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Effect of Surface Treatments on the Biaxial Flexural Strength of High Leucite Feldspathic Porcelains

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Key words
the biaxial flexural strength (bfs), dental porcelain, leucite, feldspathic ceramics, grit blasting, polishing, etching.

Abstract

The purpose of this study was to examine the effect of altering surface topography on the biaxial flexural strength (BFS) of four dental ceramics, Mirage (MI), Flexoceram (FL), Optec-HSP (OP) and IPS Empress (EM).Twelve groups of ten discs 12×3mm were prepared and fired according to the manufacturers' instructions. Ten specimens of each material were subjected to three surface treatments, polished, grit blasted and etched with 10% hydrofluoric acid (HF) for 2 minutes. Some specimens were gold coated for examination under Scanning Electron Microscope (SEM). BFS was determined using Lloyd M5K universal testing machine at a cross-head speed of 0.5 mm/min. A one-way ANOVA was used to evaluate the differences between groups.The results obtained showed that the only significant difference in the BFS was the 10% HF for OP and FL (One-way Anova, $P<0.05$). The decrease in BFS is most likely due to an increased surface flaw size, such that surface initiated crack growth dominates over the bulk internal flaw size of the ceramics.The BFS of dental porcelain used in this study may be governed either by the internal or surface flaws depending on the manner of surface preparation. Specimens etched with 10% HF became weaker for OP and FL ceramics.

Introduction

Dental ceramics have become increasingly popular because of their unique properties such as biocompatibility, chemical stability and superior aesthetic qualities. However, one of the inherent disadvantages of dental ceramic restorations is their brittle nature. This brittle behaviour combined with the presence of surface and internal flaws may result in a low strength and consequently has limited the clinical use of ceramics such as those based leucite ($K_2O.Al_2O_3.4SiO_2$) reinforcement [1].The leucite reinforced ceramics frequently fail at stresses below their reported strength values as a result of either internal or processing defects. The former could be due to residual stresses, large grains and micro-cracks resulting from the differences in the thermal expansion between the glassy matrix and the crystalline phases of the leucite Shareef et al.,[2], whereas the latter could be machining scratches, impurity phases and porosity [3]. The strength for a certain material will, therefore, depend on the number and size of defects that are incorporated within the material[4]. Recent studies have shown that grinding process caused a significant reduction in the flexural strength of the feldspathic porcelains, whereas polishing and glazing have a significant increase of the flexural strength of the same porcelains [5,6].Hussain et al.[7],Baez et al.[8]

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and Jones[9]examined the effect of chemical etching on the strength of some dental ceramics using either hydrofluoric acid (HF) or ammonium bifluoride. Levy [10]found no significant difference in the flexural strength values of some dental ceramics when the surface was chemically etched. The objective of this study was to evaluate the effect of three surface preparations namely polishing, grit blasting and etching on the BFS of the fit surface of a number of dental ceramics and establish whether surface or internal flaws determine the BFS.

Materials and Methods

Four commercial available dental ceramics were used in this study, namely Mirage (MI), Flexoceram (FL), Optec-HSP (OP), and IPS Empress (EM). The details of the dental ceramic which have been investigated are presented in the following table:

Materials	Code	Shade No.	Batch No.	Manufacturer
Mirage	MI	Body D-4	8130	Myron Int. Inc. Kansas, USA
Flexoceram	FL	D-EB1	442	Elephant Ceramics, Hoorn, Netherlands
Optec-HSP	OP	A2	B1637 E	Jeneric, Conn., USA
IPS Empress	EM	B2	684098	Ivoclar, Schaan/Liechtenstein

The chemical composition of the porcelain is confidential; however, it is within 5% of the nominal composition of the Weinstein[11], which has the following composition (wt. %):

Component	Percentage (by weight)
SiO_2	63.4
Al_2O_3	16.7
K_2O	14.2
Na_2O	3.4
Li_2O	1.5
CaO	1.5
MgO	0.8

Three groups of ten specimens were prepared for each material. A mixture of ceramic powder and condenser liquid (Myron, Inc., Kansas, USA) was cast into a silicon rubber mould 12mm in diameter × 3mm thick and vibrated to condense the particle and subsequently fired according to the manufacturers' instructions appropriate to each ceramic. The fired discs were ground with 600 grit SiC paper (Buehler-Met, Metallographic Grinding Paper, UK) to produce flat parallel surfaces and their thickness was measured by a micrometre screw gauge (Mitutoyo, Japan). Ten specimens of each material were subjected to three surface treatments, namely: (1) polished with diamond paste down to 1 µm, (2) grit blasted (alumina 50 µm) and (3) etched with 10% HF for 2 minutes. Some specimens were gold coated for examination under SEM[2].The biaxial flexural strength (BFS) values for ten discs of each material were determined by placing each specimen on an annular knife edge 9mm in diameter and loaded with a 3mm ball-ended indentor in a Lloyd M5K universal testing machine at a cross-head speed of 0.5 mm per minute. The specimens were loaded to failure and the maximum BFS values were calculated using the equation reported by other investigator[12]. Assuming a Poisson's ratio (ν) of porcelain of 0.25, the simple form of this equation is:

$$\sigma_f = \frac{p}{h^2}\{0.606\ln(a/h)+1.13\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where σ_f is the biaxial flexural strength (BFS), p is the load to fracture, a is the radius of the knife-edge support and h is the sample thickness. Statistical comparisons between groups were made using one-way analysis variance (ANOVA) significant difference test.

