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The effect of abrasive blasting on the strength of a joint between dental porcelain and metal base

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This paper presents the effect of selected parameters of abrasive blasting on the strength of a joint between dental porcelain and metal base. Experiments were conducted for different grain sizes of abrasive material and different blasting angles, with a constant blasting pressure. InLine dental porcelain was fused on samples of cobalt-chromium alloy following abrasive blasting; they were subsequently subjected to shearing forces on a testing machine. The fractures were observed under an electron scanning microscope in order to determine the character and course of fracturing. Strength tests showed that the grain size of abrasive material was a parameter with the greatest effect on the strength. The best effects were achieved for samples subjected to abrasive blasting with material with grain size of 110 μm. No statistically significant differences were found for the strength of samples worked at different angles. The results of the fractographic examinations have shown that in all the samples, fracturing occurred mainly along the porcelain–metal boundary, with few cases of fracturing through porcelain.

Key words: *abrasive blasting, metal–porcelain joint, strength*

1. Introduction

Abrasive blasting is applied in numerous production processes, including working element surfaces to achieve the appropriate parameters. The method is commonly used at different stages of production of prosthetic parts, from removing remnants of protecting mass from the surface of a metal cast to the processes of surface preparation for facing with ceramic or composite materials. Such a great diversity of applications of abrasive blasting is associated with great variability of the parameters of carrying out the process.

The condition of the surface and its preparation are of paramount importance for the durability of the product at the stage of connecting the construction parts of permanent dentures with material used to make aesthetic material which mimics the patient's own teeth. Therefore, the main aim of the preparatory procedures is to increase the strength of connection between them. In order to achieve the right connection of materials, it is important to remove fine surface structures or weakly connected overhanging material mass formed at earlier stages of processing with loss of material and to make the surface properly rough. Roughness of the surface is necessary to achieve various hooks (spots of uneven surface), which are used to achieve a mechanical joint. Other important parameters include uniformity of the structure and developing the surface which increase the area of possible connection [1], [2].

Some particles of abrasive material stick into the metal structure during the abrasive blasting process as a consequence of their high kinetic energy gained in the stream of compressed air [3]. Considering the fact that the amount of abrasive material stuck into the base surface structure may be as large as 30%, it

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seems that this is not without consequence for the connection quality. Particles of abrasive material stuck into the metal structure may cause an adverse effect of formation of cracks in porcelain, which are responsible for damage to dentures [4]. Likewise the condition of the surface following abrasive blasting, the amount of grains of abrasive material stuck into metal depends on the process parameters: size of grains of the abrasive material, pressure of the carrier (compressed air) and the angle at which the abrasive material touches the surface being worked [5].

Since the teeth and their substitutes (dentures) in a human jaw are subjected to large loads, their durability and possible damage is increasingly often an object of detailed studies [6], [7]. Such studies deal with ways of damaging dentures and analyse the causes of such damage and possibilities of limiting it. The aim of this study was to determine the effect of the parameters of abrasive blasting: size of grains of abrasive material and the angle at which it touches the surface, on the quality of joint between dental porcelain and its metal base.

2. Materials and methods

Cobalt-chromium alloy Heraenium®, whose composition is shown in Table 1, was used in the experiment, formed in cylindrical samples. Sample surface was made uniform by mechanical grinding with abrasive paper with the sizes ranging from 120

Table 1. Chemical composition of Heraenium® alloy

Alloy addition	Co	Cr	W	Mo	Si	Mn	other
Content	59.0	25.0	10.0	4.0	1.0	0.8	0.2

Table 2. Parameters of firing the ceramic opaquer IPS InLine

A – First layer of the opaquer; B – Second layer of the opaquer							
Starting temperature (°C)		Final temperature (°C)	Time of closing the kiln (min)	Temperature increase rate (°C/min)	Heating time [min]	Temperature of starting the vacuum pump (°C)	Temperature of switching off the vacuum pump (°C)
A	403	930	6	100	2	450	929
B	403	930	6	60	2	450	929

Table 3. Parameters of firing dentin mass IPS InLine

A – First layer of dentin; B – Second layer of dentin							
Starting temperature (°C)		Final temperature (°C)	Time of closing the kiln (min)	Temperature increase rate (°C/min)	Heating time [min]	Temperature of starting the vacuum pump (°C)	Temperature of switching off the vacuum pump (°C)
A	403	910	4	60	1	450	909
B	403	900	4	60	1	450	899

Table 4. Parameters of firing the ceramic glaze IPS InLine

Glaze						
Starting temperature (°C)	Final temperature (°C)	Time of closing the kiln (min)	Temperature increase rate (°C/min)	Heating time [min]	Temperature of starting the vacuum pump (°C)	Temperature of switching off the vacuum pump (°C)
403	850	6	60	2	450	849

to 1000. It was subsequently polished with diamond abrasive compound with the grain size of 1 µm. Abrasive blasting was performed on a Renfert Basic Professional device with the following process parameters:

- Grain size gradation of the abrasive material: 50, 110, 250 µm.
- Angles of the sample surface: 30°, 45°, 60°.
- Pressure of the air stream: 0.4 MPa.

