

Effects of various parameters of alumina air abrasion on the mechanical properties of low-fusing feldspathic porcelain laminate material

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ABSTRACT

Rationale: Alumina air abrasion is a commonly used surface treatment for porcelain veneers. This *in vitro* study determined the influence of various parameters of alumina air abrasion on the mechanical properties of porcelain.

Objectives: To ascertain the influence of alumina particle size, air stream delivery pressure and distance from the nozzle, on surface roughness, material loss and bi-axial flexural strength of low fusing feldspathic porcelain and to determine the optimum combination of these factors.

Materials and methods: 95 specimens of feldspathic ceramic measuring 1mm in thickness by 15 mm in diameter were prepared. Alumina air abrasion was carried out with varying parameters viz three different particle sizes (50µm, 110µm, 250µm), two different pressures (20psi, 50psi) and three different distances (1cm, 2cm, 5cm).

Results: The various combinations which produced the greatest and the least effects on the test parameters were identified and the results were statistically analysed using the factorial ANOVA test.

Conclusions: The combination of 50µm alumina particle size, 20psi air stream pressure and either 2cm or 5cm distance between the nozzle and the ceramic surface produced optimum surface roughness with reduced impact on the flexural strength of the ceramic.

Keywords: Feldspathic ceramic, alumina air abrasion, surface roughness, material loss, flexural strength.

INTRODUCTION

Porcelain laminate restorations do not biologically compromise the tooth to any extent because the technique reduces the need for radical invasion into vital dentinal tissues. The materials commonly used for the fabrication of veneers (feldspathic as well as lithium disilicate) ensure good aesthetic qualities, reasonable flexural strength and acceptable surface hardness. The thin veneers achieve their full potential only when intimately bonded to the prepared tooth surface. Bonding of a well-fitting veneer is mediated through a resin. The resin binds with the internal surface of the veneer after appropriate surface roughening treatment has been effected,^{1,2} whether through acid etching³ or alumina abrasion.⁴ Hydrofluoric acid has inherent hazards which are associated with storage, use and its disposal.⁵ Many studies have shown that alumina particle abrasion provides a roughened surface adequate-for the bonding of laminate veneers to the tooth structure.^{6,7,8,9}

The factors influencing the effect of alumina air abrasion are alumina particle size, hardness and velocity, their morphology and angle of impact.¹⁰ The properties of the substrate, the pressure at which alumina particles are propelled and the distance between the ceramic substrate and the delivery nozzle all have a qualitative and quantitative impact on the porcelain. To optimize the abrasive quality, the alumina particle size should be controlled. Particles of the same size propelled in an air stream can behave differently under varying pressures rate. Surface roughness is desirable for it improves the bonding between the laminate and the resin. Roughening the surface should not reduce the flexural strength of the restoration to a clinically unacceptable level. Many studies have shown the negative effects of surface treatments on the flexural strength of porcelain.^{3,4,11}

Information on all these variable factors has not previously been integrated, which is now the intention of this study.

MATERIALS AND METHODS

Ninety five feldspathic discs of 15mm diameter and a thickness of one mm were fabricated, using a vinyl polysiloxane (Affinis, Switzerland) mould (Figure 1). 0.99mg

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Figure 1: Porcelain discs ready for testing

of the Duceram feldspathic ceramic (Duceram-LFC, Dentsply, USA) was pre-weighed in an electronic balance and mixed with 0.33ml of distilled water to make each sample,¹² the mix being compacted into the silicone mould. The excess moisture was absorbed by using an absorbent tissue paper. After removal from the mould, the specimens were placed in a porcelain-firing oven which was preheated to 650°C and then fired to approximately 940-960°C. Polishing was carried out using Noritake polishing paste (KurarayNoritake Dental Inc) and a rubber wheel.

All the specimens were dried, firstly with tissue paper followed by oil and water free hot air for one minute. The initial weight of each disc was determined with an analytical balance (ALC 6100, Acculab, USA) having a precision of 0.001 gm. Specimens were surface treated as tabulated in Table 1. F1 was the control group. Specimens F2 – F19 were alumina air-abraded in a sandblaster (Easyblast, BEGO, Germany) (Figure 2) using varying abrasion parameters. The distance between nozzle and surface was standardized with the help of a custom made tool (Figure 3). After surface treatment all the specimens were washed thoroughly in running water and then placed in an ultrasonic cleaner for 10 minutes. Each disc was dried with a tissue paper and hot air for one minute. The weight of each disc was measured after surface treatment with the analytical balance.

