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Effect of surface finish on the flexural strength of five conventional dental ceramics

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ABSTRACT

Purpose of the study: Because of existing controversy, the present study investigated the 5 methods of surface finish and their influence on flexural strength of 5 conventional feldspathic dental porcelain.

Materials and methods: The materials analyzed were Vita VMK 95, Ceramco II, Shofu, Noritake, Ceramax. 250 porcelain discs were fabricated and were divided into 5 surface finish groups (n =10 each). The 5 groups were: Group I As-fired, Group II Self glazed, Group III Over glazed, Group IV Ground and polished, Group V Polished and self glazed. Average roughness values (Ra) were measured by a profilometer (Perthometer). All the specimens were then subjected to a ring - on - ring flexure strength test.

Results: The Surface roughness (Ra values) were in the following order: Group IV – 0.3 ± 0.1μm, Group III – 0.55 ± 0.3 μm, Group II – 0.9 ± 0.2μm, Group V – 1.1 ± 0.1 μm and Group I – 1.7± 0.2 μm. Following one-way ANOVA variance, the flexural strength values were in the following order: Group IV – 48.56 ± 2.56 MPa, Group III – 45.28 ± 2.70 MPa, Group II – 39.06 ± 2.17 MPa, Group V – 36.50 ± 1.97 MPa.

Conclusion: Ground and polished surfaces significantly improved the surface texture and flexural strength of the materials tested.

INTRODUCTION

Ceramic restorations excel in esthetics. Dental ceramics are being used as a restorative material to provide esthetic realism over the past 150 years. Their excellent bio-compatibility, light absorption behaviour, low electrical and thermal conductivity provide a significant rationale for their use in dental prostheses. They are however, extremely brittle in nature and hence liable to fracture. Their esthetic excellence depends to an extent on different techniques adopted to finish the restoration. Different researchers have reported contrasting opinions and results when testing different ceramic materials and surface finishing procedures. Hence the aims of our study were :

1. To evaluate the surface roughness of five conventional feldspathic dental ceramic materials.
2. To compare the flexural bending strength on conventional feldspathic porcelain after different surface finish procedures like as-fired, self-glazing, over glazing, grinding and polishing, polishing and self glazing.
3. To evaluate the influence of surface finish on the flexural strength of the materials evaluated.

MATERIALS and METHODS

The five conventional dental feldspathic porcelains analyzed were **Vita VMK 95, Ceramco II, Shofu, Noritake and Ceramax.** The test specimens were fabricated in the form of discs of dimension 10.8mm in diameter and 2mm in thickness with the help of a metallic mold. About 0.4 gm of dentin or body porcelain was pre-weighed on an electronic balance (AND Series HL 200) and 0.2 ml of modelling fluid which was measured in a micropipette was used to fabricate one disc specimen. The ceramic powder was placed in the metallic mold and compacted .A total of 250 specimens comprising of 50 specimens from each company product were fabricated. The disc specimens were sintered in a Multimat vacuum furnace according to each manufacturer's instructions The test specimens for each product were divided into 5 groups (n=10) according to 5 different finishing groups: Group I – As-fired, Group II- Self – glazed, Group III- Over glazed, Group IV – Grinding and polishing and Group V – Polishing and self glazing. The thickness of all the specimens were standardized to a uniform thickness of 1.8mm and was verified with a micrometer (Mitutoyo). The surface finishing procedures were done accordingly.

GROUP I: The unground surface of the as-fired specimens served as the control group.

GROUP II: The test specimens were subjected to self glazing procedure according to each manufacturer's instructions in the Multimat vacuum furnace.

GROUP III: Over glazing were done on one surface of the test specimens and were fired according

Key words: Flexural strength, Surface finish ,Dental ceramics

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to the manufacturer's instructions.

GROUP IV: Polishing consisted of subjecting one surface of the specimens with a series of emery coated discs of grades 500, 600 and 800 and finally polished with a diamond polishing paste of 2 microns

GROUP V: The test specimens were polished first with the above mentioned polishing sequence and were then subjected to self glazing procedure in the furnace.

