SURFACE FINISHING OF 3D PRINTED SAMPLE MANUFACTURATED BY FUSED DEPOSITION MODELING

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Currently, FDM (Fused Deposition Modelling) is one of the most widely used methods in field of functional prototypes of components creation in various industries. When using RepRap type of printing in some cases occurs to reduced quality of surface area of component that is located on a support, or complications when removing the supporting material. For low surface quality of components produced by using this technology it is necessary to adjust this surface, according to specific customer requirements.

The article deals with the problems of components surface post-treatment produced by FDM technology. Using standard machining methods with support and machining process simulation in Creo 3.0 software, by testing, cutting parameters and additional surface smoothing by acetone vapor bath method.

1   INTRODUCTION

The aim of 3D printers implementation in production is creation of complex models-prototypes, which shape creation cannot be achieved by standard methods of machining, or time-consuming production of conventional technology. 3D printing principle consists in successive application of thin films of material on a pad (heated or unheated). Print head tracks are generated by post processor, which creates them based on part 3D model. Surface quality and component accuracy itself is affected by many parameters such as diameter of printing nozzle, layer thickness, motion speed, cooling, material quality and many other aspects. At lower quality of components surface after treatment is necessary by etching, sandblasting, sealing or painting. Commonly used plastics such as PLA and ABS are durable and strong but finish is not always perfect.

The article refers to application possibilities of CNC machining equipment EMCO Concept MILL 55 and Creo Parametric 3.0 software in process of components produced by FDM technology surface finishing. This combination of standard technologies and prototype technologies points to new possibilities of parts surface finishing. [Michalik 2014]

Creo, the software itself, will enable creation of tested samples 3D models and simulation of surface finishing with subsequent post-processing of CL data to NC data for a particular processing device. [Vojtko 2014]

2   3D MODEL CONCEPT AND PRINT

2.1   3D model concept of tested component

The shape of printed sample was designed based on the effective usage of each area and possibility of selective testing of different areas surface finishing, without using multiple samples. When creating 3D model, actual sample mounting was also taken into account. Since the device has machine vice, it was designed to form part or the plain surface finishing. Figure.1 presents faces labelled 1 designed for clamping a test sample in a machinery clamp in machining process. Figure 2 presents areas, which surface will be subsequently modified. The model itself was created in Creo Parametric 3.0 software.
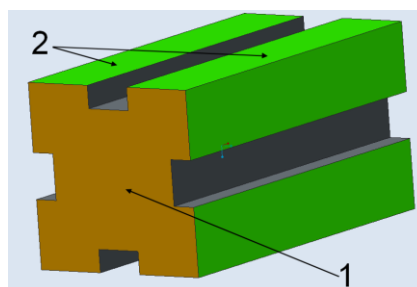

Figure 1. 3D Model

2.2   Component 3D printing

3D printing was carried out under the existing model. Preparation concerned storage model to the native format * .STL of which were subsequently worked. The sample contains intricate details; therefore it was not necessary after-treatment model before 3D printing. The post-processing of data was used Slic3r software. This tool allows distribution of model into individual layers and convert to G-code from which 3D printer can work alone. The distribution into layers and code creation is performed on the basis of selected parameters. [Teliskova 2015]
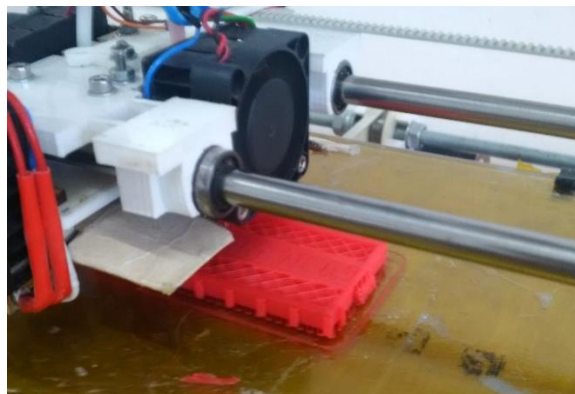

