Properties of the biocompatible Ti_6Al_4V material

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Abstract: *The article is focused on the research of the influence of different blasting means on the surface of the titanium alloy Ti_6Al_4V, which was made by the sintering technology of layered metal powders (DMLS) in terms of microgeometry. The resulting microgeometry values of the titanium alloy placed on the platform in different sectors. Individual sectors had different laser power settings. The blasting was carried out at a constant pressure of 6 bar. Samples were then subjected to roughness measurement by contact method in accordance with STN EN ISO 4287. Individual parameters were subsequently statistically evaluated. A 3D topography of roughness of individual blasted materials was made.*
Keywords*: TITANIUM ALLOY, BLASTING MEANS, STATISTICAL ANALYSIS, MICROGEOMETRY*

1. Introduction

Titanium alloy Ti_6Al_4V is nowadays often used for the production of dental implants, implants for the medical industry. Ti_6Al_4V is in demand due to its excellent bioactivity and rapid tissue adaptation. In practice, we may encounter allergic reactions to metals that are used in implantation. The patient may exhibit an allergy to elements such as: cobalt, chromium, molybdenum and other elements that are part of the implants. Therefore, care should be taken to achieve final biocompatibility with the patient's human tissue and to avoid adverse factors that could have fatal consequences. [1,2, 6]

Nowadays, we record the use of Ti_6Al_4V alloy for the production of facial parts. These are patients whose condition during the disease worsens to a state of deformation or degradation of the facial area. Extreme cooperation of physicians is required for application in these areas. This is the place where cyclic stress, temperature changes and high stresses occur during use, and therefore the correct method of implant manufacturing should be selected. The DMLS method was chosen, precisely because of its advantages, which are not achieved in comparison with conventional technologies. [4 - 6]

The Ti_6Al_4V alloy is often produced by sintering of layered metal powders by the Direct Metal Laser Sintering (DMLS) method, which is not subject to the conventional process preparation process. Additive production guarantees efficient material processing and high production speed, even with complex or compact components. It is these characteristics that are a strategic advantage. The roughness of the material is extremely important to constantly monitor, as these are implants that are operated on into the human body and require time for the process of adaptation to the human foreskin. [2, 4]

2. Material and experimental works

The material used was Ti_6Al_4V titanium alloy, which had the following mechanical properties: tensile strength - 900 MPa, elongation - 14%, yield strength - 830 MPa, modulus of elasticity - 114 GPa. Material has a high potential for application in the biomedical industry for its excellent biocompatibility and high corrosion resistance.

On Fig. 1 we can see the samples were prepared by DMLS sintering technology on the EOSINT M 280. Samples were stored in different sectors (1, 5, 9 – disintegration samples on the table) and then laser separated at different laser unit power (Sector 1 = 150W, Sector 5 = 170W, Sector 9 = 190W). Individual surfaces of Ti_6Al_4V samples were subsequently mechanically pretreated by the blasting process.

The blasting means used were (ZB) - Zirblast B60 (as representative of a regular round shape) with a grain size of 0.125-0.250 mm and (BK) - White corundum FEPA 120 (as a representative of a sharp shape) with a grain size of 0.090-0.125 mm. The pressure in the blasting process was constant at 6 bar. [1, 2]

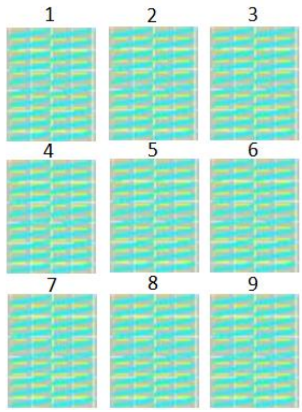


Fig. 1 *Division of samples into sectors*

The samples were also subjected to roughness evaluation. The measurement was performed with Surftest SJ-201, Mitutoyo, Tokyo, Japan.

The instrument parameters applied in the measurement were as follows:

- measured profile: R,
- filter: GAUSS,
- a sampling length λc = 0,8 mm,
- a number of sampling lengths N = 5,
- an evaluation length ln = 4 mm,
- number of measurements: 50.

Experimental measurements of surface roughness were carried out in accordance with ISO 4287, which defines individual parameters - deviations from the midline of the profile in the horizontal and vertical directions. [2]

As the roughness rating is currently insufficient with only one parameter, the roughness has been evaluated with the following parameters:

- arithmetical mean deviation of the assessed profile (Ra),
- the biggest height of profile on the basic length (Rz),
- maximum profile peak height (Rp),
- maximum profile valley depth (Rv),
- total height of profile (Rt),
- mean width of the profile elements (RSm).