Table 1: Feldspathic porcelain specimens were divided into nineteen groups (F1- F19) (Each group consisting of five specimens)

Specimen	Particle size (µm)	Pressure (psi)	Distance (cm)
F1	Control, as fired		
F2	50	20	1
F3	50	20	2
F4	50	20	5
F5	50	50	1
F6	50	50	2
F7	50	50	5
F8	110	20	1
F9	110	20	2
F10	110	20	5
F11	110	50	1
F12	110	50	2
F13	110	50	5
F14	250	20	1
F15	250	20	2
F16	250	20	5
F17	250	50	1
F18	250	50	2
F19	250	50	5



Figure 2: The Sandblaster apparatus.



Figure 3: The saddle to support the porcelain discs.

The specimen was placed below the stylus of the contact profilometer (Wyko NT1100, Veeco, UK) for the evaluation of surface roughness (Ra values), which was recorded in micrometers.¹³ The diamond stylus was moved in one direction for a specified distance of 1.5mm and then in a second direction perpendicular to the first, again for 1.5mm. The contact force was standardised at 15gms. The change in position of the diamond stylus generated an analogue signal which was converted into a digital signal, stored, analyzed and displayed.

Specimens were sequentially placed on a support with a span of 10mm for a ball on ring test to determine the flexural strength. A flexural load was applied at the midpoint of each supported specimen using a universal testing machine (Model 6025 Instron, UK) at a crosshead speed of 5mm per minute. The flexural strength was recorded in MPa.

RESULTS

Alumina air abrasion and material loss

The mean net weight loss of feldspathic specimens following alumina abrasion is given in Table 2. The highest material loss of 0.1055gm was observed in group F17 (particle size: 250µm, air pressure:50psi, nozzle distance:1cm) and the lowest material loss of 0.0382gm was observed in group F4 (50µm, 20psi, 5cm).

Alumina air abrasion and surface roughness

The mean surface roughness of feldspathic specimens following alumina abrasion is given in Table 3. Group F5 (50µm, 50 psi, 1cm) showed the highest surface roughness of 3.2935 µm and the lowest surface roughness of 1.8477 µm was observed in group F17 (250 µm, 50 psi, 1cm).

Alumina air abrasion and biaxial flexural strength

The mean flexural strength of feldspathic specimens following alumina air abrasion is given in Table 4. Highest flexural strength of 63.35 MPa was observed in group F4 (50µm, 20psi, 5cm) and the lowest flexural strength of 39.96 MPa was observed in group F17 (250µm, 50psi, 1cm).

STATISTICAL ANALYSIS

The data were statistically analyzed using a factorial ANOVA test. Multiple comparisons (post hoc-test) were carried out using the Bonferroni method to ascertain between which pairs or groups there existed a significant difference.

Alumina abrasion and weight loss (Table 5)

Particle size was found to be the most important factor influencing weight loss. The larger the particle size, the greater the weight loss. The differences in mean weight loss associated with the different particles were found to be statistically significant ($P<0.001$).

Air pressure variations also recorded a direct relationship to weight loss. A pressure of 50 Psi caused a higher mean weight loss compared to that resulting from 20 Psi and the difference between them was found to be statistically significant ($P<0.001$). The mean weight loss was found to be greater at a distance of 1cm followed by 2cms and 5cms distance respectively and the differences are statistically significant ($P<0.001$).

Table 2: Results -Mean weight loss (gm)

Particle Size	Pressure	Distance	Mean	Std dev	Median	Min	Max
50 µm	20 Psi	1 cm	0.0433	0.0024	0.0445	0.0405	0.0448
		2 cms	0.0408	0.0003	0.0408	0.0405	0.0410
		5 cms	0.0382	0.0005	0.0383	0.0377	0.0387
	50 Psi	1 cm	0.0542	0.0007	0.0545	0.0534	0.0548
		2 cms	0.0533	0.0003	0.0534	0.0530	0.0536
		5 cms	0.0472	0.0016	0.0470	0.0457	0.0488
110 µm	20 Psi	1 cm	0.0858	0.0027	0.0854	0.0833	0.0886
		2 cms	0.0710	0.0014	0.0707	0.0698	0.0726
		5 cms	0.0768	0.0023	0.0771	0.0744	0.0790
	50 Psi	1 cm	0.0965	0.0115	0.0956	0.0855	0.1084
		2 cms	0.0864	0.0106	0.0874	0.0754	0.0965
		5 cms	0.0814	0.0146	0.0758	0.0704	0.0980
250 µm	20 Psi	1 cm	0.1049	0.0052	0.1054	0.0995	0.1098
		2 cms	0.1047	0.0033	0.1034	0.0989	0.1054
		5 cms	0.1032	0.0052	0.1034	0.0980	0.1083
	50 Psi	1 cm	0.1055	0.0125	0.0984	0.0953	0.1184
		2 cms	0.1035	0.0031	0.1038	0.1003	0.1065
		5 cms	0.0985	0.0043	0.0980	0.0945	0.1030

