ANALYSIS OF SURFACE ROUGHNESS OF TRANSMISSION GEAR TEETH MADE BY DIFFERENT RAPID PROTOTYPING METHODS

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Abstract

Article presents analysis of surface roughness of aircraft and vehicle power transmission system gear teeth made by different Rapid Prototyping methods. Gear box models have been made by two rapid prototyping methods: stereolithography (SLA), three dimensional printing (3DP) and two rapid tooling methods: Vacuum Casting (VC), Low Pressure Injection (LPI). Surface roughness for rapid prototyping methods is determined mostly by layered system of building model. It depends on process parameters: layer thickness and model position in working space of RP machine. Vacuum Casting and Low Pressure Injection are Rapid Tooling technologies. For this technologies final surface roughness is a reflection of surface parameters of tools (silicon mould, silicon matrix). The paper presents results of surface roughness measurements of gear made by few RP and RT methods. The most important thing was an analysis of surface roughness made by Rapid Tooling methods. In these methods surface roughness depends on surface parameters of basis RP model. For basis RP models finishing processing was applied. This process improves parameters of the surface. This research process allowed to define the influence of chosen RP and RT method and its parameters on surface roughness of gear tooth. It permitted to order rapid prototyping methods for application of power transmission prototype making process.

Keywords: *surface roughness, rapid prototyping, bevel gears*

1. Introduction

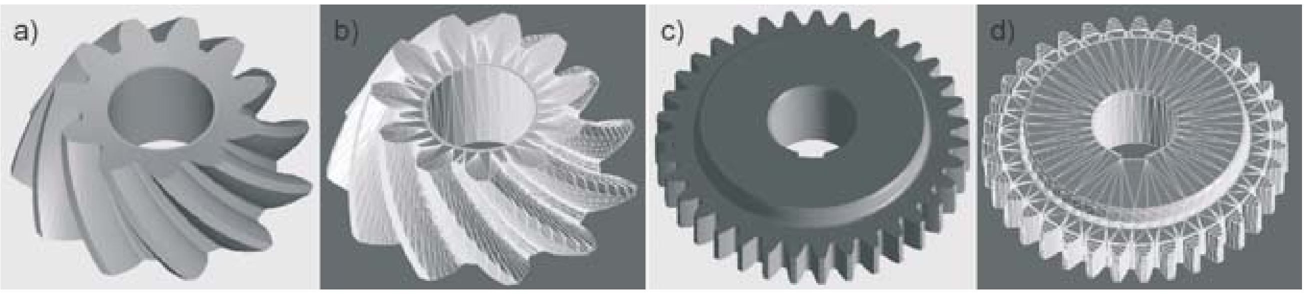
Research models of gears wheel for aircraft and automobiles transmissin can be made by various techniques of Rapid Prototyping and Rapid Tooling, depending on prototype use and the required precision [1, 4, 5, 6]. The incremental techniques of rapid prototyping are characterized by their typical stepped surface structure, typical for a laminar structure of the model. It is visible particularly on elements with complicated surface shapes, as gears wheel mostly bevel gears, among others [8]. Surface roughness of models produced with laminar incremental systems of Rapid Prototyping (three dimensional printing and stereolithography) depends on many factors, including:

a) shape of model surface,
b) position of model surface in respect to work surface,
c) surface precision of virtual model,
d) precision of the method,
e) the type of initial material.

Taking the above factors into account permits obtaining of prototypes with optimum surface roughness [10, 11, 12, 13]. Surface roughness of models produced with systems of Rapid Tooling (Vacuum Casting, Low Pressure Injection) depends on tool surface (silicone mould or silicone matrix).

2. Rapid Prototyping and Rapid Tooling models of gear wheel

In an analysis of Rapid Prototyping and Rapid Tooling methods in respect of producing the prototypes of gear wheel, only those most precise ones should be short listed. For research reasons, two Rapid Prototyping methods i.e. stereolithography (SL) and three-dimensional printing (3DP) and two Rapid Tooling method (Vacuum Casting and Low Pressure Injection) were selected [3, 9]. Gear wheel prototypes were produced on the base of the CAD model, which was exported to the STL format with precision to the nearest 0.001 mm (Fig. 1) [2, 7, 9]. Gears wheel models were positioned on the work platform of the SLA 250 and Z510 Spectrum device in positions then axis of rotation of gear wheel was parallel with *z* axis of RP machines (Fig. 2-3) [14].