The impact of the sector on the achieved roughness was also evaluated statistically by the Kruskal-Wallis test. [2,3]

3. Measurement results and discussion

Statistical verification of the influence of sectors and used blasting means on the resulting surface roughness.

Evaluation of the roughness parameter Ra:

Samples blasted with ZB1 - ZB5 - ZB9 was compared and the effect of the sector on the resulting surface roughness was determined Fig. 2. Numerical characteristics can be seen in Table 1.

Table 1: *Numerical characteristics for parameter Ra [2]*

Parameter Ra [µm]						
Sector	Average	Minimum	Maximum	Spread	Variation	Obliquity
ZB1 [µm]	3,69	3,21	4,38	0,12	0,34	0,47
ZB5 [µm]	3,77	2,95	4,88	0,24	0,49	0,42
ZB9 [µm]	4,71	4,13	5,49	0,16	0,40	0,41
BK1 [µm]	4,23	3,64	5,04	0,11	0,34	0,52
BK5 [µm]	3,84	3,06	5,05	0,28	0,53	0,39
BK9 [µm]	3,62	3,02	4,38	0,16	0,40	0,36

The highest value was found in the sample ZB9 (4.71 µm), while the lowest value was in the sample ZB1 (3.69 µm).

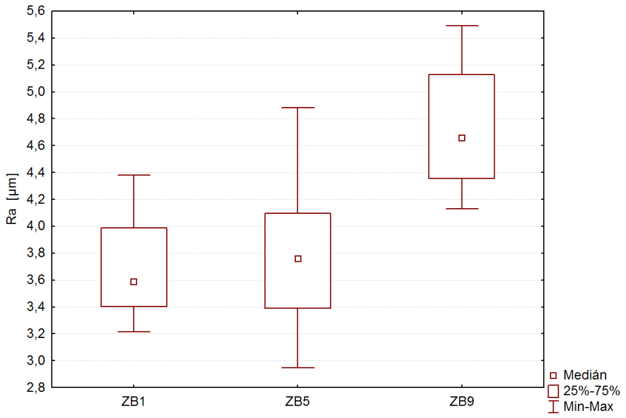


Fig. 2 *Values of Ra parameter for ZB1 - ZB5 - ZB9 samples blasted with zirblast [2]*

It was evaluated by Kruskal-Wallis test that p = 0.000 (p = 0.000, p <α), in the null hypothesis was rejected and the post hoc analysis revealed differences in Table 2.

Table 2. *Kruskal-Wallis test for samples ZB1 - ZB5 - ZB9 [2]*

Kruskal-Wallis test : H (2, N=123) = 69,43799 p=0,000			
Ra [µm]	ZB1	ZB5	ZB9
ZB1		1	0
ZB5	1		0
ZB9	0	0	

A statistically significant difference was noted between samples ZB1 and ZB5. We can confirm that the sector has an impact on the resulting roughness of the sample surface being blasted with Zirblast.

A series of samples shot blasted with white corundum BK1 - BK5 - BK9 was investigated on Fig. 3.

The highest value was recorded on a sample labeled BK1 (4.23 µm) and the lowest value was recorded on a sample labeled BK9 (3.62 µm).

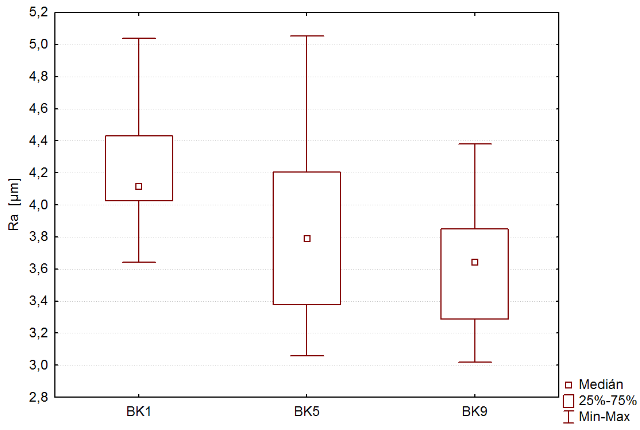


Fig. 3 *Values of Ra parameter for BK1 - BK5 - BK9 samples blasted with white corundum [2]*

Kruskal-Wallis test, Table 3. these differences were confirmed, p = 0.000 (p = 0.000, p <α), thus the null hypothesis of equality of mean values is rejected.