Table 3: Results -Mean Surface roughness (µm)

Particle Size	Pressure	Distance	Mean	Std dev	Median	Min	Max
50 µm	20 Psi	1 cm	3.18	0.40	3.18	2.79	3.58
		2 cms	3.08	0.31	3.18	2.73	3.34
		5 cms	2.86	0.17	2.89	2.68	3.02
	50 Psi	1 cm	3.29	0.03	3.30	3.27	3.32
		2 cms	2.98	0.18	2.90	2.85	3.18
		5 cms	2.90	0.03	2.89	2.86	2.93
110 µm	20 Psi	1 cm	2.69	0.27	2.71	2.40	2.95
		2 cms	2.81	0.20	2.82	2.61	3.00
		5 cms	2.46	0.28	2.32	2.27	2.79
	50 Psi	1 cm	2.09	0.01	2.08	2.08	2.09
		2 cms	2.48	0.11	2.43	2.40	2.61
		5 cms	2.58	0.10	2.54	2.52	2.69
250 µm	20 Psi	1 cm	2.02	0.02	2.01	2.00	2.04
		2 cms	2.08	0.02	2.08	2.06	2.10
		5 cms	2.00	0.11	2.00	1.89	2.10
	50 Psi	1 cm	1.85	0.13	1.78	1.76	2.00
		2 cms	1.90	0.03	1.92	1.87	1.92
		5 cms	2.09	0.01	2.10	2.08	2.10

Table 4: Results - Mean Flexural strength (MPa)

Particle Size	Pressure	Distance	Mean	Std dev	Median	Min	Max
50 µm	20 Psi	1 cm	60.16	3.65	61.08	56.14	63.27
		2 cms	61.51	2.16	60.88	59.74	63.92
		5 cms	63.35	4.14	63.62	59.08	67.34
	50 Psi	1 cm	57.59	1.80	56.84	56.28	59.64
		2 cms	60.12	3.42	60.90	56.38	63.09
		5 cms	60.32	2.19	59.43	58.72	62.81
110 µm	20 Psi	1 cm	48.43	3.67	47.88	45.06	52.34
		2 cms	56.03	3.09	56.13	52.89	59.07
		5 cms	56.27	2.54	55.89	53.95	58.98
	50 Psi	1 cm	49.95	2.76	50.93	46.83	52.08
		2 cms	48.58	1.92	49.28	46.41	50.06
		5 cms	58.94	3.98	59.70	54.63	62.48
250 µm	20 Psi	1 cm	50.54	4.18	50.31	46.48	54.83
		2 cms	44.64	2.88	46.03	41.32	46.56
		5 cms	45.56	1.87	46.09	43.48	47.10
	50 Psi	1 cm	39.96	1.86	39.36	38.48	42.05
		2 cms	40.37	2.27	39.45	38.71	42.96
		5 cms	41.59	2.38	42.96	38.84	42.98

Alumina abrasion and surface roughness (Table 6)

Particle size was found to be the most important factor influencing surface roughness. The smaller the particle size, the greater was the surface roughness produced. The differences between the mean surface roughnesses recorded by the three particle sizes were found to be statistically significant ($P<0.001$). Slightly greater mean surface roughness was recorded at 50 Psi pressure compared with 20Psi pressure, but the differences were not statistically significant ($P>0.05$). Among the three distances tested, slightly greater mean surface roughness was recorded when nozzle distance was set at 1cm followed by the 2cms and 5cms settings respectively but the differences were not statistically significant ($P>0.05$).

