared to ceramics.[1]

Conventional ceramics produce definitive restorations with excellent esthetics; however, some studies identified a higher rate of failure of these materials, usually due to their high rigidity and their abrasive effect on the antagonist teeth. On the other side, Machinable composite materials suffer from high wear level, loss of superficial gloss, color instability, and low fracture resistance.[2]

Nowadays the digital technologies have become an essential part in every industry all over the world, including both healthcare and dentistry[3]. First the subtractive manufacturing was introduced in dentistry, but the process was slow due to the limitations for the sophisticated detail fabrication, the huge amount of the waste material and last but not least the high cost of the machines needed and also the consumables significantly reduced its use in the dental industry.[4]

It is gradually replaced by the additive manufacturing that solves most of the previous mentioned issues.[5] Within the past ten years the additive manufacturing technologies have been developing with very high speed. At the same time the machines evolve from a huge industrial type with price around a couple of hundred thousand euros into desktop small devices with a hundred times lower price. This forces the new material development as well as the digital machines to be constantly upgraded for higher results to be achieved.[3-5]

Additive manufacturing is defined by the International Organization for Standardization (ISO) and American Society for Testing and Materials (ASTM) as: Process of joining materials to make parts from 3D model data, usually layer upon layer, on the contrary to subtractive manufacturing and formative manufacturing methodologies. [6]

Benefits of using 3D printing techniques are the quicker manufacturing time and less expensive cost compared to conventional methods.[7] In general, the number of models that can be obtained on a platform depends on the printing shape and direction; vertical printing can produce more models than horizontal printing. There have been many studies of SLA 3D printers because their accuracy when creating complex printed objects differs on the basis of the printing direction, parameter settings, and the material type used.

When changing the printing direction and parameters such as light intensity, exposure time, and slice thickness during the manufacturing of test specimens using various 3D printer materials. Studies demonstrated that several factors, such as the parameters and printing directions of the SLA 3D printer, affect accuracy and precision. However, most specimens have simple shapes such as a bar[8-9] crown[10-11] and prism.[12]

The aim of this study:

To study the flexural strength and surface roughness of CAD/CAM composite materials.

1. 3D printed composites with different orientations (0, 45and 90 degrees orientations).
2. Composite modified blocks

   With two thicknesses: 1mm and 1.5 mm

The null hypothesis of this study was that neither manufacturing technique nor different 3D printing orientation affects flexural strength and surface roughness of CAD/CAM composite materials.

Materials and methods

Sample preparation: 64 specimens were constructed divided into 4 groups then tested for flexural strength and surface roughness. The first group (C) n=16 was made of composite modified blocks (Crios), prepared by sectioning the block into discs then divided into two subgroups according to thicknesses, Subgroup (I) 1 mm n=8 and Subgroup (II) 1.5 mm n=8. The other three groups (P) n=48 was printed by 3D printed material (Flexcera) and divided into three different groups with three different angles P0° n=16; P45° n=16; P90° n=16, then divided into two subgroups according to thicknesses, Subgroup (I) 1 mm n=8 and Subgroup (II) 1.5 mm n=8.

Composite modified block (Crios) was rounded to the diameter of 100 mm Then sectioned using slow-speed cutting Isomet machine to fabricate 16 specimens (n=16), measuring 1 mm (n=8) and 1.5 mm (n= 8). A digital caliper was used to verify all measurements.

8 3D printed specimens were prepared using Flashforge digital 3D printing software program to the desired angle three different angles (0° 45° 90°), thickness and diameter. Then printed by 3D printed composite material (Flexcera) using RASDENT printing machine. 16 disc of each angle was

printed. Using a light curing unit all samples (n=48) were cured for 30 minutes on each side according to manufacturer recommendations. Then All specimens are immersed in alcohol jar inside a professional ultrasonic cleanser for 5 minutes.

Surface roughness measurement:

A stylus profilometer was used to measure the Ra (average roughness height) in micrometers (μm) for all samples and the data were calculated by three singles individual measurements and the final Ra value were based on the average of the 3 measurements.