Table 3. *Kruskal-Wallis test for samples BK1 - BK5 - BK9 [2]*

Kruskal-Wallis test : H (2, N=123) = 34,01250 p=0,000			
Ra [µm]	BK1	BK5	BK9
BK1		0,000291	0
BK5	0,000291		0,212086
BK9	0	0,212086	

The observed differences between BK5 and BK9 samples were evaluated by post-hoc analysis, Table 3. The sector affects the resulting surface roughness of white corundum blasted samples. [2]

Evaluation of the roughness parameter R_z:

A series of different sample configurations in sectors ZB1 - ZB5 - ZB9, which used the same blast means - zirblast, was also subjected to an analysis of the impact of location in sectors, which could mean differences in the resulting surface roughness. Fig. 4, it is evident that the largest values are taken by the sample ZB9 and its values are visibly different from the other two samples evaluated. Numerical characteristics is in Table 4.

The highest value was recorded in the sample ZB9 (24.18 µm). The lowest value was in the sample ZB1 (18.73 µm).

Table 4: *Numerical characteristics for parameter Rz [2]*

Parameter Rz [µm]						
Sector	Average	Minimum	Maximum	Spread	Variation	Obliquity
ZB1 [µm]	18,73	15,53	22,39	3,26	1,80	-0,04
ZB5 [µm]	19,47	15,29	24,15	5,13	2,27	0,15
ZB9 [µm]	24,18	20,27	28,74	5,60	2,37	0,06
BK1 [µm]	23,79	20,25	28,18	4,15	2,04	0,11
BK5 [µm]	21,27	16,46	27,87	7,38	2,72	0,36
BK9 [µm]	20,00	15,72	24,80	5,12	2,26	0,24

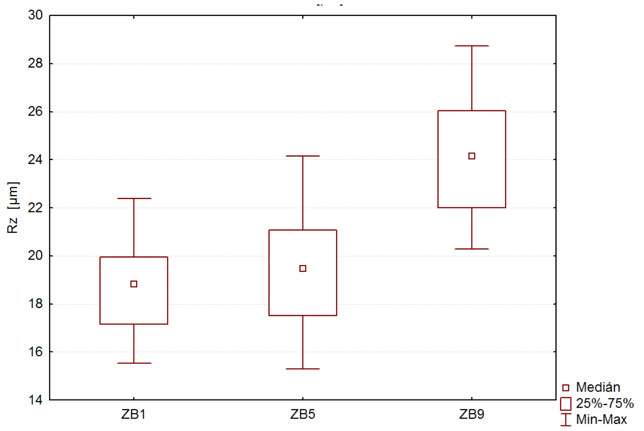


Fig. 4 *Values of Rz parameter for ZB1 - ZB5 - ZB9 samples blasted with Zirblast [2]*

The Kruskal-Wallis test evaluated p = 0.000 (p = 0.000, p <α), the null hypothesis was rejected at the significance level of α = 0.05 and differences found by post-hoc analysis are shown in Table 5.

Table 5. *Kruskal-Wallis test for samples ZB1 - ZB5 - ZB9 [2]*

Kruskal-Wallis test : H (2, N=123) = 66,79551 p=0,000			
Rz [µm]	ZB1	ZB5	ZB9
ZB1		0,618899	0
ZB5	0,618899		0
ZB9	0	0	

There is a statistically significant difference between samples ZB1 and ZB5, in the sector affects the resulting roughness parameter Rz of the sample surface.

Samples blasted with white corundum BK1 - BK5 - BK9 was subjected to the sector and different laser power on the resulting surface roughness. From Fig. 5, it is evident that sample BK1 is the largest and its values differ from the other two samples.

The highest value of the sample was BK1 (23.79 µm), while the lowest value of the sample BK9 (20.00 µm).