Rys. 1. Virtual models of gear wheel: a) CAD model, b) STL model, c) CAD model, d) STL model

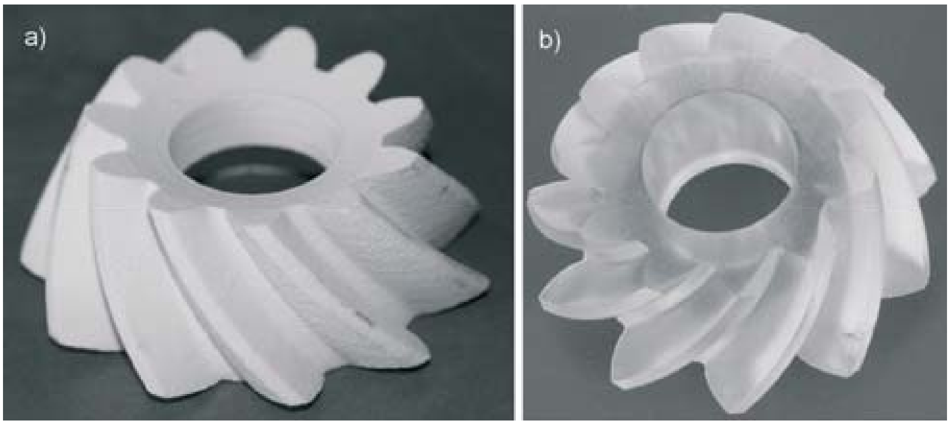


Fig. 2. Prototypes of bevel gear: a) 3DP model of bevel gear, b) SLA model of bevel gear

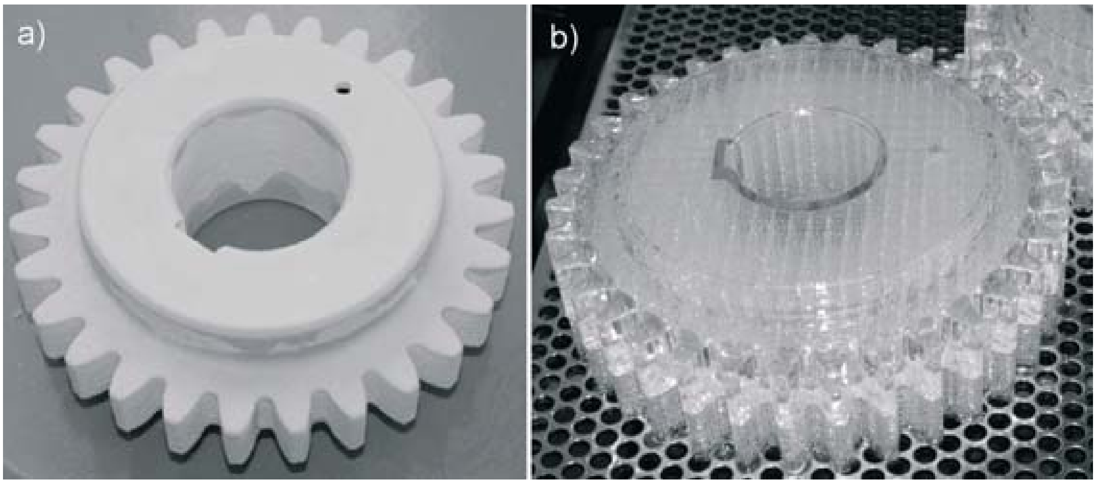


Fig. 3. Prototypes of gear wheel: a) 3DP model of gear wheel, b) SLA model of gear wheel

Silicon matrixes were made on the basis of stereolithographic base models presented here above. The silicon mold is a tool that serves for producing elements of plastics (polyester resins, epoxy polyurethanes) and plastic composites. Processing tools of silicon are suitable for making short series, from several to several dozen, of products [4].