Measuring flexural strength:

Three-point bending tests were carried out on the specimens using a universal testing machine (ElectroPuls E3000, Instron, USA) with 12 mm distance between supporting rollers. It was then uniaxially loaded and Loading was increased gradually with the crosshead speed of 1 mm/min until fracture occurred. The failure load was recorded in Newton (N) and was determined by the highest point of the load curve produced by the universal testing machines software**.** The flexural strength was calculated according to the following formula:

$$\sigma = 3FL/ 2wt^2$$

Where; “F” is load at fracture point; “L” is span length between supports;” w” is the width of specimen; “t” thickness of specimen.

Statistical analysis:

Numerical data were presented as mean and standard deviation (SD) values. They were explored for normality and variance homogeneity by checking the data distribution and using Shapiro-Wilk's and Levene's tests, respectively.

Data were normally distributed with homogenous variances across groups and were analyzed using two-way ANOVA followed by Tukey's post hoc test. Simple effects comparisons were made utilizing the ANOVA error term with p-values adjustment using the False Discovery Rate (FDR) method. The significance level was set at $p<0.05$. Statistical analysis was performed with R statistical analysis software version 4.4.1 for Windows.

Results

Results for the surface roughness shows that there was a significant difference between different materials. The highest roughness was found in P45 (1.06±0.38), followed by P90 (0.86±0.08), then P0 (0.39±0.17) while the lowest roughness was found in C (0.11±0.01). Comparisons and summary statistics of surface roughness (Ra) for different materials and thicknesses are presented in figure (1) and in table (1). For the flexural strength there was a significant difference between different materials. The highest strength was found in C (921.52±77.81) (MPa), followed by P0 (495.24±72.17) (MPa), then P45 (489.72±98.73) (MPa), while the lowest strength was found in P90 (456.02±60.54) (MPa). According to the thickness 1.5 mm thick samples (597.18±226.20) (MPa) had higher strength than 1 mm thick samples (584.06±191.05) (MPa), yet the difference was not statistically significant. Comparisons and summary statistics of biaxial flexural strength (MPa) for different materials and thicknesses in figure (2) and table (2).

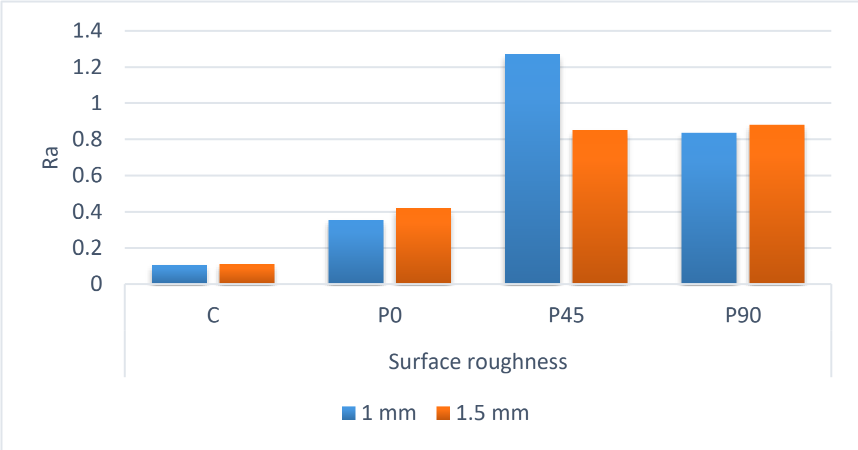

Figure (1): Bar chart showing average surface roughness (Ra) for different materials and thickness (B).