Following the abrasive blasting, each sample was cleaned with pressurised steam in order to remove abrasive material loosely bound with the surface, washed in deionised water in an ultrasound washer and subsequently dried with compressed air; the process resulted in samples ready for ceramic layers to be applied.

Dental porcelain InLine (manufacturer: Ivoclar Vivadent) was fused to thus prepared metal base. Subsequently, two layers of ceramic opaquer were applied in order to mask the colour of metal; those layers were fired in a ceramic kiln (Table 2). In the next step, facing porcelain material was applied twice; it was fired individually in a kiln at two different temperatures, in accordance with the manufacturer’s guidelines (Table 3). Finally, a layer of glaze was applied and it was also fired (Table 4). All the stages of applying and firing the ceramic layers were carried out in accordance with the manufacturer’s guidelines.

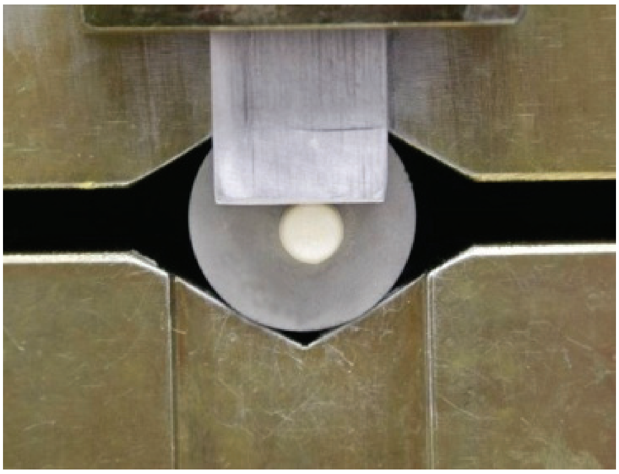


Fig. 1. Sample fixed in the device and subjected to shear strength test

Thus prepared samples were used to conduct shear strength tests of the metal–porcelain joint (Fig. 1), with the use of a Zwick/Roell Z005 device. The rod movement speed during the test was equal to 2 mm/min. Load was applied during the test until the material joint was damaged. The force which caused such damage was measured.

After the strength tests, the fractures were observed under an electron scanning microscope in order to determine the character and place of fracturing. Sample surfaces were observed and the chemical composition of the surface area was determined by the X-Ray microanalysis method. The observations were performed under a Hitachi S-3000 N electron scanning microscope, using secondary and backscattered electron imaging. The microanalysis was conducted by the EDS wave dispersion method on a device manufactured by Noran, operating together with an electron scanning microscope. In order to determine the course of fractures, maps of surface distribution of the main elements in the metal (cobalt) and ceramic (silicon) components have been made.

3. Results

3.1. Strength tests

Results of the strength tests of samples following various variants of abrasive blasting are shown in Table 5.

The shear strength tests of the metal–porcelain joint measured the force which destroyed the material joint and, subsequently, the strength of the joint was determined. Standard deviation was analysed for all the measurements. The test results show that the best connection between metal and porcelain is achieved when abrasive blasting is conducted with 110 µm grain (values around 40 MPa were achieved in this experiment). LSD tests and Sheffe’s tests were conducted in order to determine whether the differences were statistically significant. The results are listed in Tables 6 and 7 (it was assumed that differences are significant when $p < 0.05$). Both tests showed that there was a significant difference between the strength of parts sandblasted with 110 µm grain and other values at sandblasting angles of 30°, 45° and 60°. No statistically significant differences were found for the strength of samples after abrasive blasting at different angles when samples were worked with grain of the same size (110 µm). Samples worked with abrasive material with grain size of 50 µm and 250 µm showed much lower shear strength (it ranged from 24 MPa to 29 MPa). No significant differences were found in those groups between

Table 5. Mean values and standard deviation of the shear strength tests

Grain size	Blasting angle	Shear strength, MPa	
		Mean	Standard deviation
50 µm	30°	27.64	5.63
	45°	28.84	4.12
	60°	25.56	4.55
110 µm	30°	37.66	4.82
	45°	41.92	5.33
	60°	42.76	4.15
250 µm	30°	29.34	3.03
	45°	28.88	4.96
	60°	24.36	1.41

Table 6. LSD test of the significance of differences for strength test results depending on the grain size

Grain	50 µm	110 µm	250 µm
Sandblasting angle: 30°			
50 µm		0.003410	0.256919
110 µm	0.003410		0.000414
250 µm	0.256919	0.000414	
Sandblasting angle: 45°			
50 µm		0.001067	0.989770
110 µm	0.001067		0.001092
250 µm	0.989770	0.001092	
Sandblasting angle: 60°			
50 µm		0.000017	0.157382
110 µm	0.000017		0.000172
250 µm	0.157382	0.000172	