Alumina abrasion and flexural strength (Table 7)

Particle size was found to be the most important factor influencing flexural strength. The smaller the particle size, the less effect on the flexural strength. The difference in mean flexural strength recorded between the three particle sizes was found to be statistically significant ($P<0.001$). Between the two pressures, higher mean flexural strengths were recorded at 20Psi compared with 50 Psi and the differences were statistically significant ($P<0.001$). Among the three nozzle to surface distances, higher mean flexural strength was recorded at a distance of 5cms followed by 2cms and 1cm respectively. The differences in mean flexural strength were statistically significant ($P<0.001$).

DISCUSSION

Clinical success of bonded porcelain restorations is attributed to the intimate bond obtained between the restoration and the underlying tooth structure, mediated by an intervening resin. The bond has both chemical and physical dimensions. The ceramic-resin bonding is enhanced by improving the internal surface of the restoration by way of incorporating microscopic irregularities.^{1,2} For this, air abrasion using alumina particles and acid etching using hydrofluoric acid are commonly employed. By incorporating such irregularities, the surface area available to bind with the resin is increased. The shear

Table 5: Statistical analysis –Alumina abrasion and weight loss

Source	df	Sum of Squares (SS)	Mean SS	F	P-Value
Particle	2	0.059	0.029	1327.902	<0.001*
Pressure	1	0.001	0.001	59.114	<0.001*
Distance	2	0.001	0.000	16.930	<0.001*
Particle *Pressure	2	0.001	0.000	18.131	<0.001*
Particle *Distance	4	0.001	0.000	6.332	<0.001*
Pressure *Distance	2	0.000	0.000	4.173	0.019*
Particle *Pressure *Distance	4	0.000	0.000	0.510	0.729
Error	72	0.002	0.000	---	---

Table 6: Statistical analysis – Alumina abrasion and surface roughness

Source	df	Sum of Squares (SS)	Mean SS	F	P-Value
Particle	2	20.166		400.564	<0.001*
Pressure	1	0.295	0.295	11.729	0.001*
Distance	2	0.109	0.055	2.167	0.122
Particle *Pressure	2	0.386	0.193	7.673	0.001*
Particle *Distance	4	0.788	0.197	7.823	<0.001*
Pressure *Distance	2	0.469	0.235	9.320	<0.001*
Particle *Pressure *Distance	4	0.352	0.088	3.492	0.012*
Error	72	1.812	0.025	---	---

bond strength of dental ceramics to bonding resins is also enhanced by surface treatment.⁵

It is a common practice in effecting surface preparation to use a sandblaster to propel alumina particles under air pressure. The surface modifications caused by sandblasting is dependent on the particle size, air pressure, hardness of particle, velocity, distance between the nozzle and the ceramic surface and the angle of impact. The properties of the substrate will be critical in determining the results of interaction. Air abrasion using alumina particles may preferentially chip the weaker glassy phase resulting in surface modification and material loss. This phenomenon has been shown to have a degrading effect on the flexural strength of low fusing feldspathic porcelain,^{3,4,11} borne out by the results of the present study.³

Alumina air abrasion and material loss (Figure 4)

Of the three variables, namely particle size of the abrasive, air pressure employed and the distance between the nozzle and ceramic disc, particle size was found to be the most important factor influencing weight loss. The larger the particle size used, the greater was the weight loss. 250 μ m particle size caused the most weight loss followed by 110 μ m and 50 μ m particle size respectively. 50Psi caused a greater mean weight loss compared with that associated with 20 Psi. Higher pressure caused more weight loss. The mean weight loss was found to be higher at a distance of 1cm followed by losses seen at distances of 2cm and 5cm in decreasing order. Material loss is undesirable because of its effect on the strength profile.

The combination of 50 μ m, 20psi, 5cm seems to be the most desirable because it causes the least material loss. However this combination does not produce greater roughness.

It appears that no previous study has assessed the effect of various alumina abrasion parameters on material loss of ceramic material.