Figure 2. 3D print

Figure 3 presents a sequence of material layering when 3D printing. Individual steps marked by numbers 1-10 present building of model. Green colour represents support material, which prevents accidental collapse of material and ensures perfect shape of sample. This material will be then removed, without damaging the sample. PLA material was used. Thus formed sample is ready for further processing.
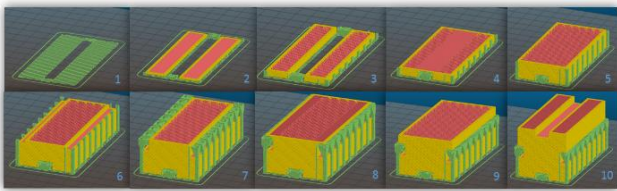
Figure 3. 3D print – layouts

Used PLA plastic is an ecological natural polymer which, after printing, creates a glossy surface. This material has inferior mechanical properties and a lower melting point, but if you have good printing setup and cooling it is possible to print acceptable details. Printing from this material may also be inaccurate, in case of materials use that had been stored in a humid environment for a long time, because PLA plastic is able to soak up moisture, which reduces material quality and caused minor flaws.

Other frequently used materials include ABS (Acrylonitrile butadiene styrene). This material and prototype parts produced from it have a wide application possibilities, according to remarkable ability to resist certain types of chemicals, temperature and humidity.

Resistance of components made by FDM from PLA or ABS is significantly better than by SL (Stereolytography) method.

Machining process was carried out on bottom layer of printed model, which may have a number of small defects that arise when applying first material layers. Figure 4 presents printed sample on a pad immediately after printing.

Figure 4. 3D printed sample

Figure 5 presents supporting material on bottom component base. This material is after printing process mechanically removed. Visibly thicker support material layer is printed in middle groove of model. This support material in center groove prevents the collapse of printed model.

Figure 5. Material support

3 MACHINING SIMULATION AND DATA POST-PROCESSING

3.1 Machining process simulation

The actual surface adjustment was performed by Emco mill55 machine. It is a 3-axis CNC milling machine designed mainly for softer materials machining such as aluminium alloy, plastic, wood and others. It has a work area 190 mm on x-axis, 140 mm

on y-axis and 190 mm on z-axis. In case of tool magazine usage the z-axis is reduced to 120 mm because it is being released from the left side of the machine towards work area.

The device allows to work in manual, automatic or editing mode with manual feed reduction during machining process. The actual device permits reduction based on percentage frequency.

Machining simulation was carried out in educational software Creo Parametric 3.0 M090. Module Manufacturing was used to perform the simulation. It enables to carry out a complete simulation of multi-axis machining with a complete set of seminifished product, zero point, machinery, tools, CL data generating and post-processing. Model presented on Figure 1 was used. Step sequence is presented on Figure 6.
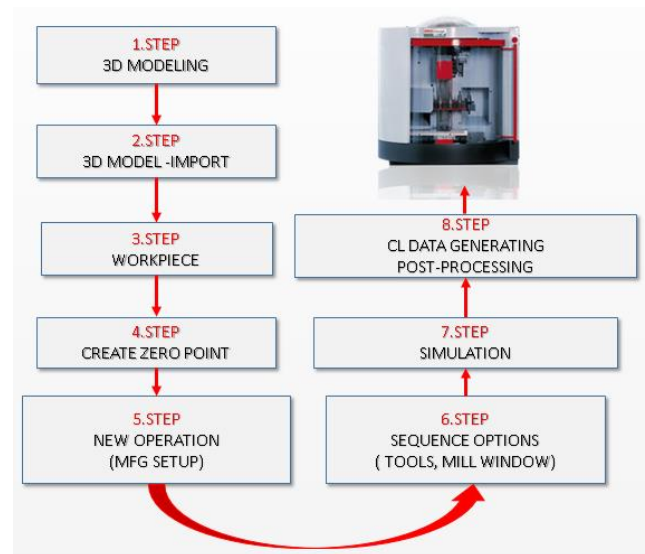

Figure 6. NC code generating step by step

To create a simulation it is required to import a 3D model used to print samples into manufacturing module and set up default path. Since the sample model was created by the same software, in which machining simulation is carried out, it is not needed to store the component itself in a native format (*.Step, *.Iges). The second step is set-semifinished product creation, on which the simulation process will be based. The software itself can insert semifinished product, during the process of formation, by correct shape and size. It is then necessary to set the additions for machining in x, y and z axes. Additions can be added on basis of main component dimensions and symmetrical, or specifically for individual dimensions.

