DUST FREE SURFACE TREATMENT PARAMETERS OF THE THREE-PHASE JET, GENERATED IN THE SANDBOT DEVICE

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This paper presents an original method for producing three-phase jet to enable efficient treatment of technical surface using the Sandbot apparatus. Exemplary results of studies describing the geometrical structure of machined surfaces in the context of their quality grading.

The stream of three-phase (air-water-abrasive) generated in innovative Sandbot devices [Prazmo 2012] is a modern and high-performance tool for dust-free surface treatment technology. Sandbot equipment enables the use of a variety of abrasive materials [Praźmo 2010, Sobczak 2013] including quartz sand (silica). Quartz sand may only be used in methods for wet and damp air in accordance with applicable in Poland guidelines contained in the Regulation of the Minister of Economy, Labour and Social Policy on occupational health and safety when cleaning the surface, spray painting and thermal spraying [Regulation 2004].

Furthermore, it describes the construction, operational and technological parameters and the area of innovative Sandbot devices, patented, designed and manufactured in Poland. These devices are intended for dust-free and high-performance cleaning of technical surface by the air-water-abrasive stream. They are used especially in industry, construction, and services.

KEYWORDS
three-phase jet, surface treatment, geometrical structure, dust free machining

1. INTRODUCTION

Technical surface treatment is a topic in many scientific research centers. Very often used for this purpose plain water jet. However, this requires very high pressures and suitable for removing layers of weakly bound to the substrate, such as graffiti, or another paint layers [Careddu 2016, Chudy 2013, Teimourian 2010]. Water jet is also recently introduced to the stone surface treatment. It is used to increase the roughness to improve its antislip properties while preserving esthetic appearance of the stone without having thermal shock, mechanical stress and the production of fumes and dust [Ozcelik 2011]. To increase the efficiency, [Madhukar 2013] presented a water jet assisted laser paint removal process.

The use of pulse techniques to increase the efficiency of water jet surface treatment introduced [Foldyna 2009]. Based on the analysis of obtained results, likely mechanism of the aluminum surface erosion and disintegration by the action of the pulsating water jet was discussed.

The use of water ice jet [Kohli 2015], or dry ice jet [Chomka 2013] has been developed as a nonsolvent method for removing surface contaminants in a variety of cleaning applications The basic principle is based on the impact of ice particles on the surface of the part. Contaminants on the surface are displaced by impact energy and the melting ice flushes away the debris.

The two-phase suspension jet (abrasive and water) is used since the mid-eighties of the twentieth century (Heron et al. 1987) and constantly developed as an efficient tool for machining [Perec 2004, Perec 2007]. It is commonly used in lightweight mobile systems used in civilian applications, and by specialized military units, eg. to non-detonating disposal of unexploded ordnance [Bunce & Fewell 2006], or by firefighter units to quickly cut off access holes in the areas covered by fire or risk of a fire or explosion [Dorle et al. 2003].

A method for producing suspension micro-abrasive water jet (with a diameter of 20-80 microns) was developed since the late nineties and now is used for precise micro cutting structural materials [Sobczak 2009].

The process for preparing a three-phase (air-water-abrasive) working jet, used for the surface treatment is a development of the known concept of forming a slurry stream of water and abrasive, and mainly used for cutting.

2. GENERAL CHARACTERISTICS OF THE DEVICE SANDBOT

Currently, a range of Sandbot machines (Fig. 1) is composed of two basic types: Sandbot100 and Sandbot200, differing mainly the volume of the slurry tank pressure water and abrasive and configuration of installations producing a working stream. To finalize the research presented in this article the Sandbot100 device was used. Increased volume of fluid bed in Sandbot200 predestined device for applications requiring machining efficiency increasing or working time extension from one charge of water and abrasive suspension deposit in tank.