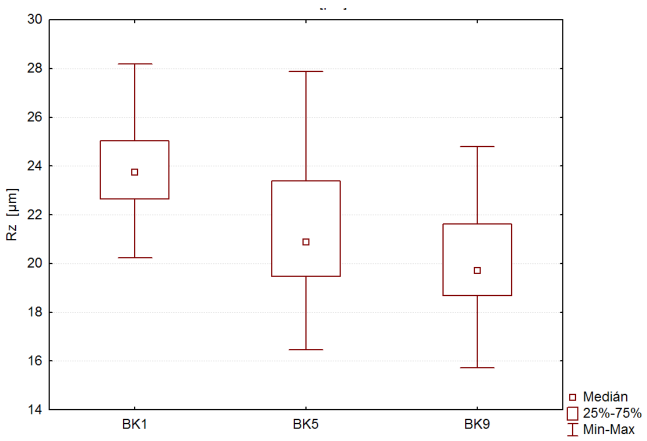


Fig. 5 *Values of Rz parameter for BK1 - BK5 - BK9 samples blasted with white corundum [2]*

Table 6. *Kruskal-Wallis test for samples BK1 - BK5 - BK9 [2]*

Kruskal-Wallis test : H (2, N=123) = 39,86788 p=0,000			
Rz [µm]	BK1	BK5	BK9
BK1		0,000084	0
BK5	0,000084		0,137678
BK9	0	0,137678	

The Kruskal-Wallis test, Table 6. evaluated the following: p = 0.000 (p = 0.000, p <α), the null hypothesis at the level of α = 0.05 was rejected. Subsequently, the differences found.

There is a significant difference between BK5 and BK9, in the sector and the different laser power affect the resulting sample roughness. [2]

Evaluation of the roughness parameter Rp:

Table 7: *Numerical characteristics for parameter Rp [2]*

Parameter Rp [µm]						
Sector	Average	Minimum	Maximum	Spread	Variation	Obliquity
ZB1 [µm]	9,50	7,84	11,66	1,11	1,05	0,26
ZB5 [µm]	9,96	8,50	11,94	1,14	1,07	0,45
ZB9 [µm]	12,03	10,05	14,65	1,71	1,31	0,15
BK1 [µm]	11,82	9,11	13,89	1,55	1,25	-0,32
BK5 [µm]	10,40	8,19	13,87	2,00	1,42	0,71
BK9 [µm]	9,67	8,02	11,65	1,01	1,01	0,12

For samples blasted with ZB1 – ZB5 – ZB9 was compared for the possible impact of the sector on the resulting surface roughness.

The highest value, Fig. 6 was in the sample ZB9 (12.03 µm), while the lowest value was in the sample ZB1 (9.50 µm).

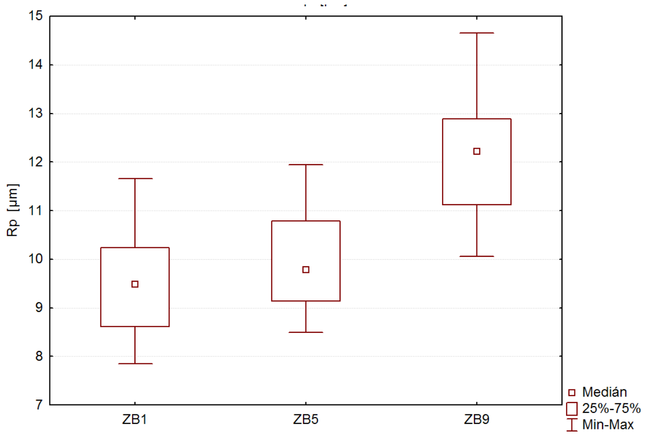


Fig. 6 *Values of Rp parameter for ZB1 - ZB5 - ZB9 samples blasted with zirblast [2]*

Table 8. *Kruskal-Wallis test for samples ZB1 - ZB5 - ZB9 [2]*

Kruskal-Wallis test : H (2, N=123) = 56,58405 p=0,000			
Rp [µm]	ZB1	ZB5	ZB9
ZB1		0,446669	0
ZB5	0,446669		0
ZB9	0	0	

The Kruskal-Wallis test, Table 8. evaluated that p = 0.000 (p = 0.000, p <α), the null hypothesis was rejected by post-hoc analysis.

A series blasted with white corundum specimens was also subjected to the sector's impact on the resulting surface roughness.