By semifinished product creation it is enabled additional step - creating zero point through coordination system, which will be on placed there. Correct adjustment of zero point will ensure correct movement of tool to workpiece respectively semifinished product. Zero point adjustment is possible on the basis of intersection of three edges, or based on the intersection of component surfaces.

This zero point means zero point for operation which will then be created. One operation is the sum of all sequences (various operations) to be carried out within one clamping. Consequently, it is necessary to set a specific sequence - face milling. This step comes with setting up Mill window, machinery, tools, set their marks and item numbers, which will mark correction on the machine. In case of incorrect indications of tools and applications of machine program, it is necessary to modify these data manually - directly on the machine.

It is important to set mandatory cutting parameters (CUT FEED-shift in mm - min. 1, STEP OVER - pitch of two parallel lines of

successive transitions in mm, STEP DEPTH - depth of material removal in single transition in mm, CLEAR DISTANCE - separation distance of tool from material after transition over already machined layer in mm, SPINDLE SPEED- in min -1) and retract plane which defines quick-movement border. In addition to mandatory cutting parameters, the software also allows setting more specific parameters, according to user requirements. Setting parameters required to start a simple simulation - PLAY PATH. The simulation takes place in basic software environment Creo Manufacturing module. The environment is only a window that contains items and buttons designed for running simulations and editing CL data. [Baron 2013]
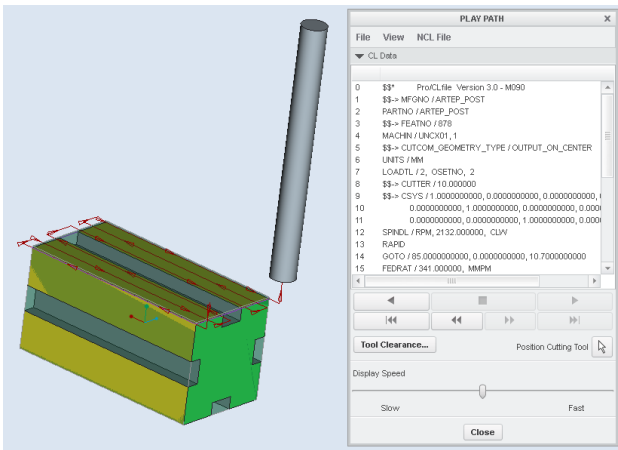

Figure 7:PLAY PATH - Simulation

This simulation allows us to look into the machining process, and optimize it. Given that simulation shows only movement of tool to the workpiece, but it does not show direct removal of material, it is necessary to use advanced simulation. For better visualization of the operation and various sequences Creo software includes integrated software tool VERICUT. It is a complex software which is useful not only for milling simulation, but also for turning.This effective tool allows not only present the advanced simulation but also removal of material. It also allows to display not only tool and workpiece, but also view of products and various fasteners. By using this tool we prevent the emergence of errors and possible accidents in the process.
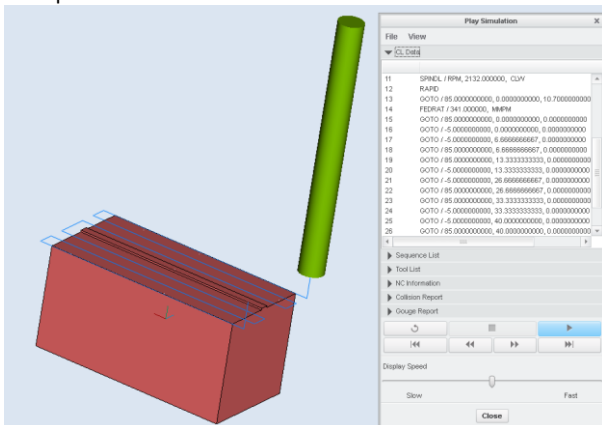