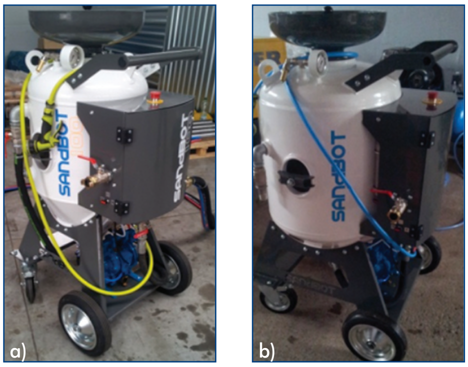

Fig. 1. View of the Sandbot devices: a) Sandbot100, b) Sandbot200

Sandbot apparatus consists of pressure slurry tank, hopper, chassis equipped with wheels, the hydraulic system and pneumatic-mechanical control device. The hydraulic system includes two circuits. The first is the washing out the slurry bed, and is based on two lines, connected through a regulator flow rate, the directional valves and arranged opposite each other two jets of the slurry tank. The second hydraulic circuit is used for eluting the slurry by water and is connected by the flow controller, the directional valve from the mixer, located at the output of the slurry tank.

Pneumatic control and drive system consists of two circuits equipped with separate tanks and compressed air preparation units. Pneumatic circuits are supplied from the same compressed air source, which is used for accelerating the abrasive and water suspension in the time of preparation the working stream. The first pneumatic circuit is connected to a pneumatic-hydraulic amplifier, which is used to generate pressure in the tank. The second pneumatic circuit is connected to the outlet of control device actuators and a manually operated valve. This makes it possible to enable or disable the work flow.

3. EXPLOITATION TESTS

In the device Sandbot the preparation of a three-phase stream is initiated as the effect of water flow, pump into the pressure vessel. This results in slurry bed elution. Next the mixture of water and abrasive flow into the mixer, where it joins with the water flows through the bypass circuit of pressure vessel. Next the slurry is transported to a mixing head, where the transfer of compressed air energy to the wetted abrasive grains takes place. Three-phase mixture is transported to the working head, where the final formation air- abrasive-water stream occurs.

In order to prepare the Sandbot device to run, it is necessary to connect the compressed air installation and water supply installation, the broadcasts a mixture of air-water-abrasive hoses and pneumatic control hoses. The tank must be partially filled with water and completes the abrasive material. Then the compressed air will turn on the driving, pneumatic-hydraulic pump, resulting in a tank encapsulation and increase the pressure inside the slurry to a level of approx. 1.1 MPa. Prepared in this manner device is ready for operation.

The three-phase flow generated in Sandbot device is well suited for high performance machining a wide range of technical and building surfaces. (Fig. 2). The machining process is performed at a selected pressure of the working stream with the range 0.3 ÷ 0.8 MPa; The maximum of abrasive flow rate is about 3 kg/min obtained with the water flow rate 3 dm^3/min, compressed air consumption about 3 m^3/min, and nozzle diameter 8.0 mm.

Fig. 2. Examples of using the Sandbot device: a), b), bodies of machines renovation; c) descaling and cleaning of welds; d), e), f) building surface renovation

The device can perform a surface treatment and additional purification steps as air-water stream from the residue of abrasive grains or drying the treated surface by the compressed air jet.

4. TECHNOLOGY RESEARCH

Technology research was carried out using a Sandbot100 device. The following abrasives were tested:

1. quartz sand (SiO_2) size range 0.10÷0.40 mm
2. quartz sand (SiO_2) size range 0.40÷0.80 mm
3. quartz sand (SiO_2) size range 0.80÷1.20 mm
4. copper slag (Polgrit) size range 0.16÷0.50 mm
5. Barton garnet # 80 size range 0.18÷0.21 mm

To carry out forming flow nozzle ID = 8 mm was used, and the pressure 0.65 MPa. Performance of the testing surface treatment using a three-phase flow of abrasive, air and water was conducted on the steel material coated with four layers of paint coating. A general view of the machined surfaces are shown in Fig. 3.