Depending on the type of molded material, prototypes may be produced in silicon molds through: gravitational casting at ambient pressure, vacuum casting, low-pressure injection.

3. Wheel gears roughness measurements

Surface roughness measurements were carried out with the Talyscan150 instrument produced by Taylor Hobson Precision and the TalyMap 3D software package used for surface analysis. The measurements were carried out on a sampling area of 1 mm x 1 mm with the sampling step of 10 μm and the three-time replication.

3.1. Surface roughness of SLA model of bevel gear

The first sample was a stereolithographic model of bevel gear, made with the SLA-250 unit manufactured by the 3D Systems. Bevel gear models were positioned on the work platform device in positions then axis of rotation of bevel gear was parallel with *z* axis of SLA 250. As a result of program processing of the gear tooth measurements the following 3D-diagrams were plotted (Fig. 4).

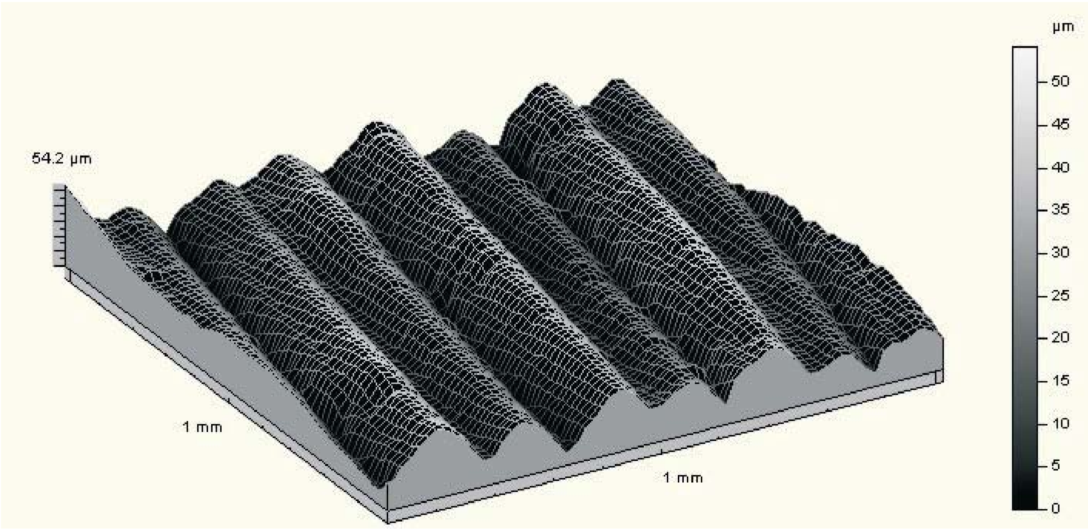


Fig. 4 Isometric view of the surface of the SLA model of bevel gear

3.2. Surface roughness of SLA model of gear wheel

The second sample was a stereolithographic model of gear wheel, made with the SLA-250 unit manufactured by the 3D Systems. Gear wheel models were positioned on the work platform device in positions then axis of rotation of gear wheel was parallel with *z* axis of SLA 250. As a result of program processing of the measurements the following 3D-diagrams were plotted (Fig. 5).

