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Evaluation of Flexural Strength and Fracture Toughness of Feldspathic Metal Ceramic-Invitro Study

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Abstract: ***Background & Objectives**: Ceramic material is being extensively used in dentistry because of its aesthetic appearance similar to the tooth structure. One of the most extensively used materials in prosthetic dentistry is the feldspathic ceramics used for fabrication of the fixed dental prostheses but are limited by their inherent brittleness which is one of the primary reasons for the use of a metal substructure to reinforce the ceramic restoration. This study was done to evaluate the flexural strength and fracture toughness of feldspathic metal ceramic. **Materials and Methods**: The present study is to evaluate flexural strength and fracture toughness of feldspathic metal ceramic. A total of 120 samples of various thickness of about 0.5mm, 1.5mm, 2mm, 2.5mm were fabricated through the standardized casting procedure following this the metal discs (10mm*2mm) are covered with feldspathic ceramic of shade A2. These samples are then immersed in the ultrasonic bath containing 75% ethanol for 10 min and are dried. Then, the samples are tested for flexural strength and fracture toughness under universal testing machine. **Results**: A combination of Descriptive Statistics, One-Way ANOVA, and Post-Hoc Pairwise Comparisons was applied. It was found that the 1.5mm thickness was found to have the highest fracture toughness and superior flexural strength when compared to the 0.5mm and 2mm, 2.5mm. **Conclusion**: It can be concluded that the 1.5mm thickness was found to have the highest fracture toughness and superior flexural strength when compared to the 0.5mm and 2mm, 2.5mm.*

Keywords: Feldspathic (VITA VMK MASTER), Flexural strength, Fracture toughness

1. Introduction

Porcelain fused metal restorations are most commonly used for fixed prosthesis. Dental restorations aim to restore lost tooth structure caused by factors such as decay or esthetic corrections. Dental ceramics are usually referred to as non-metallic, inorganic structures primarily containing compounds of oxygen with one or more metallic or semi-metallic elements like aluminium, calcium, lithium, magnesium, phosphorus, potassium, silicon, sodium, zirconium & titanium[1]. These materials that are part of systems designed with the purpose of producing dental prostheses that in turn are used to replace missing or damaged dental structures. In dentistry, ceramics are widely used for making artificial denture teeth, crowns, bridges, ceramic posts, abutments, and implants and veneers over metal substructures. They are also used in restorative dentistry as monolithic restorations, porcelain inlays, onlays and metal veneering materials due to the material quality and their aesthetic appearance. And also, are characterized by their refractory nature, hardness, chemical inertness, susceptibility to brittle fracture and are chemically stable, have long lasting color stability, excellent biocompatibility and have an acceptable wear resistance[2,3]. But these have certain disadvantages, mostly due to their inability to withstand functional forces that are present in the oral cavity, hence initially they found limited application in premolar and molar areas. This led to the fusion of ceramics and metallic structures that could function as a core. Metal ceramic systems combine both the exceptional esthetic properties of ceramics and the extraordinary mechanical properties of metals.

2. Methodology

Preparation of Metal Ceramic Samples:
A total of about 120 specimens was fabricated of the inlay wax (Red Regular 250GM, Sigma dent) was cut in the form of the disc into the required specific dimension of 10mm x 2 mm by using the stainless- steel metal die.

Figure 1: Stainless Metal Die

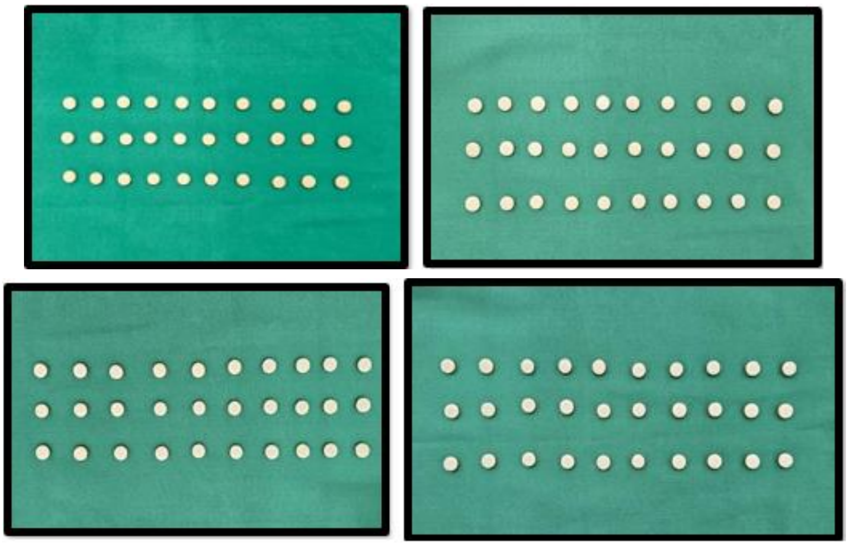


Figure 2: Feldspathic metal ceramic samples of various thickness (0.5,1.5,2,2.5 mm)