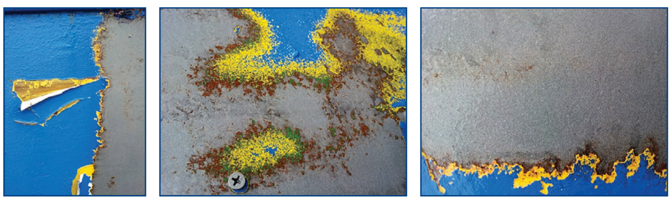

Fig. 3. General view of the machined surfaces

Abrasive materials used in tests have different properties, such as the size and shape of the particle and the bulk density. Each abrasive grains may be described by three dimensions:

1. Length
2. Width
3. Thickness

Due to the proportions of the three dimensional shape of the grains can be defined as: isometric (1:1:1), tabular (1:1:0.33), plate-like (1:1:0.66) pole-like (1:0.66:0.66) gladiate (swordlike) (1:0.66:0.33), acicular (needle-shaped) (1:0.33:0.33) [Jankowski 1971]. The abrasive waterjet abrasives are the most prized of isometric shape and have a large number of sharp edges. Grains with sharp edges have a greater ability machining then pebbles with rounded surfaces. An example of the shape of grains of quartz sand used in the surface treatment are shown in Fig. 4.

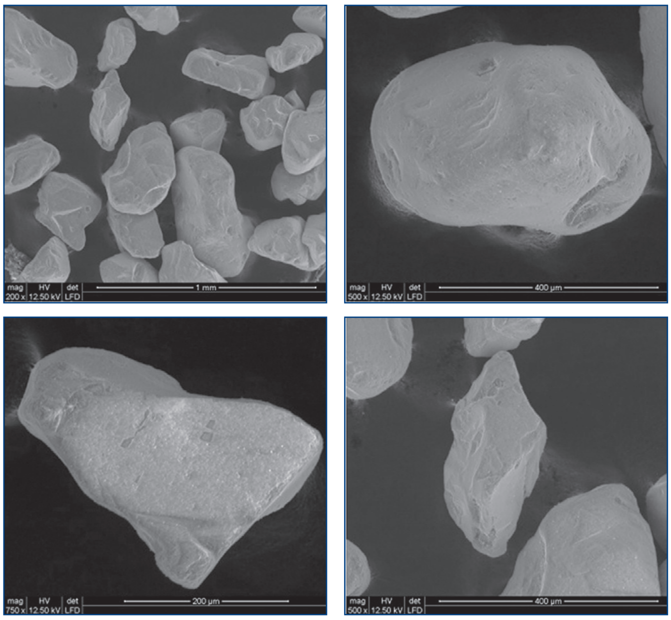

Fig. 4. An example of the quartz sand grains shape [Sobczak 2013]

The low rate of water, which eluted the fluid bed, combined with the use of various abrasive materials (with different particle sizes and shapes and different bulk density) result in specific of the abrasive flow rate during the abrasive machining process. The maximum abrasive mass flow rate is shown in Fig. 5. Barton garnet used as an abrasive, with the greatest density (2 200–2 500 kg/m^3), results in the largest abrasive flow rate, equal to 4.5 kg/min. In the case of quartz sand with grain size 0.40–0.80 mm and 0.80–1.20 mm (a bulk density of 1280–1 460 kg/m^3) the abrasive flow rate was equal 3 kg/min. The lowest mass abrasive flow rate obtained in the case of silica sand with a particle size of 0.10.4 mm and copper slag with particle size 0.15–0.5 mm

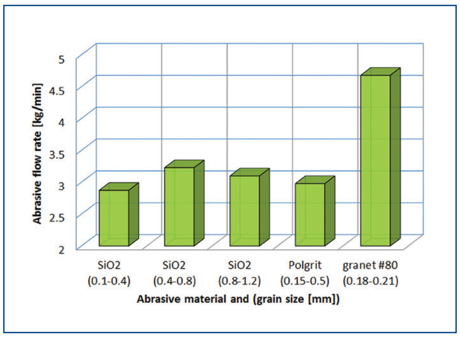

Fig. 5. The dependence of abrasive flow rate and abrasive material type and size

The treatment efficiency was determined by measuring the total removing time of 1 m^2 of the surface by each abrasive (with duplicate measurements). The results illustrate the efficiency of treatment with various abrasives shows Fig. 6. The efficiency of treatment significantly depends also on the nature and properties of the removable surface.