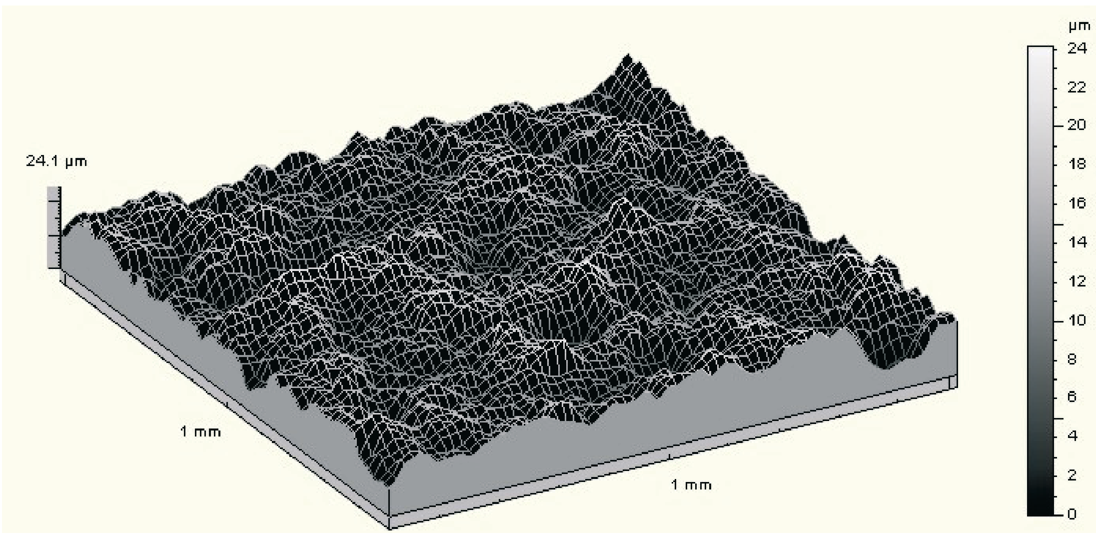


Fig. 5. Isometric view of the surface of the SLA model of gear wheel

3.3. Surface roughness of 3DP model of gear wheel

The third sample was a three dimensional printing model of gear wheel, made with the Z510 Spectrum unit manufactured by the ZCorporation. Gear wheel models were positioned on the work platform device in positions then axis of rotation of gear wheel was parallel with *z* axis of Z510 Spectrum. As a result of program processing of the measurements the following 3D-diagrams were plotted (Fig. 6).

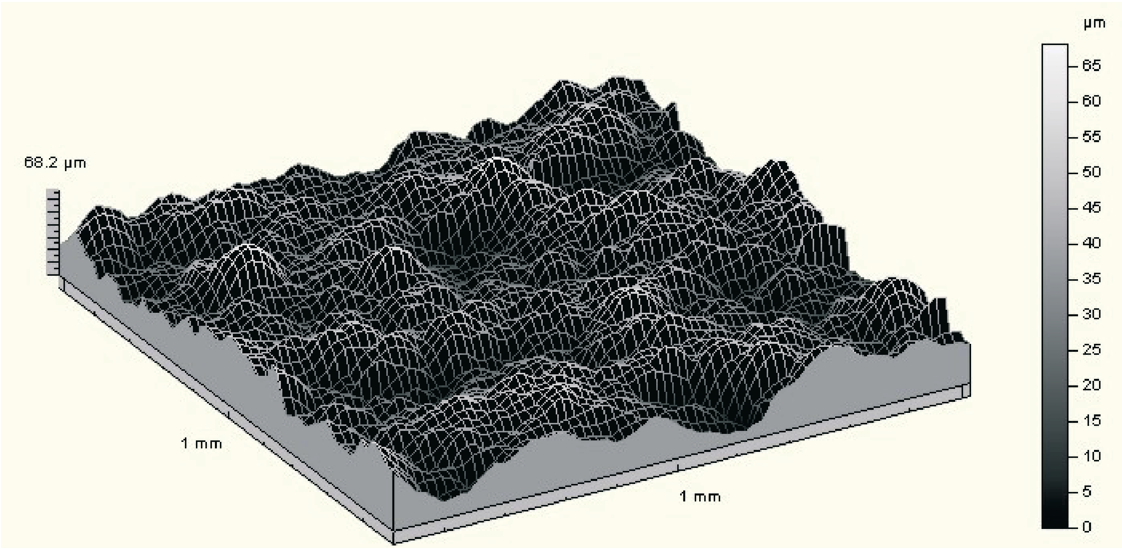


Fig. 6 Isometric view of the surface of the 3DP model of gear wheel

3.4. Surface roughness of Vacuum Casting model of gear

The fourth sample was Vacuum Casting model of gear wheel, made with the Schuechl VAKUUM UHG-400Easy. As a result of program processing of the measurements the following 3D-diagrams were plotted (Fig. 7).