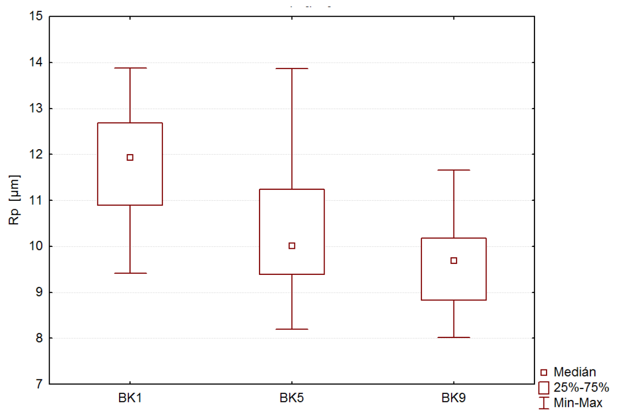


Fig. 7 *Values of Rp parameter for BK1 - BK5 - BK9 samples blasted with white corundum [2]*

The highest value, Fig. 7 was in the sample BK1 (11.82 µm) and the lowest value in the sample BK9 (9.67 µm).

Table 9. *Kruskal-Wallis test for samples BK1 - BK5 - BK9 [2]*

Kruskal-Wallis test : H (2, N=123) = 41,37518 p=0,000			
R_p [µm]	BK1	BK5	BK9
BK1		0,000084	0
BK5	0,000084		0,098474
BK9	0	0,098474	

The Kruskal-Wallis test, Table 9. evaluated: p = 0.000 (p = 0.000, p <α), thus the null hypothesis was rejected, and differences were found by post-hoc analysis.
A statistical difference was found between BK5 and BK9, the sector affects the resulting surface roughness. [2]

Evaluation of the roughness parameter Rv:

Table 10: *Numerical characteristics for parameter Rv [2]*

Parameter R_v [µm]						
Sector	Average	Minimum	Maximum	Spread	Variation	Obliquity
ZB1 [µm]	9,30	7,58	11,51	1,14	1,07	0,24
ZB5 [µm]	9,60	8,07	11,90	1,44	1,19	0,30
ZB9 [µm]	12,35	10,17	14,82	1,62	1,27	0,25
BK1 [µm]	11,97	9,59	14,50	1,30	1,14	0,33
BK5 [µm]	10,89	8,45	13,18	1,70	1,30	-0,06
BK9 [µm]	10,33	8,68	11,91	0,96	0,98	0,12

Samples blasted with ZB1 - ZB5 - ZB9 zirblast were subjected to the possible impact of the sector on the resulting surface roughness of individual samples.

The highest value was in the sample ZB9 (12.35 µm) and the lowest in the sample ZB1 (9.30 µm).

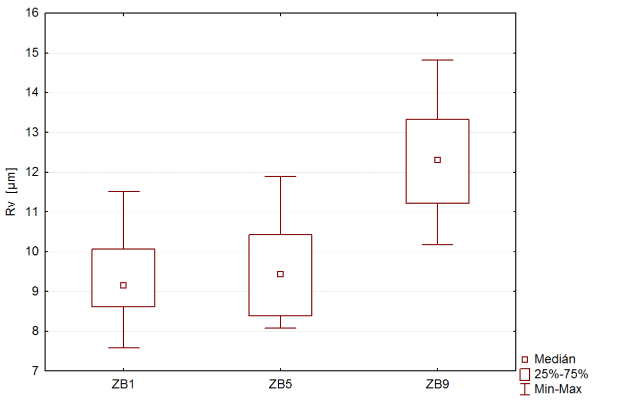


Fig. 8 *Values of Rv parameter for ZB1 - ZB5 - ZB9 samples blasted with zirblast [2]*

Table 11. *Kruskal-Wallis test for samples ZB1 - ZB5 - ZB9 [2]*

Kruskal-Wallis test : H (2, N=123) = 68,36534 p=0,000			
R_v [µm]	ZB1	ZB5	ZB9
ZB1		1	0
ZB5	1		0
ZB9	0	0	

The Kruskal-Wallis test, Table 11. evaluated the following: p = 0.000 (p = 0.000, p <α), the null hypothesis is rejected.
A statistically significant difference was found for samples ZB1 and ZB5, the sector has an impact on the resulting surface roughness.

Series of blasted white corundum samples BK1 - BK5 - BK9 have been subjected to the possible impact of the sector on the resulting surface roughness.

The highest value, Fig. 9 was in the sample BK1 (11.97 µm) and the lowest value in the sample BK9 (10.33 µm).