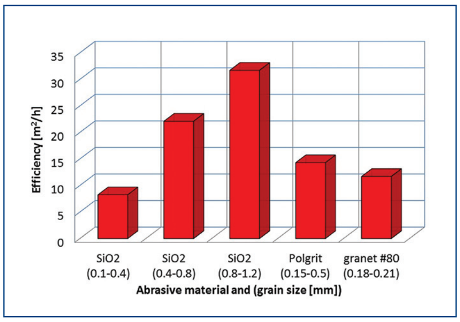

Fig. 6. Processing efficiency
(target – 4 layers of paint on S235 steel sheet; pressure = 0.65 MPa, nozzle ID = 8 mm, distance = 150 mm, Angle of attack = 60°)

The best efficiency of the treatment, about 30 m^2/h, was obtained by using quartz sand with grain size 0.8-1.2 mm. Reducing the grain size to range 0.4–0.8 has lowered efficiency of the surface machining to about 20 m^2/h. The use of the abrasive Polgrit 0.15–0.5 mm reduces the machining efficiency to nearly 13 m^2/h.

Slightly worse in this combination proved Barton garnet # 80. The effectiveness of treatment was slightly more than 10 m^2/h. The lowest efficiency of processing near 7 m^2/h was achieved with the use of quartz sand with grain size 0.1–0.4 mm.

5. QUALITATIVE RESEARCH

S235 steel plates were prepared for qualitative research. Samples were treated by 3-phase stream from Sandbot100 device under the same technological parameters: the jet pressure p = 0.65 MPa, nozzle diameter ID = 8 mm, the stand-off distance l = 150 mm, the angle of jet attack α = 60 degree, and when fully open valve regulating bypass water flow. Used different abrasive materials:

1. quartz sand (SiO_2) size range 0.10÷0.40 mm
2. quartz sand (SiO_2) size range 0.40÷0.80 mm
3. quartz sand (SiO_2) size range 0.80÷1.20 mm
4. copper slag (Polgrit) size range 0.16÷0.50 mm
5. Barton garnet # 80 size range 0.18÷0.21 mm

A general view of the macroscopic structure of the prepared samples are shown in Fig. 7

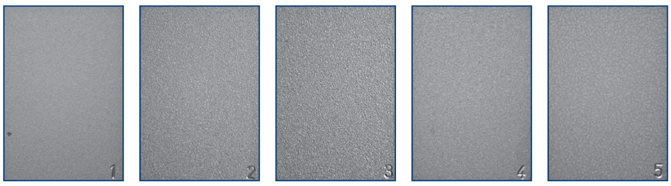

Fig. 7. Macrostructure of the steel S235 samples machined by 3-phase stream. Parameters: pressure=0.65 MPa; nozzle ID=8 mm; stand-off distance=150 mm; angle of attack α=60°. 1) SiO_2 0.1÷0.4 mm; 2) SiO_2 0.4÷0.8; 3) SiO_2 0.8÷1.2; 4) Polgrit 0.16÷0.5; 5) garnet #80

The surface tests were carried out on a Taylor Hobson Form Talysurf contact profilometer, with internal base and inductive transducer head. This type of equipment is widely used both in industrial and scientific research units. Schematic diagram of the concept of measured surface profile processing in the commonly used 2D range presents Fig. 8.

The profilometer measuring tip, finished with a diamond needle having a radius of 2 μm, moves across the measured surface. Altering the tilt in the Z axis are recorded. Based on the data obtained from the

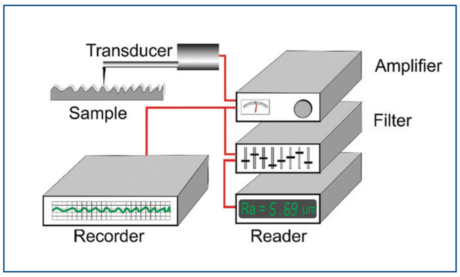

Fig. 8. Schematic diagram of the 2D profile measurement

ruler of the incremental recording needle position in the X-axis surface profile is created in one plane. Deflection changes are converted into an electrical signal, appropriately amplified, filtered and digitized and then processed by software.