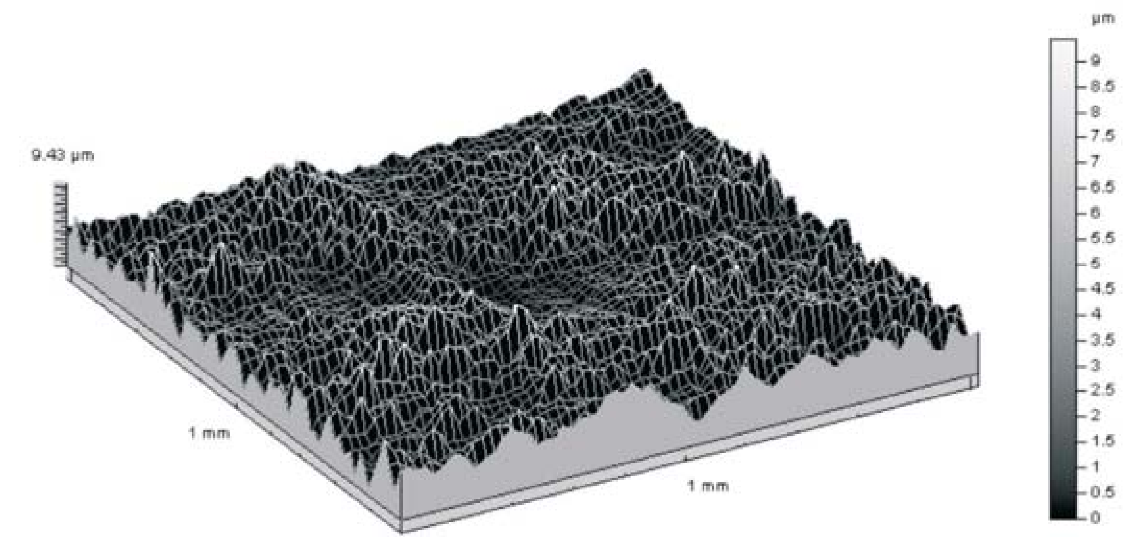


Fig. 7. Isometric view of the surface of the Vacuum Casting model of gear wheel

3.5. Surface roughness of LPI model of gear

The fifth sample was Low Pressure Injection model of gear wheel. As a result of program processing of the measurements the following 3D-diagrams were plotted (Fig. 8).

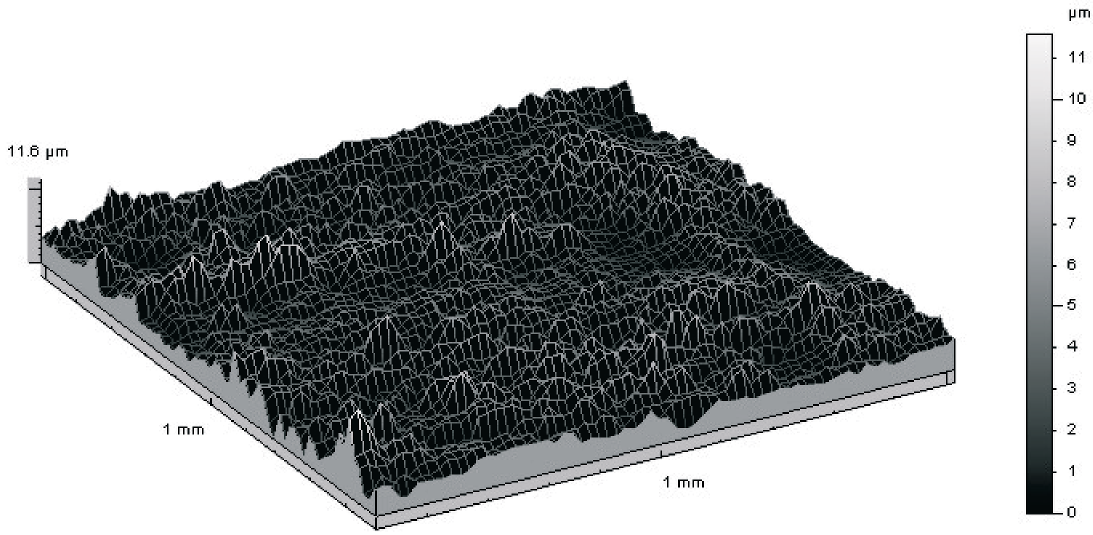


Fig. 8. Isometric view of the surface of the Low Pressure Injection model of gear wheel

