# Assessment of the texture and topographic features of a surface produced by the 3D printing process

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**Abstract:**

Presented in the paper is a study of the surface texture as produced by the Up3D printer from Solveere with the printing parameters varying in relation to those of the surface under survey. Used for the measurements was optical profilometer Nanovea PS50 operating to the chromatic aberration principle. The results were used for estimation of the 3D printer output data and also for consideration whether some parts or items as released by 3D printers were practicable for use in a production process.

KEYWORDS: **3D printing**, **surface texture**, **profilometer**

## Introduction:

Presented results of the study of surface texture as produced by a 3D printer provide the grounds of assessment of visual features of the solid body models intended for use in technical environment. The research work is expected to assist in identification of the surface texture in the aspect of the intended use.

The problems related to surface texture of the objects produced by means of 3D printing technique and to the methods of filling the space within the printed shell surfaces are more and more often discussed and investigated. Currently printed are already members of prosthetic appliances or implants (fig. 1). Also produced are common utility structures in the broad sense of pattern designing work while printing methods of large structures such as boats or houses are developed as well (fig. 2).

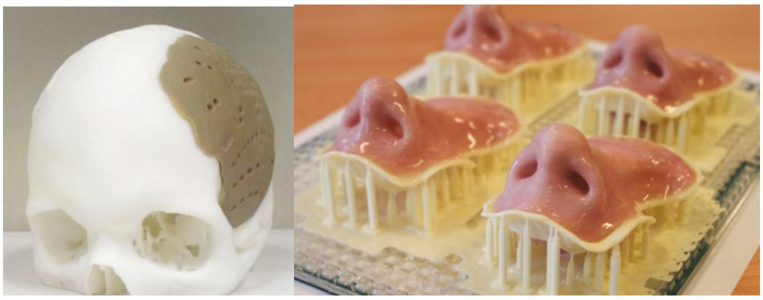


*Fig. 1. An example of 3D prints for medical applications [9]*

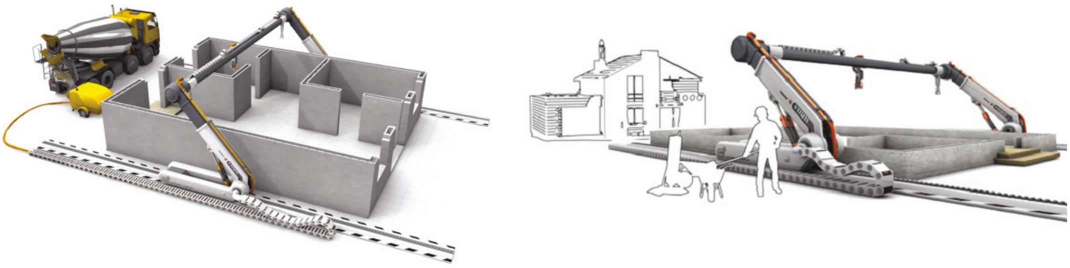


*Fig. 2. Examples of printing bulky objects (houses) [9]*

Metal powders including such materials as titanium are increasingly used in engineering applications of 3D prints (fig. 3).

Titanium alloys are considered to be the best among materials used to build constructions for the aerospace and/or automotive applications. Regrettably, structures manufactured in a traditional way are rather expensive due to the specifically applicable subtractive machining methods [1,3-4]. But the 3D printing process will reduce the amount of waste, and thus cost. Common efforts of the two cooperating British companies - Renishaw and EmpireCycles have been crowned with a success by 3D print of the world's first high-performance bicycle frame from titanium alloy, with its weight reduced against that of traditional aluminum frame by 1/3.