Surface roughness test:

The surface roughness of each sample was evaluated with the help of a surface profilometer – Perthometer (Mahr 5 SP)(Figure I). This equipment analyzes the surface profile of the specimen under 5-micron magnification. The profiles were obtained in the form of a tracing (Figures 2, 3, 4, 5, 6). The values of the profiles were recorded (Table 1).

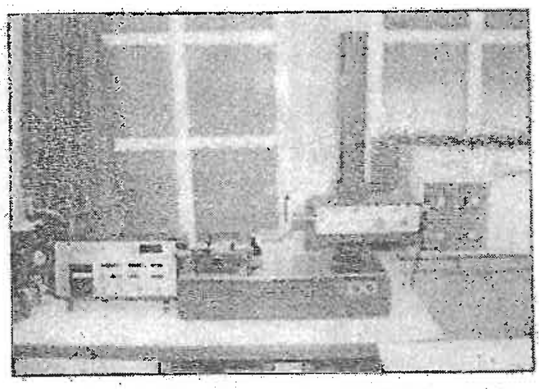

Fig. 1 : Surface profilometer - perthometer (Maher 5 SP)

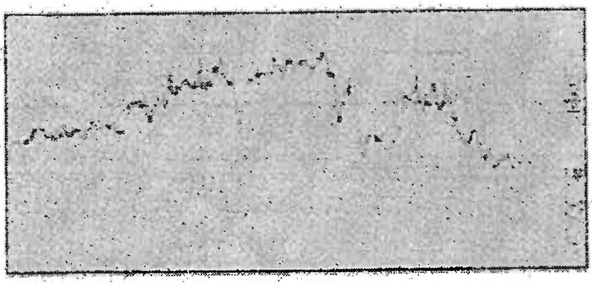

Fig. 2 : Perthograph of GROUP I – As Fired

Fig. 3 : Perthograph of GROUP II – Self Glazed

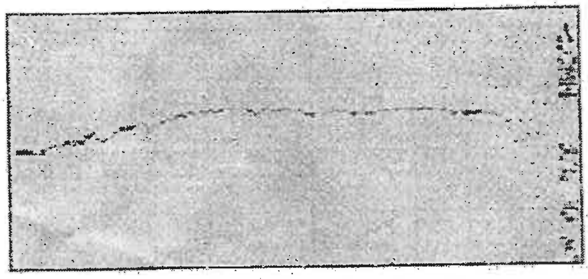

Fig. 4 : Perthograph of GROUP III – Over Glazed

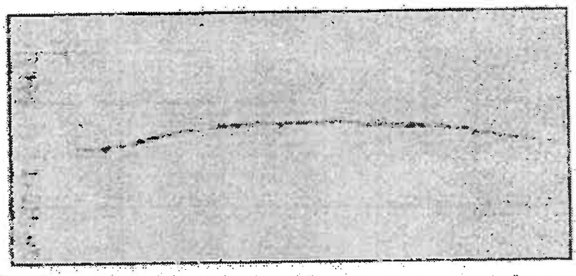

Fig. 5 : Perthograph of GROUP IV – Grinding and Polishing

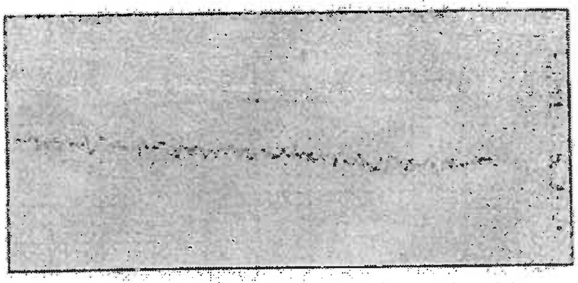

Fig. 6 : Perthograph of GROUP V – Polishing and Self Glazing

TABLE I

Surface roughness evaluation of the finishing groups

FINISHING PROCEDURES	Ra (Surface Roughness in μm)	STANDARD DEVIATION
GROUP I (AS FIRED)	1.7	0.2
GROUP II (SELF GLAZED)	0.9	0.2
GROUP III (OVER GLAZED)	0.5	0.3
GROUP IV (GROUND AND POLISHED)	0.3	0.1
GROUP V (POLISHED AND SELF GLAZED)	1.1	0.1