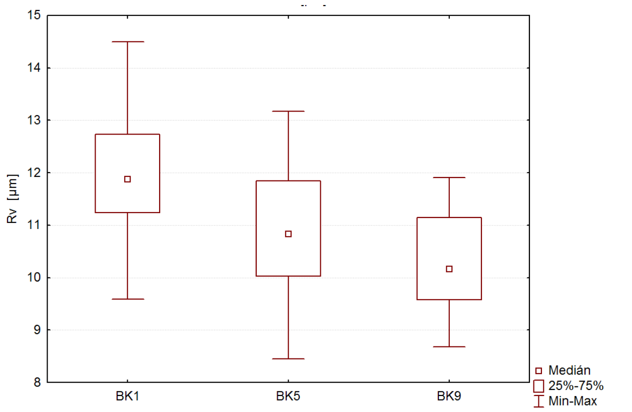


Fig. 9 *Values of Rv parameter for BK1 - BK5 - BK9 samples blasted with white corundum [2]*

Table 12. *Kruskal-Wallis test for samples BK1 - BK5 - BK9 [2]*

Kruskal-Wallis test : H (2, N=123) = 32,51889 p=0,000			
R_v [µm]	BK1	BK5	BK9
BK1		0,001427	0
BK5	0,001427		0,093273
BK9	0	0,093273	

The Kruskal-Wallis test confirmed p = 0.000 (p = 0.000, p <α), thus the null hypothesis is rejected and subsequently differences were found by post-hoc analysis, Table 12.
A significant difference was found between the BK5 and BK9 samples, meaning that the sector affects the resulting surface roughness. [2]

Evaluation of the roughness parameter Rt:

Table 13: *Numerical characteristics for parameter Rt [2]*

Parameter R_t [µm]						
Sector	Average	Minimum	Maximum	Spread	Variation	Obliquity
ZB1 [µm]	25,36	19,76	33,31	12,92	3,60	0,05
ZB5 [µm]	26,01	20,34	33,89	14,44	3,80	0,21
ZB9 [µm]	33,26	24,47	45,21	25,48	5,05	0,11
BK1 [µm]	30,12	25,41	36,82	9,12	3,02	0,25
BK5 [µm]	28,08	20,22	39,46	25,60	5,06	0,68
BK9 [µm]	25,85	20,01	33,03	11,08	3,33	0,30

A series of samples blasted with zirblast and white corundum were subjected to an analysis of the possible impact of the sector on the resulting surface roughness of the samples.

The highest value was found in the sample ZB9 (33.26 µm), while the lowest value was in the sample ZB1 (25.36 µm), Fig. 10

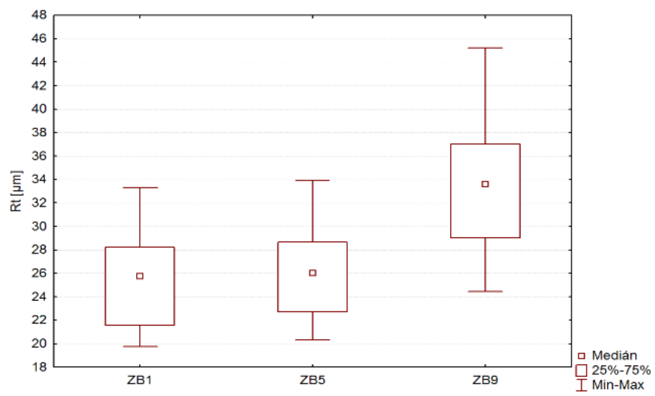


Fig. 10 *Values of Rt parameter for ZB1 - ZB5 - ZB9 samples blasted with zirblast [2]*

Table 14. *Kruskal-Wallis test for samples ZB1 - ZB5 - ZB9 [2]*

Kruskal-Wallis test : H (2, N=123) = 47,34329 p=0,000			
Rt [µm]	ZB1	ZB5	ZB9
ZB1		1	0
ZB5	1		0
ZB9	0	0	

By the Kruskal-Wallis test determination of statistical data on values related to the values of ZB1 and ZB5, which has an effect on the resulting surface roughness.

A series of samples, Fig. 11 originating from different sectors and blasted with white corundum BK1 - BK5 - BK9 was subjected to the impact of the sector on surface roughness.