In which metal ceramics of various ceramic thickness of 0.5mm,1.5mm,2mm,2.5mm were fabricated. The metal disc is obtained through the standardized casting procedure then the finishing is done through the carborundum discs to achieve uniform thickness. Following this, samples are covered which wash opaque, opaque, dentin and enamel. The shade A_2 is taken as the standardized color for all the specimens firing is done according to the manufacturer's instructions. The ceramic discs of various thickness obtained are immersed in ultrasonic bath containing 75% ethanol and samples are dried prior to testing.

Testing for Fracture Toughness and Flexural Strength:

The testing for the fracture toughness and flexural strength is done under the universal testing machine

Fracture Toughness:
$M=3WL/2bd^2$

where W is the breaking load (N), L is the test span(mm), b is the width of the specimen (mm), and d is the thickness of the specimen (mm). The indenter (Vickers) will be used during application of stress. The treated surface was placed on a jig consisting of two supports at a span distance of 10.5 mm. The opposite surface was loaded with a universal testing machine at a crosshead speed of 0.5 mm/min.

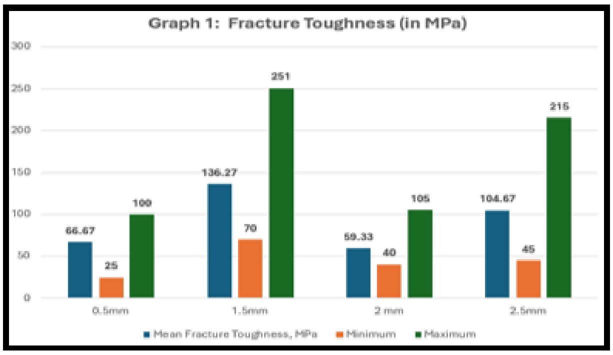
For Flexural strength:
The compressive load (v = 1 mm/min, load cell of 50 kgf) will be applied until catastrophic failure. The flexural strength (MPa) is calculated based on the formula: $3\ PL/2\ WT^2$ where P is the load recorded at fracture, L is distance between supports, W is specimen width and T is the specimen thickness.

3. Results

The study evaluated the flexural strength and fracture toughness of the feldspathic metal ceramic, for which a combination of **Descriptive Statistics**, **One-Way ANOVA**, and **Post-Hoc Pairwise Comparisons** was applied. The table 1 and graph 1 presents the descriptive statistics for the fracture toughness of feldspathic metal ceramic at different thickness. Data reveals that fracture toughness tends to be higher at intermediate thickness, particularly at 1.5mm, while thinner and thicker samples exhibit more variability and generally lower toughness values.

Table 1: Descriptive Statistics of Fracture Toughness (in MPa) of Feldspathic Metal Ceramic at Different Thickness

Fracture Toughness	N	Mean	SD	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0.5mm	15	66.67	23.73	6.127	53.53	79.81	25	100
1.5mm	15	136.27	56.61	14.61	104.92	167.62	70	251
2 mm	15	59.33	18.11	4.677	49.30	69.36	40	105
2.5mm	15	104.67	45.84	11.87	79.28	130.05	45	215
Total	60	91.73	49.43	6.32	78.96	104.50	25	251

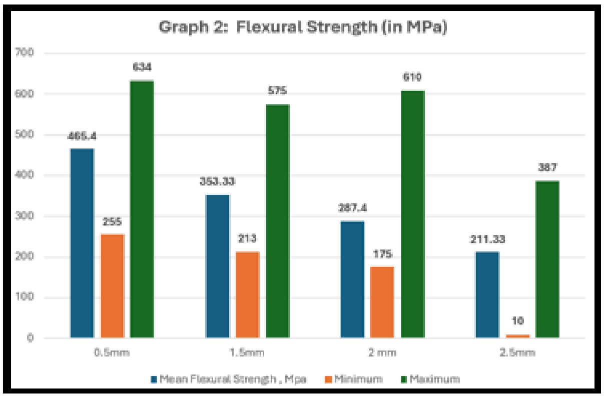


Graph 1: Descriptive Statistics of Fracture Toughness (in MPa) of Feldspathic Metal Ceramic at Different Thickness

The table 2 and graph 2 presents the descriptive statistics for the flexural strength of feldspathic metal ceramic at different thickness. that flexural strength generally decreases as the thickness of the material increases, with the 0.5mm exhibiting the highest strength and the 2.5mm showing the lowest mean flexural strength.