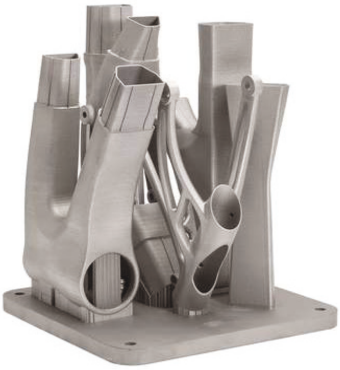


*Fig. 3. Elements of the frame printed by laser sintering powders. Press Releases - Copyright Renishaw*

Plastic properties of titanium and its high mechanical strength combined with considerable hardness number require that only special expensive cutting tools can be used to machine the material with ample quantities of chips supplied as byproducts. Also, due to high oxygen reactivity, titanium parts should be welded in an inert gas shield (e.g. argon), which also results in higher production costs. Consequently, the 3D printing process may soon be recognized as a cost saving method. It is financially advantageous because of reduction of production waste in comparison with conventional methods of production and machining of metal parts.

## Abrasive tool body design-to-production project completed by the 3D print technique

The Authors have attempted to use the 3D technique to produce the abrasive tool body specifically formed to supply coolant to the machining area through suitable openings in working surface of the grinding wheel. A suitably resilient abrasive tool body has been produced with provision made to control flexibility of the body in working area (fig. 4).

In order to ensure flexibility control of the abrasive tool body within the grinding area, models of grinding wheels have been produced suitably arranged to hold coolant liquid for adequate relief of thermal stresses arising from the abrasive grains scraping off the machined surface. See fig. 4 for models of abrasive tools as developed in recent years in the Department of Production Engineering Koszalin University of Technology [5, 7].

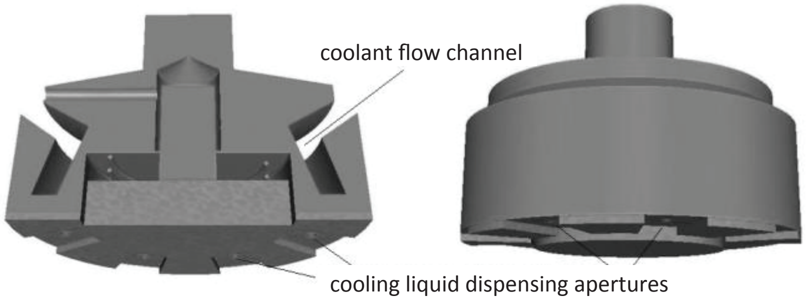



*Fig. 4. A view of abrasive body suitably designed to hold cooling liquid and to dispense it to grinding zone [8]*

Introduction of the 3D printing technique has created an opportunity to build the prototypes of abrasive tools incorporating controllable deflection zones, which made it possible to provide resilient grinding bodies suitable for treatment of the freely accessible faces by means of industrial robots. Special coolant flow channels now can be provided within the abrasive tool body, which could be otherwise impracticable or extremely difficult to obtain (if produced by subtractive machining method). With appropriate 3D printing process control software it is also possible to produce high strength openwork structures (see fig. 5)

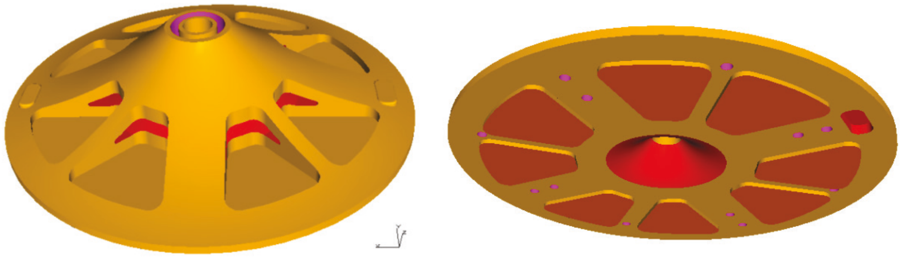


*Fig. 5. Exemplary resilient grinding wheel designed to the requirements of 3D printing process [3]*

Prints of the bodies were produced from ABS plastic. Shown in fig. 5 are the areas filled with Trizact grain inserts. And there between two openings can be seen to dispense coolant liquid. The space between the members supporting the resilient abrasive body can be additionally filled with a mesh structure produced at the time by the 3D printer which needs its options suitably preset before starting the printing process (fig. 6).