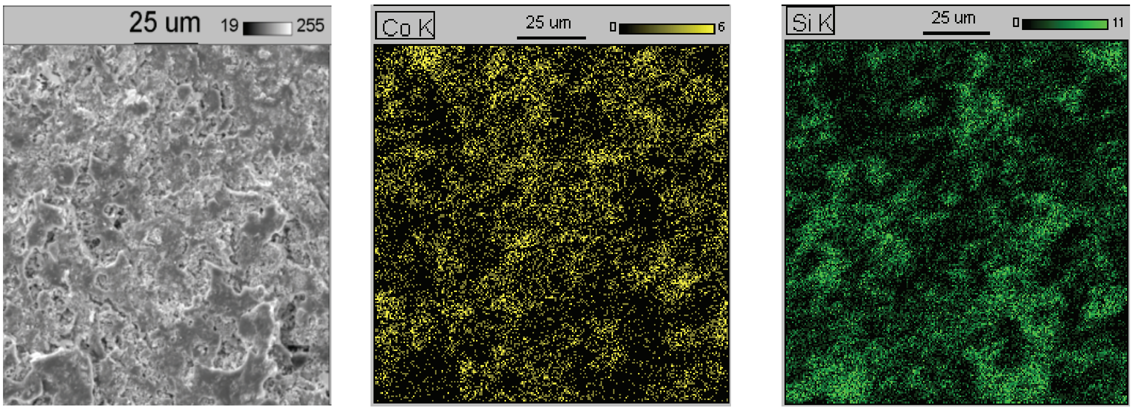
Table 7. Sheffe's test of the significance of differences for strength test results depending on the grain size

Grain	50 µm	110 µm	250 µm
Sandblasting angle: 30°			
50 µm		0.011594	0.511871
110 µm	0.011594		0.001544
250 µm	0.511871	0.001544	
Sandblasting angle: 45°			
50 µm		0.003838	0.999914
110 µm	0.003838		0.003924
250 µm	0.999914	0.003924	
Sandblasting angle: 60°			
50 µm		0.000070	0.352950
110 µm	0.000070		0.000660
250 µm	0.352950	0.000660	

strength of samples worked at different angles or between samples worked with abrasive material of different grain sizes. In general, it can be concluded that all connections tested meet the requirements of ISO 9693, which determines the strength of the ceramic to metal surface to 25 MPa.

3.2. Fractographic examination

The nature of fractures was similar in all the samples. Examples of results of fractographic examinations are shown in Fig. 2. The presence of both elements which comprise the ceramic component (silicon) and the metal base (cobalt) indicates that the samples fractured both along the metal–porcelain boundary and through the porcelain part. An analysis of a map of surface distribution of elements on the fractures shows that the percentage of area containing cobalt (base) is larger than those containing silicon (ceramic part).



a) b) c)

Fig. 2. Image of the BSE surface (a); and distribution of Co (b) and Si (c) of a fracture of the sample worked with abrasive material with the grain size of 110 μm

4. Discussion

The surface condition of materials constituting the ground for future connections is of interest in various systems. One can consider the connection of body tissues with different materials, but also the combination of materials that will create restorative dental structures for lost or damaged tissue [8]. Studies on the state of the surface are of fundamental importance to determine their specific properties, directly affecting their functionality and future behavior during their lifetime [9]. The strength of the ceramic–metal, which was presented in the paper, has a close relationship with the state of the metal surface, which is obtained by abrasive blasting with different parameters.

There are three factors responsible for the strength of metal-ceramics joints: physical adhesion, chemical bonds and mechanical bonds effected by anchoring of initially liquid ceramic material in the metal surface irregularities. It seems that the joint strength is affected by the first two factors to the same extent in all the variants and that it should not be affected by the grain size selected according to the treatment mode. The diverse size of grain used in the treatment affects the surface roughness, thereby affecting the ceramics ability to hook to the metal surface. The experiments have shown that the most effective joints are achieved with 110 μm grain. Most probably, this kind of treatment results in the optimum size of surface irregularities. Those resulting from the treatment with 50 μm grain may be too small to be filled completely with liquid ceramics and to provide effective mechanical joints. On the other hand, the surface irregularities resulting from the treatment with 250 μm may be so large that – despite being filled completely with liquid ceramics – they fail as microhooks.

Examinations of fractures have shown that majority of fractures run along the metal–porcelain boundary. Therefore, the boundary between the metal base and the fused porcelain seems to be the weakest link in the connection. A similar character breakthroughs were observed also in relation to other ceramic metal substrates [10]–[13].

The results are the connection strength at the same level as in the other studies for similar alloys [14]–[16]. However, compared to other alloys such as titanium, it is approximately two times higher [17], [18]. Considered by us to be the best parameters of blasting are similar to those obtained by other researchers. Papadopoulos and Spyropoulos in their research for the best processing parameters before applying ceramic titanium recognized: the size of grains of 110 microns and a pressure of 3 bar [12]. Similar values were considered optimal by Hussaini and Wazzan [19] and Atsu and Berksun [18].

5. Conclusions

1. The strength of the metal–porcelain connection depends on the grain size used in abrasive blasting.

2. Such connections fracture mainly along the metal–porcelain joint and – partly – through the ceramic component.

3. The best strength results were achieved for samples worked with 110 μm grain.

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