The essence of the contact surface stereometry measuring in the 3D system is illustrated in Figure 9. 3D measurements, in fact, are a combination of several hundred or more linear measurement offset in parallel in the direction perpendicular to the direction of travel of the needle measurement by a predetermined level step.

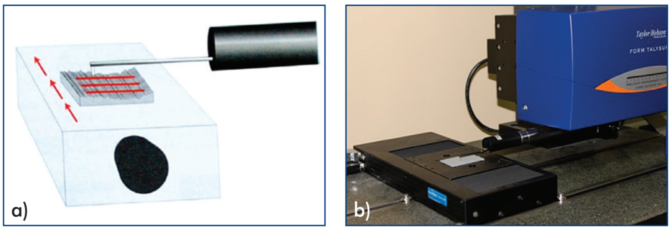

Fig. 9. The 3D measuring system rig: a) scheme, b) measurement practical implementation

The comparative studies (2D and 3D) were carried out on five samples treated by various flow parameters of the air-water-abrasive jet. The measurement speed equal 1 mm/s was selected. At higher speeds, the measurement can occur both the effect of the absence of effective penetration of all wells. This can cause the undervaluation of the parameters analyzed and the effect of bouncing tip on a slope causing overstating the parameters analyzed. The phenomenon applies in particular amplitude parameters which are planned to analyze. It was established measuring field size 5 x 5mm – ensure adequate representativeness of measurement [Czarnecki 2013] and step measuring 10 μm in both axes [Chmielik 2012].

6. THE RESULTS AND ANALYSIS OF MEASUREMENT

Each measured surface is composed of three components the shape, the wave and the roughness [Oczos 2003]. The right approach to their analysis is the basis for a fully representative assessment of the quality of the surface [Adamczak 2008, Tavodova 2013]. In the case of flat surfaces treated air-to-water and abrasive created in 3D system analysis without the separation of the constituent waviness and roughness. This approach provides an assessment of the quality of the surface [Valicek 2012], taking into account both long wave and short wave components that arise during processing. The basic and most common parameters of the 2D surface structure: arithmetic average of absolute values Ra, average distance between the highest peak and lowest valley in each sampling length Rz, maximum peak height Rp, maximum valley depth Rv and maximum height of the profile Rt (ISO 4287) and 3D surface structure: arithmetical mean height of the surface Sa, maximum height of the surface Sz, maximum height of peaks Sp and maximum height of valleys Sv (ISO 25178) were analyzed.

The area measured on a sample No. 1 with visual assessment is characterized by the lowest roughness. Surface of samples No. 2 and No. 3 are similar to each other, indicating greater roughness of the surface of samples No. 2. The use of abrasive SiO_2 more granulation has a direct effect on increasing roughness. This assertion is based

	Sa [μm]	*Sz* [μm]	*Sv* [μm]	*Sp* [μm]	*Ra* [μm]	*Rz* [μm]	*Rv* [μm]	*Rp* [μm]
Sample 1	6.02	193.0	157.0	35.4	4.57	25.1	12.8	12.4
Sample 2	12.80	167.0	100.0	67.1	7.25	38.3	18.9	19.4
Sample 3	16.00	178.0	80.7	97.7	8.31	40.9	18.7	22.2
Sample 4	8.81	187.0	116.0	70.1	6.49	35.6	17.8	17.9
Sample 5	5.96	88.0	47.3	40.7	5.18	27.4	13.3	14.2

Tab. 1. Values of roughness parameters

on visual observations it was confirmed by the obtained values of roughness parameters, both in the 2D and 3D. When the changes in the parameters in 2D are relatively small changes derived from the analysis parameters in a 3D system. This fact is linked with filtration system for the analysis of 2D. When analyzing long-term 3D components (waviness) are taken into account when determining the parameters of the surface topography. Surfaces No. 4 machined using Polgrit abrasive and No. 5 using Barton garnet have a size similar to the roughness of samples No. 1 (Fig. 10). Values of roughness parameters are shown in Tab. 1.