The highest value was in the sample BK1 (30.12 µm) and the lowest value was in the sample BK9 (25.85 µm)

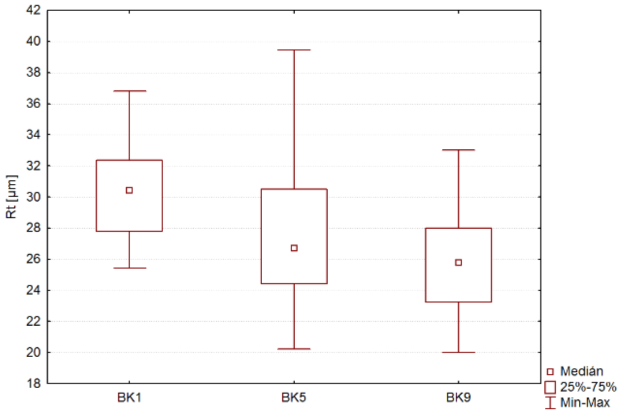


Fig. 11 *Values of Rt parameter for BK1 - BK5 - BK9 samples blasted with white corundum [2]*

Table 15. *Kruskal-Wallis test for samples BK1 - BK5 - BK9 [2]*

Kruskal-Wallis test : H (2, N=123) = 24,51936 p=0,000			
Rt [µm]	BK1	BK5	BK9
BK1		0,014886	0,000002
BK5	0,014886		0,100391
BK9	0,000002	0,100391	

The Kruskal-Wallis test, Table 15. revealed: ($p = 0.000$, $p < \alpha$), the null hypothesis is rejected, differences were found by post-hoc analysis. [2]

Evaluation of the roughness parameter RSm:

A series of samples blasted with zirblast and white corundum were subjected to an analysis of the possible impact of the sector on the resulting surface roughness of the samples.

Table 16: *Numerical characteristics for parameter RSm [2]*

Parameter RSm [µm]						
Sector	Average	Minimum	Maximum	Spread	Variation	Obliquity
ZB1 [µm]	292,36	185,20	359,20	2390,65	48,89	-0,87
ZB5 [µm]	303,74	248,00	378,90	1818,06	42,64	0,26
ZB9 [µm]	306,20	233,80	385,00	1560,06	39,50	0,36
BK1 [µm]	246,18	180,80	316,40	1360,26	36,88	0,03
BK5 [µm]	215,44	160,20	296,80	1713,64	41,40	0,57
BK9 [µm]	216,91	156,00	292,60	1848,77	43,00	0,19

The highest value, Fig. 12 of the sample was ZB9 (306.20 µm) and the lowest value of the sample ZB1 (292.36 µm).

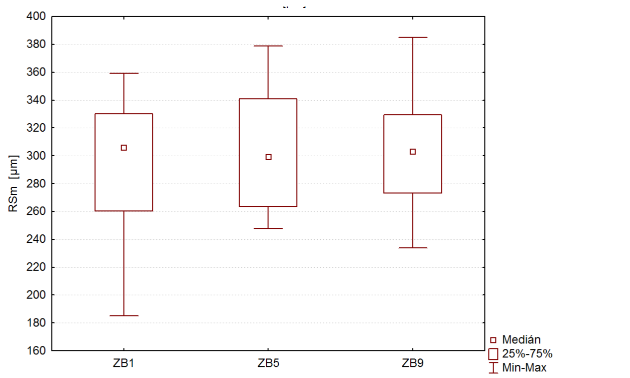


Fig. 12 *Values of RSm parameter for ZB1 - ZB5 - ZB9 samples blasted with zirblast [2]*

Table 17. *Kruskal-Wallis test for samples ZB1 - ZB5 - ZB9 [2]*

Kruskal-Wallis test : H (2, N=123) = 61,38306 p=0,7357			
RSm [µm]	ZB1	ZB5	ZB9
ZB1		1	1
ZB5	1		1
ZB9	1	1	

The Kruskal-Wallis test, Table 17. concluded that at ($p = 0.7357$, $p > \alpha$) greater than the significance level of $\alpha = 0.05$, the null hypothesis was subsequently rejected.

A series of samples Fig. 13 originating from different sectors and subsequently blasted with white corundum were also examined for the possible impact of the sector on the resulting surface roughness.

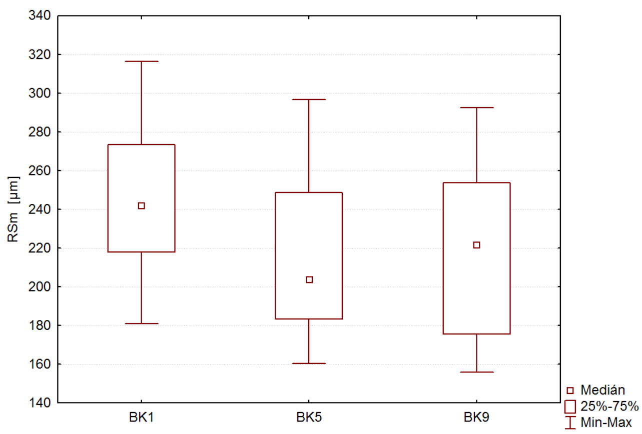


Fig. 13 *Values of RSm parameter for BK1 - BK5 - BK9 samples blasted with white corundum [2]*