Table 2: Descriptive Statistics of Flexural Strength (in MPa) of Feldspathic Metal Ceramic at Different Thickness

Flexural Strength	N	Mean	SD	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0.5mm	15	465.40	113.57	29.32	402.5	528.30	255	634
1.5mm	15	353.33	96.31	24.86	300.0	406.67	213	575
2 mm	15	287.40	121.42	31.33	220.2	354.60	175	610
2.5mm	15	211.33	102.85	26.56	154.3	268.31	10	387
Total	60	329.37	141.804	18.30	292.7	366.00	10	634



Graph 2: Descriptive Statistics of Flexural Strength (in MPa) of Feldspathic Metal Ceramic at Different Thickness

Table 3 shows the one-way ANOVA results reveal significant differences in the fracture toughness of feldspathic metal ceramic at different thickness. With a p-value of ≤0.0001, the results are highly statistically significant, indicating that the fracture toughness varies significantly across the different thicknesses of feldspathic metal ceramic.

Table 3: One-Way ANOVA Analysis of Fracture Toughness

Fracture Toughness, MPa	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	57428.800	3	19142.933	12.355	**≤.0001***
Within Groups	86768.933	56	1549.445		
Total	144197.733	59			

Table 4 shows the one-way ANOVA results for the flexural strength of feldspathic metal ceramic at different thickness also show statistically significant differences between the groups.

Table 4: One-Way ANOVA Analysis of Flexural Strength, MPa

Flexural Strength, MPa	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	521588.067	3	173862.689	14.645	**≤.0001***
Within Groups	664799.867	56	11871.426		
Total	1186387.933	59			

This high F-value indicates a substantial difference between the groups' flexural strength. With a p-value of ≤0.0001, the results are highly statistically significant. This suggests that flexural strength of feldspathic metal ceramic varies significantly based on the thickness of the material.

Table 5 shows the post hoc pairwise comparisons of fracture toughness (MPa) between different thickness of feldspathic metal ceramic

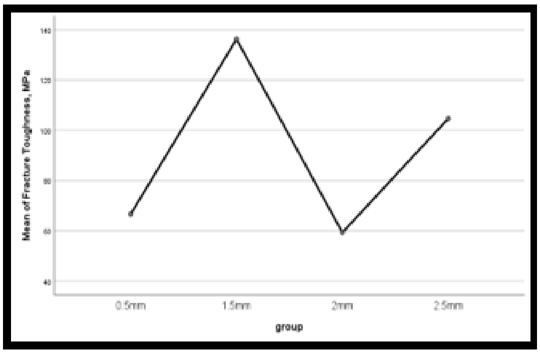
Results suggest that the fracture toughness of feldspathic metal ceramic is optimal at a thickness of 1.5mm, and increasing the thickness beyond 2mm may not provide additional benefits in terms of fracture toughness.

Table 5: Post Hoc Pairwise Comparisons of Fracture Toughness (MPa) Between Different Thickness of Feldspathic Metal Ceramic Using Dunnett T3 Test

Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	Std. Error	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
Fracture Toughness, MPa	0.5mm	1.5mm	-69.600*	15.849	.002	-115.82	-23.38
		2mm	7.333	7.708	.913	-14.49	29.16
		2.5mm	-38.000	13.329	.054	-76.44	.44
	1.5mm	0.5mm	69.600*	15.849	.002	23.38	115.82
		2mm	76.933*	15.347	.001	31.64	122.23
		2.5mm	31.600	18.809	.464	-21.56	84.76
	2mm	0.5mm	-7.333	7.708	.913	-29.16	14.49
		1.5mm	-76.933*	15.347	.001	-122.23	-31.64
		2.5mm	-45.333*	12.727	.013	-82.55	-8.11
	2.5mm	0.5mm	38.000	13.329	.054	-.44	76.44
		1.5mm	-31.600	18.809	.464	-84.76	21.56
		2mm	45.333*	12.727	.013	8.11	82.55