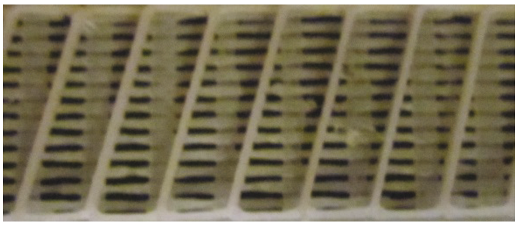


*Fig. 6. Detail of the structure to fill the space between support members before further printing of the abrasive body can be carried on [3]*

In order to check the project when completed, prints of the abrasive tool bodies were produced duly provided with channels to have the coolant passing and supplied to the grinding zone (fig. 7).

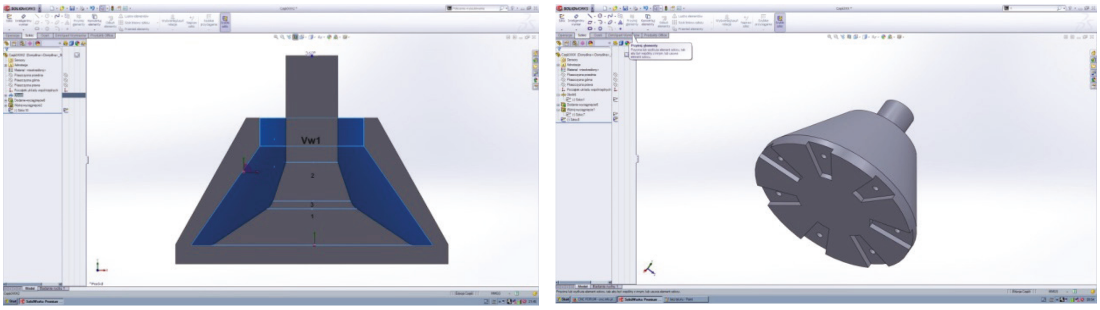


*Fig. 7. Abrasive tool body with coolant flow channels [2]*

A model of the abrasive tool body was printed showing average material layer densities as applied to the nearest 0.15 mm.

The printer UP!3D is shown in fig.8 during the operation of printing a model of an abrasive body utilizing ABS plastic as the print material.

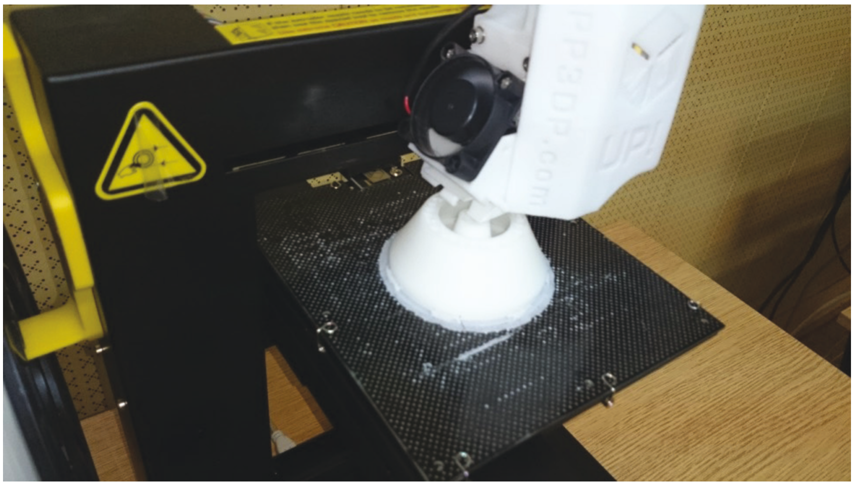


*Fig. 8. Production of 3D print of an abrasive tool body [2]*

Production tests carried on the abrasive body has shown coolant flows ranging from 1.3 $dm^3$ to 2.65 $dm^3$ per 60 sec at the speeds starting from the lowest 84 rpm to the top spindle speed of 417 rpm respectively.