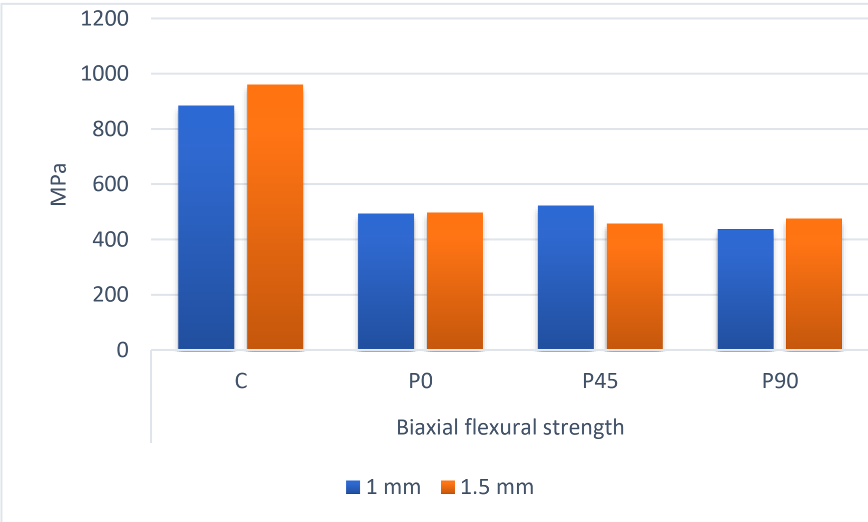

Figure (2): Bar chart showing average biaxial flexural strength (MPa) for different materials and thickness (B).

Table (1): Comparisons and summary statistics of surface roughness (Ra) for different materials and thickness.

Material / Thickness	Surface roughness (Ra) (Mean±SD)				p-value
	C	P0	P45	P90	
1 mm	0.11±0.01 D	0.35±0.14 C	1.27±0.39 A	0.84±0.05 B	**<0.001 ***
1.5 mm	0.11±0.01 C	0.42±0.20 B	0.85±0.23 A	0.88±0.11 A	**<0.001 ***
p-value	**0.967ns**	**0.481ns**	**<0.001***	**0.633ns**	

. Values with different superscripts within the same horizontal row are significantly different, * significant ($p<0.05$), ns not significant

Table (2): Comparisons and summary statistics of biaxial flexural strength (MPa) for different materials and thicknesses.

Material / Thickness	Biaxial flexural strength (MPa) (Mean±SD)				p-value
	C	P0	P45	P90	
1 mm	883.23±34.63^{A}	493.27±94.25^{B}	522.02±88.47^{B}	437.74±56.19^{B}	**<0.001***
1.5 mm	959.82±91.78^{A}	497.21±47.62^{B}	457.42±103.33^{B}	474.30±62.72^{B}	**<0.001***
p-value	**0.051ns**	**0.918ns**	**0.095ns**	**0.341ns**	

Values with **different superscripts** within the **same horizontal row** are significantly different, * significant ($p<0.05$), ns not significant

Discussion

The objective was to evaluate the flexural strength and surface roughness of CAD/CAM composite materials. 3D printed composites with different orientations (0, 45and 90 degrees orientations) and composite modified blocks with two thicknesses (1mm) and (1.5 mm).

CAD/CAM composite materials was selected in this study as it offers several advantages compared with ceramic materials because composites have less hardness and stiffness, in addition, they are easily fabricated and their lower brittleness allows less chipping and crack introduction during manufacturing [13]

CAD/CAM materials are commonly commercialized in blocks, so preparation of the bars is necessary in this study for three-point bending test (3PBT) and surface roughness test is simplified in respect to the one required for biaxial flexure test (BFT), where a disc has to be produced.

In this study two different thicknesses for the discs were selected (1mm and 1.5 mm) in order to mimic different clinical situations and to represent crowns with minimal thickness, as currently most of the clinical approaches are mainly shifting toward minimally invasive dentistry, which conserves tooth structure and decreases the risk of tooth devitalization.[13]

Furthermore, in order to obtain accurate and standard disc-specimens with the required dimensions of 10 mm in diameter and 1 and 1.5 mm in thickness, Isomet milling apparatus is necessary.

The roughness average (Ra) is the most commonly used parameter in dentistry for description of surface roughness among different types of machines. ***Sarikaya et al.***[14] stated that Ra parameter describes the overall roughness of a surface and can be defined as the arithmetical average value of all absolute distances of the roughness profile from the center line within the measuring length. Ra gives a representative estimate of surface roughness and it is easy to calculate it. Moreover, it is easy to measure and the machine is available and affordable.[15]

Two types of Profilometer are available contact and non-contact devices. Non-contact devices usually used a light beam or lasers to scan the surface. However, this method can lead to false values when used with shiny surface such as ceramics.[16] This is due to the scattering effect of the reflected light. Therefore, a contact device was used in this study as it directly touches the sample surfaces.