4. Conclusions

The incremental methods of rapid prototyping have a surface structure characteristic for laminar structure of the model. If models have curvilinear surfaces (bevel gear), a stepped structure is an inherent feature.

Surface parameters depend on the position of the model on the platform of rapid prototyping machine. In case of bevel gear and gear wheel, the rotational axis of a gear wheel should be parallel to the vertical axis (or z axis of the machine). Such positioning ensures uniformity of manufacturing parameters of all gear wheel teeth.

Surface roughness of the model is also affected the rapid-prototyping method itself. The best surface roughness parameters are ensured by the stereolithography method. If a smooth prototype surface is required, an allowance of material should be left for finishing. A coating may also be applied on the model prior to finishing.

Machined model may serve as a master to produce a silicon matrix. Castings or moldings from such tool have a surface structure that matches the matrix or mould, and thus it matches the machined model as well.

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References

[1] Bernard, A., *Rapid product development case studies and data integration analysis*, Computers in Industry 43, pp. 161-172, Elsevier 2000.

[2] Budzik, G., Sobolak, M., *Generating Stereolitographic (STL) Files from CAD Systems*, Acta Mechanica Slovaca, 2B/2006 PRO-TECH-MA, Košice 2006.

[3] Budzik, G., Cygar, M., Sobola, M., *Dokładność odwzorowania powierzchni w opisie stereolitograficznym*, Prace naukowe Instytutu Technicznego PWSZ w Nowym Sączu, PWSZ Nowy Sącz 2004.

[4] Budzik, G., Kozdęba, D., Sobolak, M., *Wykorzystanie technologii Rapid Prototyping w odlewnictwie precyzyjnym*, Archiwum Odlewnictwa, Nr 18 (2/2), s. 207-212, Katowice 2006.

[5] Budzik, G., Markowski, T., Sobolak, M., *Hybrid foundry patterns of bevel gears*, Archives of Foundry Engineering, Vol. 7, Issue 1/2007, pp. 131-134, 2007.

[6] Bullinger, H. J., Warschat, J., Fischer, D., *Rapid product development - an overview*, Computers in Industry 42, pp. 99-108, Elsevier 2002.

[7] Cuilliere, J. C., *An Adaptive Method for the Automatic Triangulation of 3D Parametric Surfaces*, Computer-Aided Design, Vol. 30, No. 2, pp. 139-149, Elsevier 1998.
[8] Jaskólski, J., Sobolak, M., Budzik, G., *Rapid prototyping using in models building of engine elements*, Journal of KONES Internal Combustion Engines. Institute of Aeronautics, Warszawa 2004.
[9] Jee, H. J., Sachs, E., *A Visual Simulation Technique for 3D Printing*, Advances in Engineering Software 31, pp. 97-106, Elsevier 1999.
[10] Gebhardt, A., *Rapid Prototyping*, Carl Hanser Verlag, Munich 2003.
[11] Legutko, S., Nosal, S., *Kształtowanie technologicznej i eksploatacyjnej warstwy wierzchniej części maszyn*, Ośrodek Wydawnictw Naukowych PAN Oddział w Poznaniu, Poznań 2004.
[12] Oczoś, K., Liubimov, V., *Struktura geometryczna powierzchni*, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2003.
[13] Pawlus, P., *Topografia powierzchni - pomiar, analiza, oddziaływanie*, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2006.
[14] Spectrum Z510/Designmate^{TM} CX 3D Printer, User Manual Rev. X, ZCorporation 2006.