Results

BFS data for each group of MI, FL, OP and EM are plotted in Figure 1. Statistical analyses of these results are shown in Table 1 with analysis of variance (ANOVA) and Tukey HSD tests used to evaluate significance between groups. The results show no significant difference in the BFS for the polished and grit blasted. In contrast, the BFS reduced after etching with 10% HF, which was significant for OP (69 MPa) and FL (45 MPa) (one-way Anova, $P<0.05$), but not

for MI (63 MPa) and EM (82 MPa).Values for the average flaw size (C) were calculated using Equation (2) and are shown in Figure 2 and summarised in Table 2.

$$\sigma_f = \frac{K_{ic}}{Y}\sqrt{C} \quad \text{.....} \quad (2)$$

where σ_f is fracture strength, K_{ic} is fracture toughness, C is flaw size and Y is the geometric constant. The fracture toughness (K_{ic}) values were obtained from data reported by Bieniek and Marx[13]and our BFS data were used for σ_f .

Discussion

As shown in Fig. 1, the BFS decreased significantly for samples prepared from OP and FL materials when etched with 10% HF, whereas polishing and grit blasting treatments have no effect on the BFS. The reduction in the BFS values after etching with 10% HF is most likely due to an increase surface flaw size which would be sufficient to induce fracture initiation from the surfaces. Other investigators have also found that a decrease between 20% to 40% in the strength values after acid etching of dental ceramics[7-9]. However, it should be noted that etching with HF does not always has an effect on the BFS values. Levy[10] reported that no significant difference in the flexural strength values of some dental ceramics between polishing with pumice and etching after air and vacuum glazing and overglazing. Also, Jones[9]reported that a reduction of 40% in strength of on brand of feldspatic dental porcelain rods and no weakening effect of another brand when etched with HF. The BFS was unaffected for the specimens polished with diamond paste down to 1 μm and grit blasted (alumina 50 μm). This suggests that the BFS is governed primarily by the internal flaw size. However, Sano et al.[14]reported that feldspathic porcelain specimens showed a higher four-point flexural strength when polished with 0.3 μm alumina. Sherrill and O'Brien[15]found that no difference between the strength of feldspathic porcelain specimens when their surfaces were fine polished or autoglazed. Fairhurst et al.[16]and Giordona et al.[17], on the other hand showed that polishing surfaces with 1 μm and 15 μm diamond pastes produced significant stronger specimens than autoglazing. Also, it has been reported that no statistically significant differences in the load at failure of glazed porcelain and polished autoglazed porcelain[18]. However, polishing the glazed specimens showed higher strength values[10].These suggested that the characteristic properties of dental porcelains are not always dependent on the characteristics of the surface. A measure of the severity of fracture-initiating flaws can be obtained from the measured values of strength and fracture toughness by assuming that the flaws had a particular simple geometry (Equation 2). Therefore, usable strength is a function of flaw size. Based on the present data the estimated flaw size values were approximately ranging between 100 to 300 μm (Fig. 2), which corresponds well to the observed internal cracks size that have been reported in the previous study[2].

Conclusions

1.The BFS for the polished and grit blasted surface finishes of dental porcelain used in this study is governed primarily by the internal flaw size.

2.Etched surfaces (10% HF for 2 minutes) caused a reduction in the BFS values because the large surface flaws created dominate the fracture process.