Alumina air abrasion and surface roughness (Figure 5)

Particle size was found to be the most important factor influencing surface roughness after sandblasting. The smaller the particle size used for abrasion, the greater the surface roughness obtained. This could be attributed to the fact that in case of smaller size particles, greater numbers of particles acted on a given unit area whereas in the case of large sized particles, a lesser number acted on a given unit area. Particle size of 50 μ m caused a higher mean surface roughness at 50 Psi compared with that produced by a pressure of 20 Psi whereas particle size of 110 μ m and 250 μ m caused a higher mean surface roughness at 20 Psi compared with that effected by 50 Psi. The role of pressure differs with the particle size. Surface roughness increased with increase of pressure only with smaller particle size. With larger particle sizes, when the pressure was increased, surface roughness decreased. Particle size of 50 μ m caused a greater mean surface roughness at a nozzle distance of 1cm followed by 2cm and 5cm respectively. But particle size of

Table 7: Statistical analysis – Alumina abrasion and flexural strength

Source	df	Sum of Squares (SS)	Mean SS	F	P-Value
Particle	2	5109.66	2554.83	467.527	<0.001*
Pressure	1	260.49	260.49	47.670	<0.001*
Distance	2	169.65	84.83	15.523	<0.001*
Particle *Pressure	2	103.69	51.85	9.488	<0.001*
Particle *Distance	4	298.38	74.59	13.651	<0.001*
Pressure *Distance	2	26.03	13.01	2.381	0.100
Particle *Pressure *Distance	4	203.47	50.87	9.308	<0.001*
Error	72	393.45	5.46	---	---

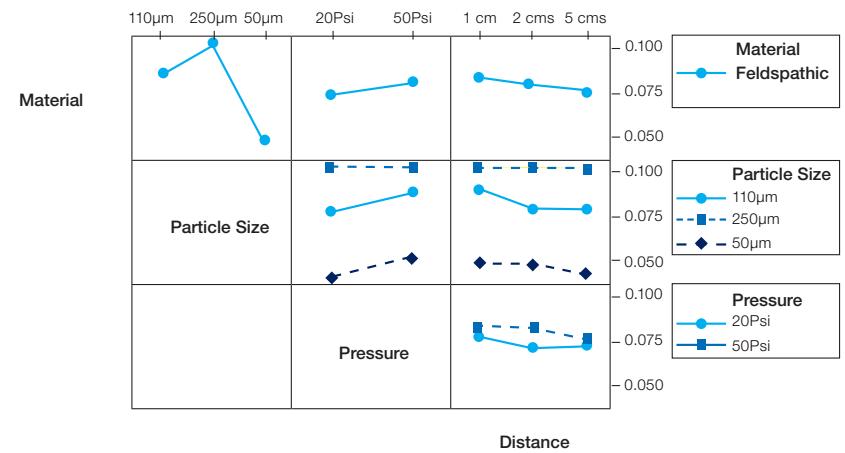


Figure 4: Interaction plot for Weight Loss (gms)

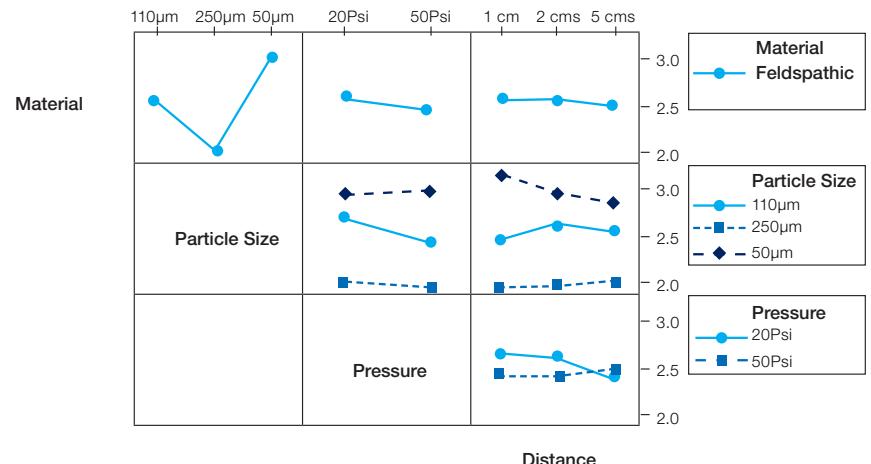


Figure 5: Interaction plot for Surface Roughness (microns)