Flexural strength test:

A ring on ring test was employed for assessing the flexural strength of the surface finished specimens. The test was performed using a Universal testing machine (Hounsfield H25K). A loading ring apparatus with a diameter of 1.4mm and a support ring diameter of 10mm was custom fabricated (Fig - 2). The specimens

TABLE II

Comparison of mean and standard deviation between the finishing groups and the products

GROUP	VITA		CERAMCO II		SHOFU		NORITAKE		CERAMAX	
	MEAN	*S.D*	*MEAN*	*S.D*	*MEAN*	*S.D*	*MEAN*	*S.D*	*MEAN*	*S.D*
I	30.64	3.845	29.97	2.905	29.68	2.485	30.54	1.587	27.57	2.72
II	40.85	1.812	36.59	3.658	39.14	2.302	40.50	1.435	38.23	1.69
III	42.46	1.511	40.72	2.450	48.57	4.383	53.48	2.985	41.21	2.21
IV	48.19	3.064	48.97	2.178	52.38	3.497	44.83	1.321	48.47	2.80
V	36.50	2.539	34.20	1.973	38.19	2.482	38.30	1.641	35.35	1.26

were placed on the support ring apparatus fixed to the Universal-testing machine. The displacement rate of the Universal testing machine was standardized at a rate of 0.05 mm /min (as recommended by ISO / DIS 6872: 1994.).

The breaking load values were obtained and the flexural strength of all the test specimens was evaluated using the Timoshenko"s equation[11] which is

$$M = \left[\frac{3P}{4\pi t^2}(1+v)\ln\frac{a}{r}+1\right]$$

Where,

P = Load at fracture in Newtons.

t = Thickness of the specimen.

a = Radius of the circle of support.

b = Radius of the loading ring.

n = Poissons ratio (0.25)

r = Equivalent Radius $\rightarrow \sqrt{1.6b^2 + t^2} - 0.675t$

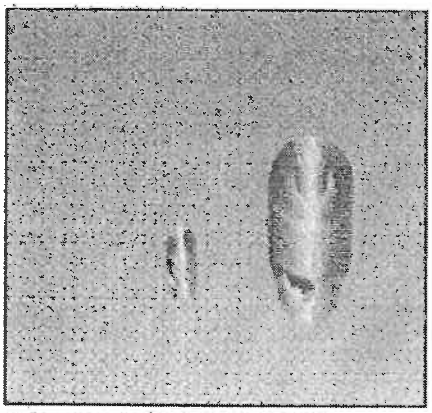

Fig. 7 : Loading ring apparatus and support

Mean and Standard deviation were estimated from the sample for each study group and for each product. The mean values were compared by One Way Analysis for Variance. Tukey – HSD procedure was employed to identify the significant groups if the p value is significant in One way ANOVA (Table II). In the present study, $p<0.05$ was considered as the level of significance. The statistical package SPSS – PC+ (Statistical Package for Social Science, Version 4.01) was used for statistical analysis.

RESULTS

Surface Roughness:

The overall Ra value for the Group I (As fired) porcelain surfaces was 1.7 ± 0.1 mm, Group II (Self Glazed) surfaces was 0.9 ± 0.2mm, Group III (Over Glazed) surfaces was 0.55 ± 0.3mm, Group IV (Ground and Polished) specimens was 0.3 ± 0.1mm and Group V (Polished and Self glazed) specimens was 1.1 ± 0.1 mm. A higher figure for Ra represents a rougher surface. The findings indicated that Ground and Polished specimens were the smoothest followed by Over Glazed specimens and Self-Glazed specimens. The Ra value was significantly higher for Polished and Self Glazed specimens with the as fired specimens showing the roughest surface.