Figure 8. VERICUT - Simulation

3.2 Postprocessing of CL data

Simulation is the last step before CL data storage and subsequent post-processing of CL data to NC code. CL data can be saved separately for each operation or sequence. For OP10 operation one sequence was set up - face milling, which was

subsequently modified. For post-processing, equipment was selected, which is specifically designed and adapted for CL-conversion data transfer into NC code (G-code) applicable in EMCO mill 55 device with FANUC control system. [Stulpa 2015] Text file from NC code should be placed in the system respectively library, from which this code is then selected. Before realisation itself, it is necessary to set the reference machine. Next step is to clamp the sample, tool selection, set zero point of sample, set linear correction tool and NC code control. These operations are carried out in editor or manual mode. After machining starting, the machine operates in automatic mode and tool movements are controlled by created NC code (G-code).

Sample coating

For the machining process a standard tool - cutter HSS 10 has been selected. For this instrument, cutting conditions presented in Table 1 were selected. During the machining process major part of the experiment was carried out, by which an increase in displacement to determine the effect of displacement change on surface quality, was driven.

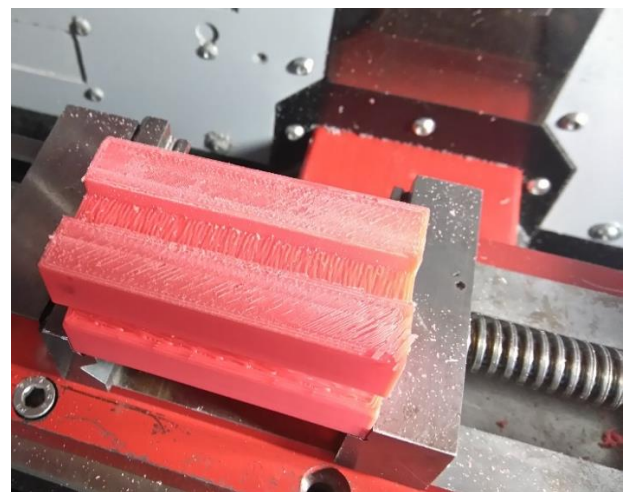| Displacement [%]	50%	60%	70%	80%	90%	100%
Displacement [mm.min^{-1}]	170.5	204.6	238.7	272.8	306.9	341
Cutting depth [mm]	0.2/0.4	0.2/0.4	0.2/0.4	0.2/0.4	0.2/0.4	0.2/0.4
Turns	2132	2132	2132	2132	2132	2132

Table 1. Cutting parameters

Figure 9. Ap-0.2mm

When printing the model, the thickness of the top and bottom layer of printed sample is determined by three times thickness of a single layer, e.g. 1.2 mm (3x0.4 mm) from top and bottom. For surface milling, thick of removed layers of 0.2 mm and 0.4 mm were selected. After removal a layer with thickness of 0.2 mm the surface was rough with remains of print string. In the process itself, individual layers were removed by reduced movement, which, however, in this case did not affect surface quality. The milling prevented melting of a plastic cord, or other undesirable phenomena on sample surface.

Subsequently, layer of 0.4 mm was taken off, same cutting parameters with movement reducing from 50% to 100% in order to identify the best cutting conditions for this type of

machining this specific material. By this method first layer of 0.6 mm thickness was removed. The best results were demonstrated when moving from 80 to 100%. The surface quality of the bottom layer finished by turning was flat surface, without remains of supporting material, but when comparing to top layer the surface was rougher.
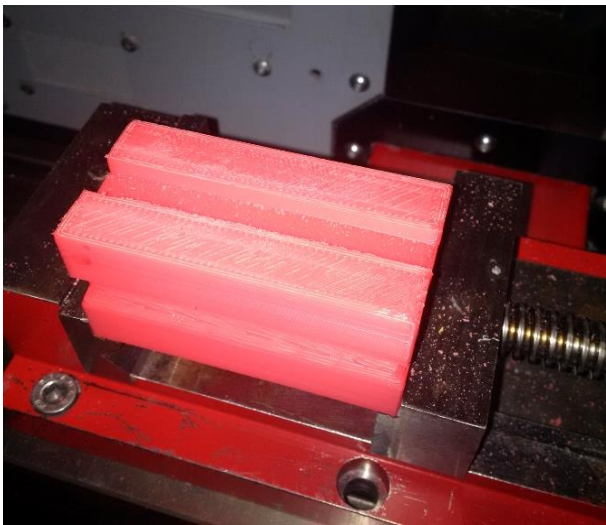