On the other hand, Strength is an important mechanical property that can assist in predicting the performance of different materials. The uniaxial flexural strength tests, including three-point, and four-point bending tests, and biaxial bending tests are the most commonly applied methods for evaluating the strength of dental restorations. [17]

Based on the obtained results, the null hypothesis was rejected since different manufacturing techniques and different orientations affects both the flexural strength and surface roughness of CAD/CAM composite materials.

Regarding Surface Roughness:

The highest roughness was found in P45 (1.27±0.39), followed by P90 (0.84±0.05), then P0 (0.35±0.14), while the lowest roughness was found in C (0.11±0.01). This decrease may be due to the fabrication process of pre-polymerized resin blocks, where it is fabricated at high temperature and under appropriate pressure which improved degree of conversion and lesser residual monomer. Therefore, the pre-polymerized resin exhibited little shrinkage, porosity, or freemonomers.[18]

The results of this study agreed with the study made ***Mohamed et al.***[18] to evaluate the Surface Properties and Impact Strength of CAD/CAM Milled, 3D Printed, and Polyamide Denture Base Resins ,the results of this study showed that CAD/CAM milled resins showed a significant decrease in surface roughness value when compared with 3D-printed resin

The findings of this study stated that the P45 group (3D printed with angle 45) has the highest surface roughness among the printed groups with different angles and this was supported by previous studies.

According to ***Mohamed et al.***[18] who evaluated surface properties of CAD/CAM milled and 3D printed denture base resins found that the layering technique and printing orientation (45°), results in stepwise edges between successive layers leading to higher surface roughness.

Regarding Flexural strength:

There was a significant difference between different materials. The highest strength was found in C (921.52±77.81) (MPa), followed by P0 (495.24±72.17) (MPa), then P45 (489.72±98.73) (MPa), while the lowest strength was found in P90 (456.02±60.54) (MPa).

In co ordinance with a study made by ***Adolfo Di Fiore et al.***[19] to compare the flexural properties and surface properties of milled and 3D-printed PMMA resins for denture bases, the results show that CAD group displayed the best flexural properties.

The results are also in agreement with ***Passent at al.***[20] who evaluated the influence of CAD/CAM milling and 3D-printing fabrication methods on the mechanical properties of 3-unit interim fixed dental prothesis and found that superior flexural strength reported in milled compared to 3D printed. This might be related to the reduced hydrolytic degradation susceptibility and fracture of milled resins resulting from the fabrication of blocks under high pressure and temperature.

Also ***Digholkar et al.***[21] who studied the effect of fabrication method on fracture Strength of Provisional Implant-Supported Fixed Dental Prostheses reported lower flexural strength of 3D-printed micro hybrid-filled composite resins when compared to milled resins.

This study shows that the vertically printed samples (P0) have higher flexural strength than the other printed groups and this was in agreement with a study done by ***Todd et al.***[22] who studies the material property testing of 3D printed specimens in PLA on and entry-level 3D printer and found that when a 3-point bending fixture was used to conduct flexural testing on printed specimen and the 0° raster orientation produced the strongest parts with an ultimate bending stress of 102 MPa.

Another study by ***Shim et al.***[23] who evaluated the effect of printing orientation on the printing accuracy, flexural strength, surface characteristic of 3D-printed denture base resin found that Flexural strength increased in order of the specimens printed at orientation degrees of 90<45<0 with statistical significance.

Results for biaxial flexural strength (MPa) for different thicknesses in this study showed that 1.5 mm thick samples (597.18±226.20) (MPa) had higher strength than 1 mm thick samples (584.06±191.05) (MPa), yet the difference was not statistically significant.

This result is in agreement with a previous study by ***Abdullah at al.***[24] who studies effect of printing layer thickness and post curing conditions on flexural strength of a 3D printed resins and found that The 100µm 3D printing layer thickness had the highest flexural strength compared to the 25µm and 50µm layer thicknesses.

Conclusion: Within the limitations of this in vitro study, the following conclusions could be drawn:

1. The CAD/CAM milled showed lowest surface roughness when compared with 3D-printed composite material.
2. Specimens printed at 45 degrees reported the highest surface roughness.
3. The CAD/CAM milled showed highest flexural strength when compared with 3D-printed composite material.
4. Specimens printed at 0 degree had the highest flexural strength, followed by 45 and 90.
5. 3D printing layer thickness had no significant effect on the mechanical properties of 3D printed resins.

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