Also the body of abrasive tool has been exposed to strength tests, which revealed relatively high operating stability under load of the flowing coolant. No defects such as cracks and/or defragmentation of structure have been revealed during inspection of surface of the body by means a digital microscope.

## 3D print samples produced to the operating parameters set at different values

Satisfactorily completed tests and prototypes of abrasive tool bodies have encouraged the studies of the surface structure after printing in order to determine the optimum print parameters so as to obtain the best strong and tough structure of abrasive tools and also, to provide for means of control of their resiliency by modifying structure and compactness of the print layers.

There were nine samples printed to varying parameters such as layer thickness or print speed. The samples were subjected to the surface topography survey. For the study of the surface texture there has been used optical profilometer Nanovea PS50, designed to perform non-contact measurements to the chromatic aberration principle. All the measurement results were processed by the Mountains Expert 3D version 7.1.7106 surface examination software.

These samples of the 3D prints have been obtained to varying parameters as set to the printer of the following specification (fig. 9):

| | |
|---|---|
| Model material: | ABS & PLA Plastic |
| Size of working chamber: | 140 x 140 x 135 (h) mm |
| Layer thickness: | 0,15/0,20/0,25/0,30/0,35 mm |
| Printing speed: | 10-100 $cm^3$/h |
| Printer size | 245 x260x350 mm |
| Weight: | 5 kg |
| Power: | 100-240V, 50-60Hz, 220W |
| System requirements: | Windows XP, Vista, Win 7 & Mac |
| Input file: | STL |
| Working temperature: | 15°C-30°C |
| Air humidity: | 20%-50% |

*Fig. 9. Printer specifications. Up3D [User's Guide. 3D Up! User's Guide. Solveere. Sosnowiec 2014]*

Nine samples were taken. For the procurement parameters see table 1.

*Table 1. Table of output parameters*

| Item | Sample reference | Print time | Material depth (Z Resolution) | Quality |
|---|---|---|---|---|
| 1 | f#1 | 3 min | 0,20 mm | fast |
| 2 | f#2 | 4 min | 0,30 mm | fast |
| 3 | f#3 | 5 min | 0,40 mm | fast |
| 4 | n#1 | 6 min | 0,20 mm | normal |
| 5 | n#2 | 4,5 min | 0,30 mm | normal |
| 6 | n#3 | 4 min | 0,40 mm | normal |
| 7 | fi#1 | 9 min | 0,20 mm | fine |
| 8 | fi#2 | 6 min | 0,30 mm | fine |
| 9 | fi#3 | 5 min | 0,40 mm | fine |

See fig. 10 for the resulting print samples as prepared and tested on the profilometer.