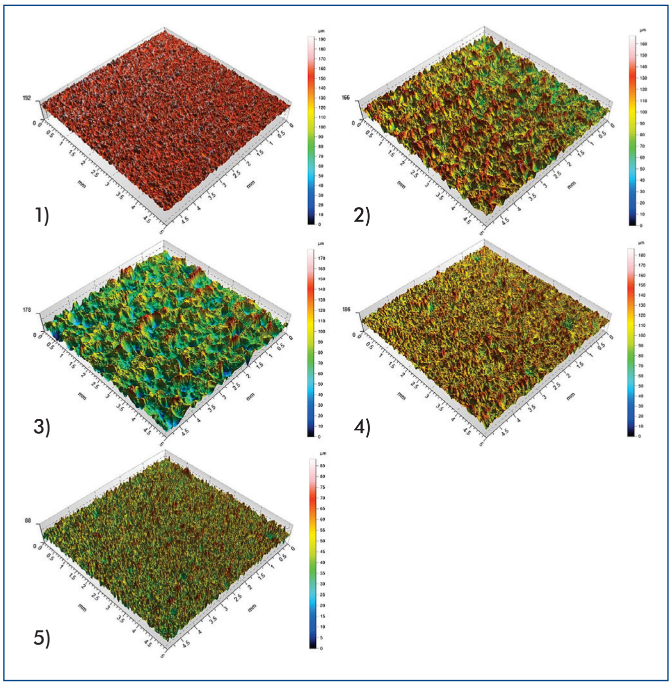

Fig. 10. The geometric structure of the test samples surface after 3 phase jet treatment with: 1) quartz sand (SiO_2), size 0.10÷0.40 mm; 2)quartz sand (SiO_2), size 0.40÷0.80 mm; 3) quartz sand (SiO_2), size 0.80÷1.20 mm; 4) copper slag (Polgrit) size 0.16÷0.50 mm; 5) Barton garnet # 80, size 0.18÷0.21 mm

The most popular surface quality parameter – *Ra* is the smallest, equal 4.57 μm, on the sample No. 1, the largest, equal 8.31 μm in the sample No. 3 – (difference 82 %). The smallest 3D measurement parameter *Sa*, equal 6.02 μm, obtained on sample No. 1 – and equal 5.96 μm on sample No. 5, the largest, equal 16.00 μm, on a sample No. 3 – (a difference of 270 %).

Variability of *Rz* parameter is similar to *Ra*. The smallest values were obtained for samples No. 1 – 25.1 μm and No. 5 – 27.4 μm. The largest on the sample No. 3 – 40.9 μm (difference approx. 60 %). The value of the *Sz* parameter is the smallest in sample No. 5 – 88.0 μm and is smaller by 48 % – 55 % from the value obtained for the other samples. It indicates the presence of peaks and valleys of smaller, closely spaced values. *Sv* and *Sp* parameters are similar. From the remaining samples only samples No. 3 was obtained uniform distribution of peaks and valleys (*Sp* = 80.7 μm, *Sv* = 97.7 μm). On the sample No. 1, No. 2 and No. 4 are much higher peaks than the depth of the valleys. Fig. 11 shows a graphic compilation of roughness parameters measured in samples. The

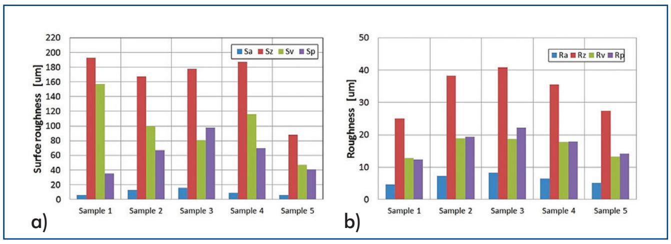

Fig. 11. Summary of roughness parameters tested samples

3D roughness parameters shows Fig. 11a and 2D roughness parameters shows Fig. 11b.

The *Pt* parameter value takes into account components of both long-term and short when analyzed in a 2D system (Fig. 12) is the smallest, equal 38.4 μm, sample No. 2 and the largest, equal 78.1 μm sample No. 4 (difference 51 %). For the sample No. 1 value *Pt* = 45.5 μm and is larger than the smallest obtained for of samples No.2 in value by 16 %.