110 μ m caused a greater mean surface roughness at 2cm followed by 5cm and 1cm respectively. The mean surface roughness at 250 μ m was found to be slightly higher at 5 cm compared to 1cm and 2cm. Greater surface roughness was obtained at shorter distances with lower particle sizes. With particle sizes 110 μ m and 250 μ m, greater nozzle distances produced higher surface roughness. Therefore to obtain greater surface roughness with larger particle size, the nozzle to surface distance has to be increased. At 1cm and 2cm distances, a pressure of 20 Psi showed a greater mean surface roughness but at a distance of 5cms, a pressure of 50 Psi yielded a slightly greater mean surface roughness. When pressure and distance are related, it

was observed that when the distance increases a higher pressure has to be used in order to obtain more surface roughness. A higher pressure will ensure the reach of the particles to distant substrates. Ayad *et al*⁹ found in their study that a mean surface roughness of 2.54 μ m obtained by alumina air abrasion improved the bond strength between the ceramic and the tooth structure. Curtis *et al*¹⁴ also observed that increasing alumina particle size for abrasion resulted in a decrease in the prepared surface roughness of porcelain.

Alumina air abrasion and biaxial flexural strength (Figure 6)

Increased weight loss had a weakening effect on the specimens, thus causing a reduction in the biaxial flexural strength of the porcelain discs. Particle size had the most influential role with air pressure having a supplementary role. The use of smaller particle sizes allowed for a decreased effect on alteration of the flexural strengths. Those specimens exposed to bombardment with particles of 50 μ m recorded a higher mean flexural strength after testing than did those abraded by 110 μ m and 250 μ m particles respectively, at different pressures as well as at different distances. Larger particle size resulted in greater material loss and a weakening of the ceramic. Abrasive particles blasted at 1cm distance caused greater material loss than that seen when blasting at 2cm and 5cm distances. Fleming *et al*¹⁵ in their study found that with an increase in alumina particle size from 25 μ m to 110 μ m, the mean flexural strength decreased from 85MPa to 49MPa. In another study by Fleming *et al*,⁴ it was found that with increase in particle size from 25 μ m to 110 μ m, the mean biaxial flexural strength decreased from 94MPa to 54MPa. Bhamra *et al* also observed a relative increase in the mean biaxial flexure strength when there was a decreased degree of coarseness of the bombarding silica particles.¹⁶

CONCLUSIONS

The following conclusions were drawn from the present study]:

- Particle size was the main factor affecting the post-abrasive-treatment-effects of weight loss, surface roughness and flexural strength of feldspathic ceramic material.
- Increase in particle size caused an increase in material loss, a decrease in surface roughness and a decrease in the flexural strength of the feldspathic ceramic material.
- Increase in the pressure of the air blast caused an increase in material loss, an increase in surface roughness and a decrease in the flexural strength of the feldspathic ceramic material. It was only with the lower particle size that surface roughness increased with an increase in pressure. When the pressure was increased with larger particle sizes, the resulting surface roughness decreased.
- Increased distances between the nozzle and ceramic surface reduced material loss and surface roughness with a relatively lesser effect on reduction in the flexural strength of feldspathic ceramic material.
- The best combinations of alumina abrasion parameters which in this study produced optimum surface roughness with reduced loss of flexural strength of ceramic were 50 μ m alumina particle size, 20psi air stream pressure and 2cm distance between the nozzle and the ceramic surface or 50 μ m alumina particle size, 20psi air stream pressure and a 5cm distance between the nozzle and the ceramic surface.

Limitations of the study: The study is limited to only one type of ceramic. It cannot be assumed that other porcelain laminate material will show similar results due to possible differences in

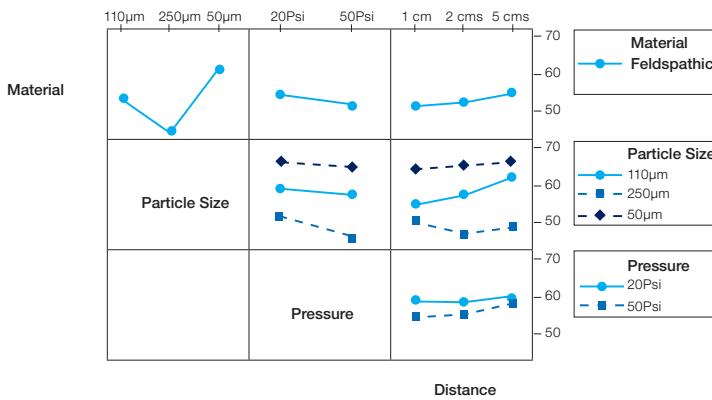


Figure 6: Interaction plot for Flexural Strength (MPa)

their composition and inherent properties. Further studies could evaluate the effects of hydrofluoric acid etching in comparison with those of alumina air abrasion.

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