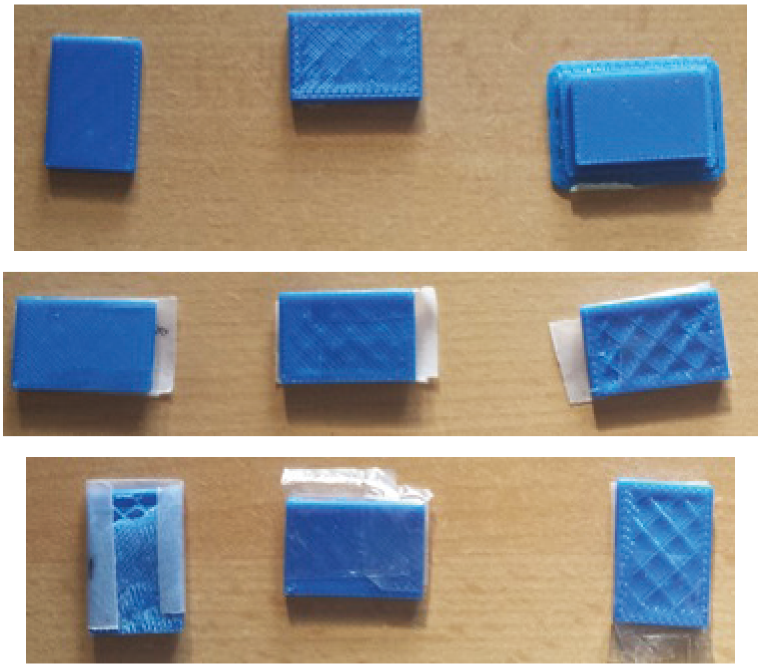


*Fig. 10. Samples obtained from printing process*

## The study of surface topography by chromatic aberration technique

The surfaces of samples obtained in the printing process to varying printer setting parameters were tested on the profilometer Nanovea PS50 which allows to perform tests using non-contact optical measurement based on the chromatic aberration technique (fig. 11).


*Fig. 11. Profilometer Nanovea PS50. Test stand*

Research results as recorded by 3D software NonovaN PS50 Version 4.0.2. (fig. 12).

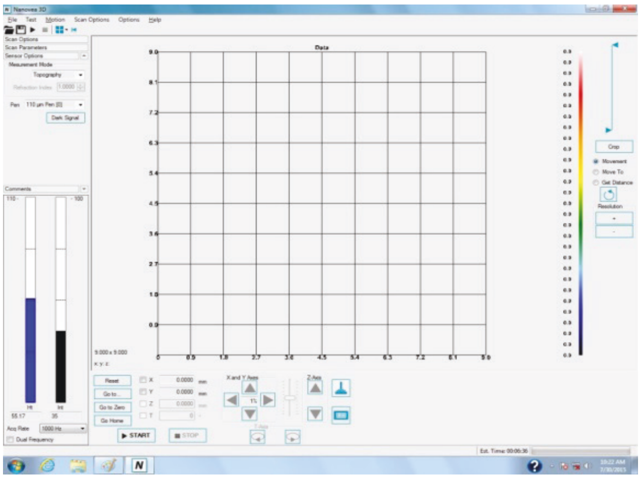
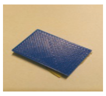
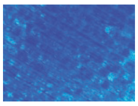
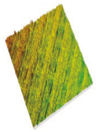
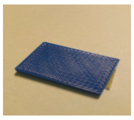
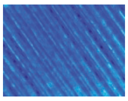
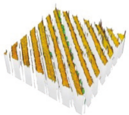
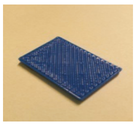
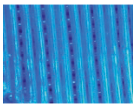


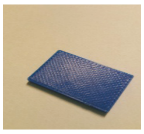
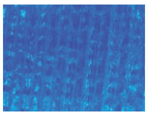
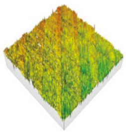
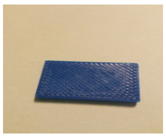
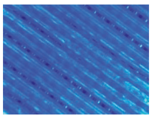
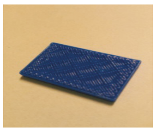
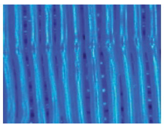
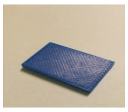
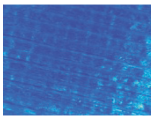
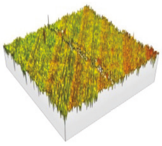
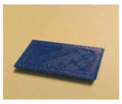
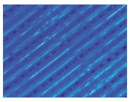
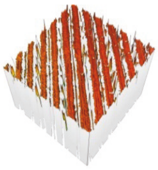
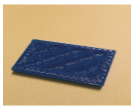
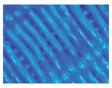
*Fig. 12. Software interface Nanovea N3D PS50 Version 4.0.2*

Used in the study was a single lens to handle the maximum available vertical measure of 10 mm (out from the three offered, viz: 110 microns; 3mm, 10mm). Field measurement area has been established to 5x7 mm (in x and y axis respectively).