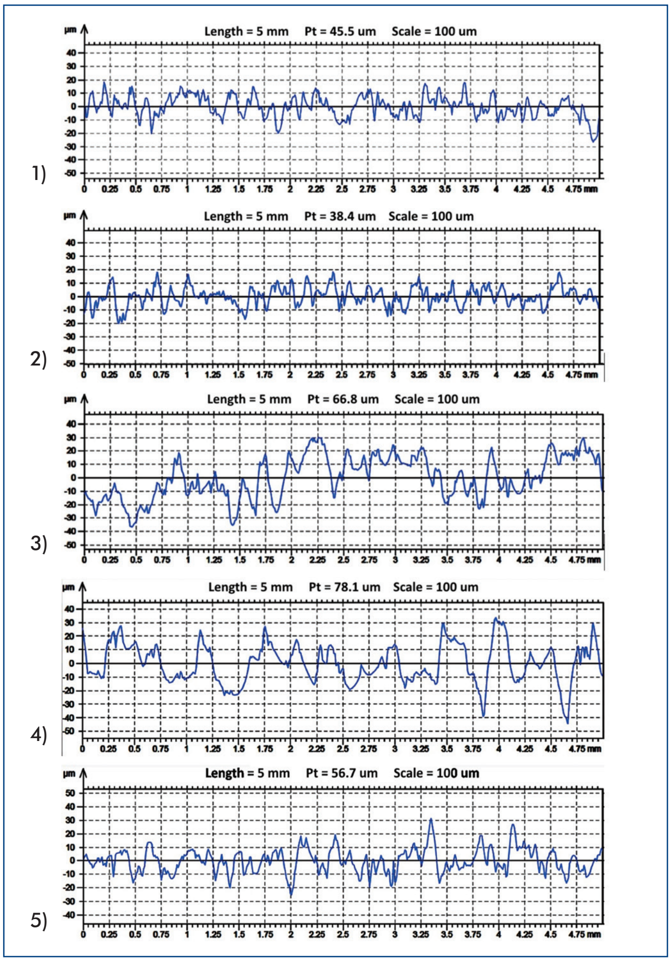

Fig. 12. The 2D contours of tested surfaces after 3 phase jet machining with abrasives: 1) quartz sand (SiO_2), size 0.10÷0.40 mm; 2) quartz sand (SiO_2), size 0.40÷0.80 mm; 3) quartz sand (SiO_2), size 0.80÷1.20 mm; 4) copper slag (Polgrit) size 0.16÷0.50 mm; 5) Barton garnet # 80, size 0.18÷0.21 mm

In summary, the sample No. 1 processed using the abrasive SiO_2 size range 0.1– 0.4 mm has the lowest values of surface roughness in both a 2D and 3D except the symmetry of the peaks and valleys that occur and the value of Sz. In the case of sample No. 5 – abrasive garnet # 80 roughness reaches a slightly larger values, with the exception of the *Sz* parameter, which value is 2 times lower than the values obtained for the other samples.

7. CONCLUSIONS

Three-phase stream generated in Sandbot innovative devices is a modern and efficient tool, used for dust-free and high efficient engineering and construction surface treatment. This device is applicable both for renovation of machine housings and renovating the building facades and removal of paint signs from the roadway, as well as to clean the surface of the technical danger fire or explosion zone.

On the basis performed tests, following conclusions were made:

- A typical surface treatment efficiency (depending on treatment parameters, type of abrasive and the nature of the removed contaminations) is in range of 7-30 m^2/h,
- A typical surface the roughness parameter Sa of machined steel surfaces is in the range 6-16 μm and is dependent mainly on the used abrasive type and grain size.
- The smallest surface roughness achieved with the abrasive SiO_2 size range 0.10.4 mm.
- The biggest surface roughness achieved with the abrasive copper slag (Polgrit) size range 0.16÷0.50 mm.

The next step in the research of this device will detail tests the performance parameters of various surface treatment.

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