Flexural Strength:

Flexural strength values were calculated according to the formula derived by Timoshenko. The flexural strength values for Group I (As fired) was 29.68 ± 2.70 MPa, for Group II (Self Glazed) was 39.06 ± 2.17 MPa, for Group III (over Glazed) was 45.28 ± 2.70 MPa, for Group IV (Ground and Polished) was 48.56 ± 2.56 MPa and for Group V (Polished and Self Glazed) was 36.50 ± 1.97 MPa.

The results of one way ANOVA for the flexural strength values exhibited by the specimens of different companies to Group I (As Fired) and Group II (Self-Glazing) finishing procedure showed that no two groups are significantly different at the 0.05 level.

The results of One way ANOVA for the flexural strength values exhibited by the specimens of different companies to Group III (Over Glazing) finishing procedure showed that Mean value of NORITAKE (53.48 ± 2.985) is significantly higher ($P<0.05$) than the mean value of VITA (42.46 ± 1.511), CERAMCO II (40.72 ± 2.450), CERAMAX (41.21 ± 2.21) and SHOFU (48.57 ± 4.38). Also the mean value of SHOFU is significantly higher ($P<0.05$) than VITA, CERAMCO II and CERAMAX. However, no other contrasts are statistically significant ($P>0.05$).

The results of One way ANOVA for the flexural strength values exhibited by the specimens of different companies to Group IV (Grinding and Polishing) finishing procedure showed that the mean value of SHOFU (52.38 ± 3.497) is significantly higher than VITA (48.19 ± 3.064), NORITAKE (44.83 ± 1.321) and CERAMAX (48.47 ± 2.80). Also the mean values in CERAMCO II (48.97 ± 2.178) and CERAMAX are significantly higher than NORITAKE. However, no other contrasts are statistically significant ($P>0.05$).

The results of One way ANOVA variance for the flexural strength values exhibited by the specimens of different companies to Group V (Polishing and Self Glazing) finishing procedure showed that the mean value of NORITAKE (38.30 ± 1.641) is significantly higher ($P<0.05$) than the mean values of CERAMCO II (34.20 ± 1.973) and CERAMAX (35.35 ± 1.26). Also the mean value in SHOFU (38.19 ± 2.482) is significantly higher than the mean values of CERAMAX and CERAMCO II. However, no other contrasts are statistically significant ($P>0.05$).

DISCUSSION

Brittle materials such as dental ceramics fail because of the formation and growth of microscopic flaws that can form during fabrication or during service.[10] The fracture of glasses and ceramics is always affected or initiated by a tensile stress and can often be traced to the propagation of surface flaws through the bulk material.

The strengths of the brittle materials is usually measured in flexure (bending) because this test is generally easier to perform than a pure tensile test. In flexure (bending), the tensile stress reaches a maximum on one surface and compressive stress reaches a maximum on the opposite surface. Brittle materials usually fail in tension, therefore flexure (bending) tests provide information on tensile strength. Analysis of fractured ceramic crowns reveals that the origin of the fracture is generally on the surface of the crown, the fracture energy is low and the fracture is most commonly flexural in nature.

Flexure strength is used as a measure of crack propagation from surface micro-cracks. Traditionally, this has been done by assessing the flexural stress on the undersurface of a rectangular bar[4]. More recently, biaxial flexure tests using disc specimens have become popular to avoid the effects of flaws common with rectangular bars. Biaxial tests are also relatively insensitive to specimen geometry and are independent of flaw direction.

According to Mclean[7], the strength tests for porcelain can produce scattered and inconsistent results. There is considerable controversy surrounding the strengths of various ceramic materials and contradictory research will undoubtedly continue to appear in the literature. Reliable laboratory data concerning the strengths of brittle materials are difficult to obtain and coefficients of variations are high[6]. Values are affected by a variety of factors such as geometry, temperature, loading rates, technique variations and fabricational thermally induced imperfections. All these factors partially account for variations in reported flexure strengths.