Figure 10. Ap-0.4mm

The surface can be additionally adjusted by "acetone vapor bath" method. The use of this method ensures surface uniformity and reduces roughness. Results of the application of this method are visible immediately when removing the part from acetone vapor. This way you can tune the surface to final shape. In case if this method was applied immediately after printing and mechanical removal of support material, the surface might possess a number of inequalities that are removed by milling.

When using special tools designed for working plastics we could achieve a surface that does not need after treatment. It is also necessary to apply correct cutting conditions and test them also in case of complex shaped components. This adjustment is necessary only if printed version is designed especially for activities where priority is model design and visual aspect.

Figure 11 presents the sequence of steps for experiment implementation. In first step, part surface is immediately after printing. In second step, the material was removed and then in the third step aligned with milling. In final step, the surface is after treatment in boiling acetone.
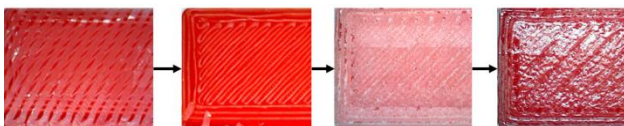

Figure 11. Surface finishing step by step

Figure 12 presents comparison of quality of each area 1 to 3. Surface no. 1 is original base surface of the sample directly after printing. Surface no. 2 is after modification by milling and then placed into vapor rich in acetone, in order to dull the surface. Last surface no. 3, is top surface of the sample, which has not undergone milling. By comparing samples no. 2 and 3, we can conclude that with such adjustment of surface, we can achieve quality of top surface of printed samples and with greater accuracy. In case of direct application of method "acetone vapor bath" it is not possible to guarantee the dimensional accuracy of manufactured component. If it contains inequalities, which lead to plastic smearing and formation of unequal ragged part relief. More appropriate is production of components with dimensional allowance for subsequent milling and finish by acetone vapor.
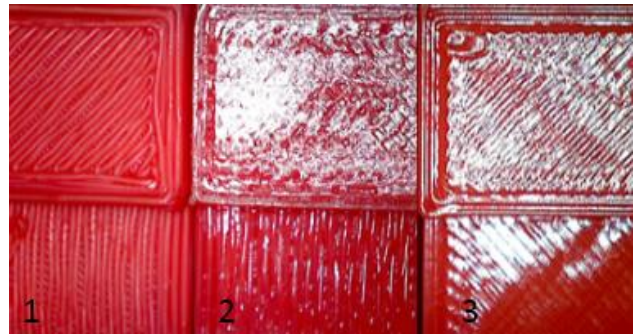

Figure 12. Surfaces comparing

4 CONCLUSIONS

3D print is one of latest technological trends currently arising in various fields. It can be used not only in engineering, but also in medicine and many other fields. Today's 3D printers offer a broad spectrum of parts, surface quality is significantly better however, the price range of quality facilities often exceeds several times the price of conventional devices available for small businesses.

It is therefore necessary to look for new ways to finish components, like FDM to adjust and achieve the desired quality approaching the quality of commercial facilities and higher price points.

Surface milling of parts produced by FDM is supporting processes in case of surface finishing of components produced using this method. This treatment is not always necessary, but it is necessary in the case of equipment whose priority is not only the visual aspect but also very accurate. To achieve the highest accuracy is required prior to printing components take into account allowances for machining. These allowances should also be considered in process of machining components simulation.

By milling we can debug minor imperfections, remove support material, smooth out the surface or milled parts which have been implemented incorrectly in printing process. When using tools and cutting conditions specified for PLA plastic, it is be possible to achieve much higher surface quality. In case of components designed for different types of visualization, model can be subsequently etched, sealed, or lacquered with various types of colours.

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