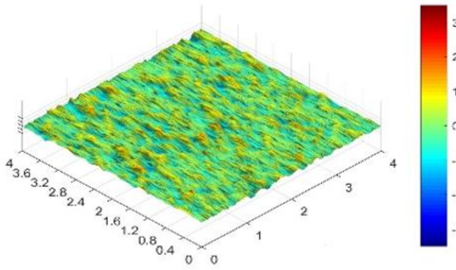
The highest value was shown by sample BK1 (246.18 µm), while the lowest value was by sample BK5 (215.44 µm).

Table 18. *Kruskal-Wallis test for samples BK1 - BK5 - BK9 [2]*

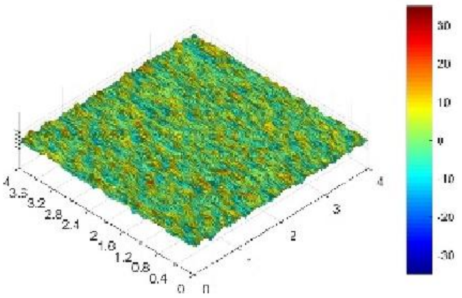
Kruskal-Wallis test : H (2, N=123) = 13,58016 p=0,011			
RSm [µm]	BK1	BK5	BK9
BK1		0,00347	0,005243
BK5	0,00347		1
BK9	0,005243	1	

The Kruskal-Wallis test, Table 18. was evaluated as follows. It was found that statistically significant differences in values were not found in samples BK5 and BK9.

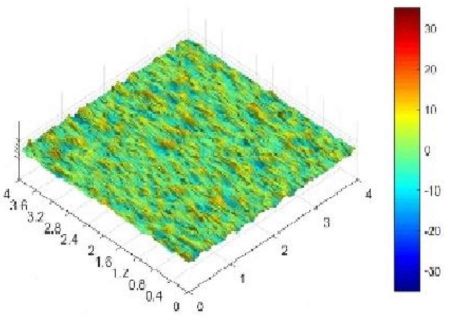
3D blasted surfaces is on Fig. 14.



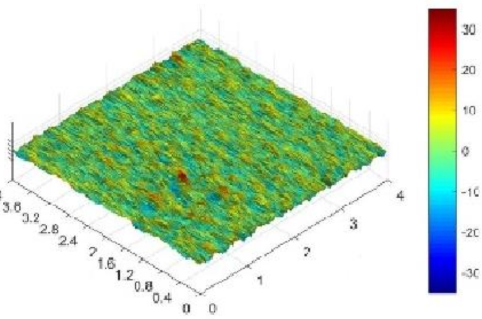
a) 3D - ZB1



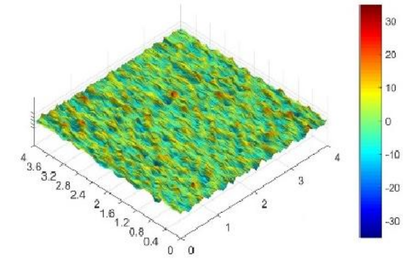
b) 3D - ZB5



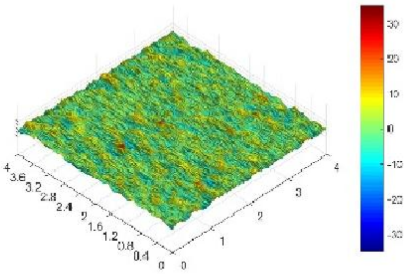
c) 3D - ZB9



d) 3D - BK1



e) 3D - BK5



f) 3D - BK9

Fig. 13 *3D blasted surfaces*

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Conclusion

In conclusion, we can state that the placement of samples on the platform during the DMLS process showed a statistically significant effect on the surface roughness. During the research, it was statistically demonstrated that the samples deposited in the center of the platform achieved the highest resulting surface quality. When applying metal powder, it is extremely important to check the quality and purity of the preparation before starting the processing process. The results of the research help to reduce the likelihood of inhomogeneity and contribute to the improvement of the reliability and subsequent repeatability of the process.

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