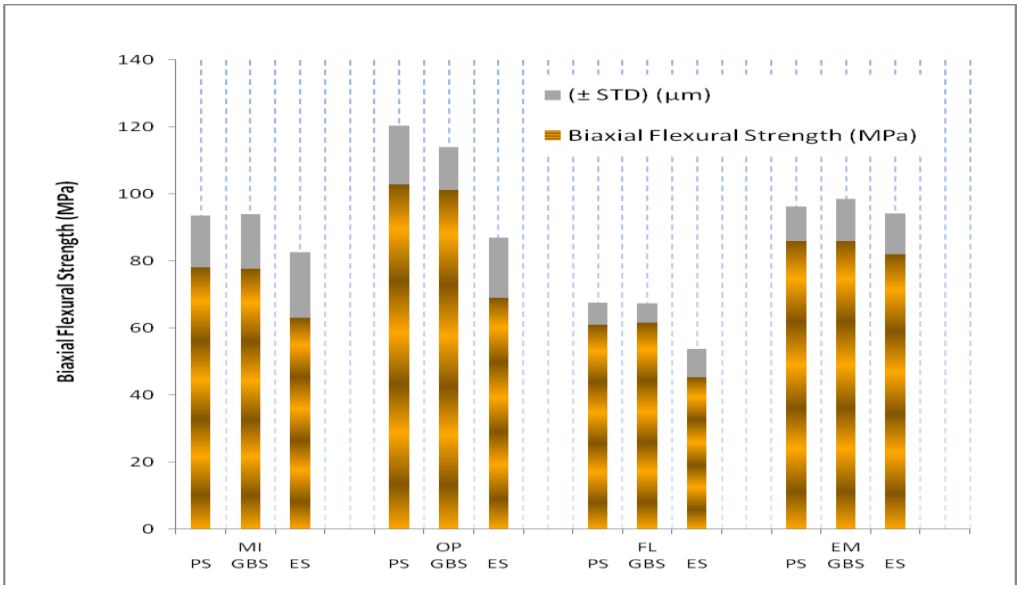

Fig.(1): Biaxial flexural strength plotted against surface treatments for MI, OP, FL and EM materials.

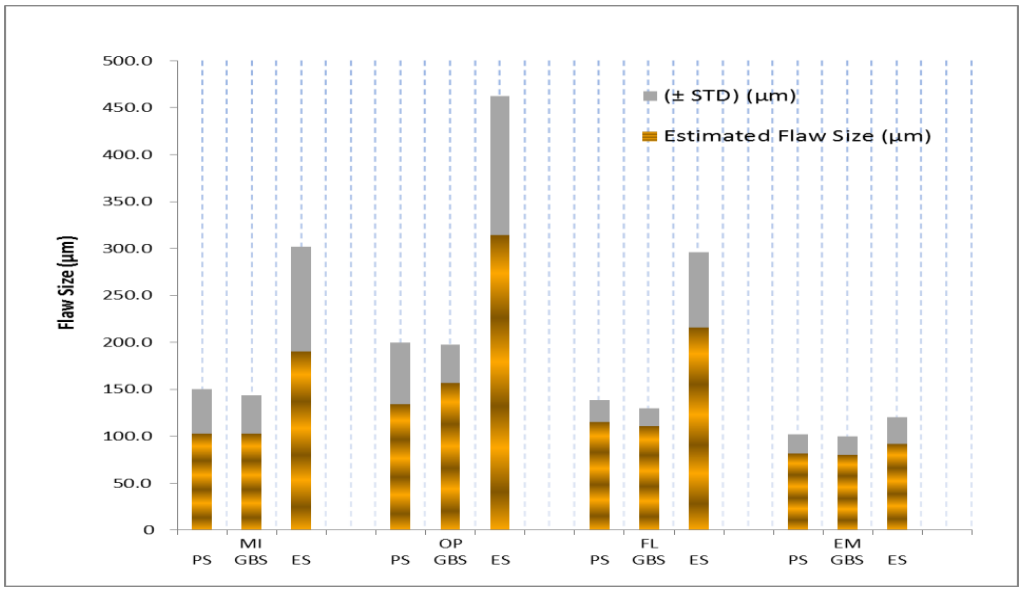

Fig.(2): Flaw size plotted against surface treatments for MI, OP, FL and EM materials.

Table (1):- Biaxial Flexural Strength values and their statistical analysis.

Materials	Surface Treatments*	Biaxial Flexural Strength (MPa)		
		Mean (%)	(± STD)	C.V.
MI	PS	78.0	15.5	19.9
	GBS	77.7	16.2	20.8
	ES	63.0	19.6	31.1
OP	PS	102.8	17.5	17.0
	GBS	101.1	12.8	12.7
	ES	69.1	17.9	25.9
FL	PS	60.9	6.7	11.0
	GBS	61.7	5.7	9.2
	ES	45.3	8.4	18.6
EM	PS	86.0	10.3	12.0
	GBS	86.0	12.4	14.4
	ES	82.1	12.1	14.7

*Surface Treatments
- Polished Surface (PS)
- Grit Blasted Surface (GBS)
- Etched Surface (ES)

Table(2):- Estimated flaw size values (±STD).

Materials	Surface Treatments	Estimated Flaw Size (±STD) (μm)**
MI	PS	102.9 (47.3)
	GBS	102.8 (41.1)
	ES	190.5 (111.5)
OP	PS	134.4 (65.4)
	GBS	156.9 (40.4)
	ES	314.0 (148.2)
FL	PS	115.2 (23.2)
	GBS	111.0 (18.8)
	ES	216.1 (79.8)
EM	PS	81.7 (20.6)
	GBS	80.1 (20.1)
	ES	91.6 (28.7)

** K_{ic} values were taken from Bieniek and Marx (1994).

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