The surface finish of ceramic restorations is of paramount importance with respect to esthetics, strength and wear of opposing restorations or dentition. Traditionally, glazing has been advocated as the last surface treatment before final cementation[7]. A glazed surface was thought to produce stronger and more cleansable surfaces. Initially, polishing was not considered as an effective surface finish procedure mainly due to fears of strength degradation and premature failure.

Levy[13] tested the effect of polishing with pumice and etching on the flexural strength of dental ceramics after air and vacuum glazing and over glazing. Results showed no significant difference in strengths between the various procedures; however polished glazed specimens had higher strength values. *Brackett et al*[1] reported no significant difference in the load at failure of glazed versus polished autoglazed porcelain.

Rosenstiel[9] found a significant increase in fracture toughness of polished dental porcelain versus glazed porcelain. He indicated that a polished surface improved the fracture resistance of the ceramic in contrast to a glazed surface. Campbell[2,3] reported in his study that the Tuf - coat ion exchange system strengthened the porcelain but it was not significantly different from overglazing and the strengthening effect was lost if the porcelain was subsequently self glazed or finished. Other studies have indicated that sequential polishing may also significantly improve the flexural strength of feldspathic porcelain by around 22%. The objective of this study was to assess the efficacy of four different surface finishing procedures on the flexural strength of five conventional feldspathic dental porcelains. We also wanted to ascertain the relationship between surface roughness and the flexural strength. Flexural studies of different products subjected to varying surface treatments has clearly illustrated that among the surface treatment procedures, Grinding and

Polishing (Group IV) gives the most highest mean flexural strength in all the products except Noritake. Grinding and polishing generates areas of compressive stresses beneath each abrasive particle. The overlapping of these stresses produces a layer of compression. This affects the flaws, which are oriented perpendicular and parallel to the surface, thereby increasing the flexural strength of the porcelain[8].

Over glazing (Group III) was the finishing procedure, which gave the highest flexural strength next to Grinding and Polishing (Group IV). This might be due to the lower coefficient of thermal contraction of the over glaze as compared to the underlying porcelain. The cooling would produce residual compressive stresses in the over glaze, which would inhibit crack propagation[13].

Self glazing (Group II) was the next best finishing procedure after Grinding and Polishing (Group IV) and Over glazing (Group III) but was better when compared to the As fired (Group I) and Polishing and Self glazing (Group V) procedures. Self-glazing forms a glassy surface which does not contract at a greatly different rate than the underlying porcelain from which the glaze is produced[13]. Consequently, residual compressive stresses are not induced in self-glazed surfaces, hence the porcelain is not strengthened.

This study shows that the mean flexural strength values for the group V specimens (Polished and Self-Glazed) have decreased. According to *Wagner*[12], polishing and self-glazing can cause micro-cracks and these cracks could grow by static fatigue, leading to material breaking away from the porcelain surface. In another study by *Giordano*[5], the self-glazing procedure after polishing is an annealing procedure which allows for the relaxation of residual stress, thus causing a decrease in flexural strength values. From this it can be inferred that the type of the product is not sensitive to polishing and glazing and as a whole has resulted in an inferior flexural performance. The flexural strength values for this group are better than the specimens of the As fired group (Group I).

CONCLUSION

A total of 250 specimens of the 5 commercially available ceramic products were fabricated and were then subjected to 5 different surface finishing procedures. The disc specimens were subjected to surface roughness and flexural strength tests. Under the conditions of this study and the materials used, the following conclusions may be made:

1. As the surface roughness value (Ra) increases there is a reduction in the mean flexural strength values.
2. Grinding and polishing has produced the most optimal flexural performance in all the products tested barring Noritake in which over glazing gave the maximal flexural performance.
3. Self-glazing procedure increases the strength and homogenizes the material.
4. There is a decrease in the mean flexural strength of all the products after polishing and self-glazing (Group V).

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