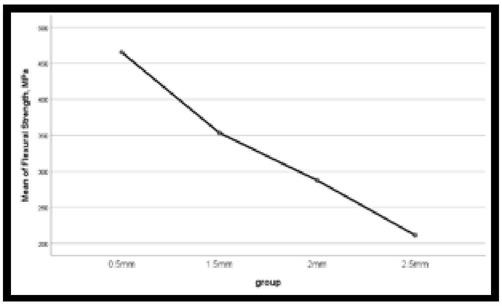
Table 6 presents the results of the post hoc pairwise comparisons for flexural strength (MPa) between different thickness of feldspathic metal ceramic, using the Dunnett T3 test. The 0.5mm group showed a significantly lower flexural strength compared to all other thickness. And, the 1.5mm exhibited a significant increase in flexural strength when compared to the 2.5mm.

Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	Std. Error	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
flexural strength, MPa	0.5mm	1.5mm	112.067*	38.450	.040	3.52	220.62
		2mm	178.000*	42.914	.002	57.04	298.96
		2.5mm	254.067*	39.569	.000	142.49	365.64
	1.5mm	0.5mm	-112.067*	38.450	.040	-220.62	-3.52
		2mm	65.933	40.000	.485	-47.19	179.05
		2.5mm	142.000*	36.388	.003	39.43	244.57
	2mm	0.5mm	-178.000*	42.914	.002	-298.96	-57.04
		1.5mm	-65.933	40.000	.485	-179.05	47.19
		2.5mm	76.067	41.077	.357	-39.90	192.03
	2.5mm	0.5mm	-254.067*	39.569	.000	-365.64	-142.49
		1.5mm	-142.000*	36.388	.003	-244.57	-39.43
		2mm	-76.067	41.077	.357	-192.03	39.90



Graph 3: Mean of fracture toughness between 0.5mm,1.5mm,2mm,2.5mm of feldspathic metal ceramics

The 0.5mm consistently showed significantly lower flexural strength compared to the other thickness, while the 1.5mm demonstrated superior flexural strength compared to both the 2mm and 2.5mm.



Graph 4: Mean of flexural strength between 0.5mm, 1.5mm, 2mm, 2.5mm

The 0.5mm thickness consistently showed significantly lower flexural strength compared to the other thicknesses, while the 1.5mm demonstrated superior flexural strength compared to both the 2mm and 2.5mm thicknesses.

4. Discussion

Feldspathic metal ceramics, commonly used in dental restorations, are known for their excellent esthetics but are limited by their inherent brittleness. Recent studies have focused on enhancing their mechanical properties, particularly flexural strength and fracture toughness, to improve their clinical longevity and performance under masticatory forces. In addition, for many years, Metal ceramic feldspathic prostheses have been the most widely used restorative material in the aesthetic zone due to the clinical longevity and the accepted aesthetics of the restoration. The flexural strength of feldspathic porcelains is quite low, generally in the range of 60 to 70MPa, which is one of the primary reasons for the use of a metal substructure to reinforce the ceramic restoration. Crispin etal in 1990[7], ion exchange on the flexural strength of feldspathic porcelains, which are commonly used in dental restorations.

S. S. Porter et al in 1988 [8] use the indentation technique to measure the fracture toughness of disks of a commercial dental porcelain and compare these to the apparent fracture toughness of metal-ceramic crowns. This demonstrated that apparent fracture toughness and elastic modulus-to-hardness ratio of metal ceramic restorations was found to be significantly greater than that of individual porcelain specimens, presumably due to residual compressive stresses in their surface. Roja k et al in 2021[4], fracture resistance, color change and, surface roughness has increased with the concentration of silver nanoparticles highest being with the concentration of 2000ppm.The ceramic discs became darker in shade with the increase in concentration of silver nanoparticles affecting the color stability. Reinforcement with various metallic nanoparticles can improve the properties to enhance clinical application. A major weakness of these materials is the sensitivity to flaws, which may have developed as a result of thermal, chemical or mechanical processes, and act as local stress raisers. At a certain critical applied stress, a crack can originate from a flaw and propagate, engendering final catastrophic fracture. In dental literature, mostly crosshead speeds of 0.5 and 0.1mm/min have been used. In the current investigation, crosshead speeds ranging from 0.5 to 0.05mm/min were used, which covered the range of speeds often used in ISB test and it was found that a high load speed elevated the ISB fracture toughness.

5. Conclusion

The study evaluated flexural strength and fracture toughness of feldspathic metal ceramic following conclusions were drawn that 1.5mm thickness was found to have highest fracture toughness and superior flexural strength when compared to 0.5mm and 2mm, 2.5mm.

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