Results of the measurements were processed into images of surface topography as obtained in the printing process and a list of selected parameters defining the surface irregularities in the specified areas (table 2).

*Table 2. The results of examination on the profilometer and a digital microscope*

| Item | Sample reference | $Sa_{(\mu m)}$ | $Sq_{(\mu m)}$ | 3D image |
|---|---|---|---|---|
| 1 | f#1  | 32,96643,765  | |  |
| 2 | f#2  | 58,679101,612  | |  |
| 3 | f#3  | 216,449270,718  | |  |

| | | | |
|---|---|---|---|
| 4 | n#1  | 36,19246,650  |  |
| 5 | n#2  | 132,281202,670  |  |
| 6 | n#3  | 142,308202,698  |  |
| 7 | fi#1  | 23,50630,656  |  |
| 8 | fi#2  | 81,270125,838  |  |
| 9 | fi#3  | 229,425295,078  |  |

# Summary and conclusions

The main objective, the research has been carried out to, was to examine texture of surface of the models printed on the 3D printer to various printing parameters and to draw conclusions as to the applicability of particular print parameters, taking into account the aspects of aesthetic and practical features, with reference to the parameters of surface topography as registered by the profilometer. Research work has been carried out on the flat samples produced on the same printer in the form of flat cuboid tiles from ABS plastic, and then examined on the profilometer.

- High print quality and small thickness of the layers (sample fi#1(7)) result in optimum parameters Sa and Sq (the values of these parameters would be the lowest). Consequently, the produced surface would be relatively smooth with the texture most evenly distributed. With these parameters the produced print has shown the most true representation of the real shape of the sample against the CAD model.

- Low printing precision and thick material layers if set to the print head would tend the material to collapse under its own weight (samples: 6;9). With these parameters the structure of the support material would manifest through the surface of the deposited material spoiling quality and good outlook and possibly affecting functional capacity of the part in macro scale. The parts produced to such parameters may reveal higher resilience, but may also be more susceptible to breakage and destruction caused by rotation and operation of centrifugal force.
- Samples f#1, n#1 and fi#1(1;4;7), as noted for high accuracy in deposition of the print material, are considered to be the most recommendable for use in design and manufacture of the 3D printed prototype bodies of abrasive tools. However printing process takes longer times, more dense structure is obtained (in case of the bodies designed for supply of cooling liquid in the grinding zone the structure is also more watertight).
- To produce abrasive tool bodies provided with controlled resiliency segments it should be suggested to employ the openwork print option involving application of suitably designed mesh structure or else, if with coarse print parameters which should mean low accuracy of positioning of the printing head and if with relatively thick elementary print material layer fi#2(8) and n#2(5), this should however require additional check procedure to prevent the problems of the nature as referred to under 2.
- Samples marked fi#3 and n#3(9;6) were noted for significant irregularity of the print material which deposited in peculiar strands rather disorderly laying over the supports or foregoing layers of the printed matter. The resulting structure deposited to the specified parameters should be expected to tend to local distortion and higher vulnerability to local rupture or deformation with respect to more extensive structure volume (in macro scale). It should be mentioned that the said parameters have been rejected from the projects related to resilient abrasive tool bodies for the reason of potential failure of the 3D load bearing structure.

The study should be regarded as preliminary, but the results are promising and worth further research. Abrasive tool bodies can also be produced by the way of sintering metal powders using the precision lightweight structures style, such as e.g. honeycomb structure, in which walls as thin as 0.6 mm are available (promising to increase accuracy of 3D printing process in the nearest future). To this end however, the method of SLS - 3D should be used (selective laser sintering).

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