Comparison of Different Rapid Prototyping Methods

M. Stanek, D. Manas, M. Manas, J. Navratil, K. Kyas, V. Senkerik and A. Skrobak

***Abstract*—** Rapid prototyping technologies for easy production of prototypes, parts and tools are new methods which are developing unbelievably quickly. Successful product development means developing a product of high quality, at lowest cost, in the shortest time, in at a reasonable price. The development of the part and its introduction to market is time consumption process. But „time is money“ and therefore could be said that money saving is greatest when time to market is minimalized utmost. The main objective of this article is to give the basic introduction to this problematic and compare two different methods commonly used for prototype parts production. Especially cost and time consumption and final mechanical properties of the produced model.

***Keywords*—** Rapid prototyping, prototype, 3D printing, model, FDM, polymer.

I. Introduction

SUCCESSFULL product development means developing a product of high quality, at lowest cost, in the shortest time, in at a reasonable price. The development of the part and its introduction to market is time consumption process. But „time is money“ and therefore could be said that money saving is greatest when time to market is minimalized utmost.

On principle, the conventional model making processes based on two-dimensional (2D) drawings. The rapid prototyping process is based on complete 3D models. The 3D geometric information from the CAD is split into layer information and the layers are gradually built directly with the aid of the computer. The advantage of the rapid prototyping technologies is the part building possibility using 3D CAD data only. All process by which 3D models and components are produced additively, that is, by fitting or mounting volume elements together (voxels or layers) are called generative production process.

Rapid prototyping describes the technology of generative production processes. The application of rapid prototyping technology lays in solid imagining and functional prototyping. Prototypes are made from plastics (mainly ABS, PVC or special resins, metals or other materials that simulate one or more mechanical or technological functionalities of the final serial component). Often use word Rapid tooling describes a principles and technologies for tools and molds preparation. These prototypes are used for production of prototypes and preseries products. The rapid tooling uses the same processes as those used in rapid prototyping. Rapid manufacturing represent such a rapid prototyping applications that produce products with serial character. For these purposes can be used most of rapid prototyping methods. But the mechanical and other properties of materials used for the rapid prototyping do not reach mostly the characteristics of the serial final products. [1-3]

II. Principles of Rapid prototyping

Rapid prototyping belong to the additive production processes. In contrast to abrasive processes such a milling, drilling, grinding eroding etc. in which the form is shaped by material removing, in rapid prototyping the part is formed by joining volume elements. Most of used rapid prototyping processes work with layers where single layers are produced and joined to a final geometry. On principle, rapid prototyping processes are two and half D processes, that is tacked up 2D contours with constant thickness. But for layer creation 3D model is necessary.

Rapid prototyping as the generative manufacturing processes are divided among two fundamental process steps:

- generation of the mathematical layer information,
- generation (production) of the physical layer model.

Industrially are used many types of rapid prototyping systems working on different physical principles:

- solidification of liquid materials (polymerization process),
- generation from the solid phase:
    = cutting from foils or paper (LOM),
    = binder of powder or granules,
    = powder sintering,
- generation form the pasty phase.

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The basic methodology for all current rapid prototyping techniques can be summarized as follows:

- A CAD model is constructed then converted to STL file format. The resolution can be set to minimize stair stepping.
- The RP machine software processes the .STL file by creating sliced layers of the model.
- The first layer of the physical model is created. The model is then lowered by the thickness of the next layer, and the process is repeated until completion of the whole model.
- The model and any supports are removed. The surface of the model is then finished and cleaned. [11]

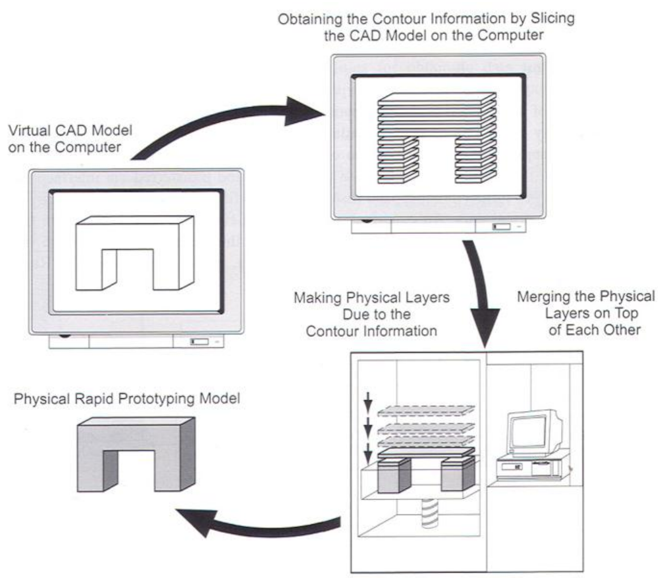

Fig. 1 Rapid prototyping principle

A. Fused deposition modeling (FDM)

Extrusion process is based on melted polymer which is extruded from nozzle system (extrusion die) and deposited geometrically defined onto a structure. FDM begins with a software process, developed by Stratasys, which processes an STL file (stereolithography file format) in minutes, mathematically slicing and orienting the model for the build process. If required, support structures are automatically generated. The machine dispenses two materials – one for the model and one for a disposable support structure. FDM works on an "additive" principle by laying down material in layers. A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism The materials are deposited in layers as fine as 0,127 mm thick (usually 0,17; 0,25, 0,35 mm) and the part is built from the bottom up – one layer at a time. As building materials are used different types of polymers (ABS, PC, etc.). [5, 9]

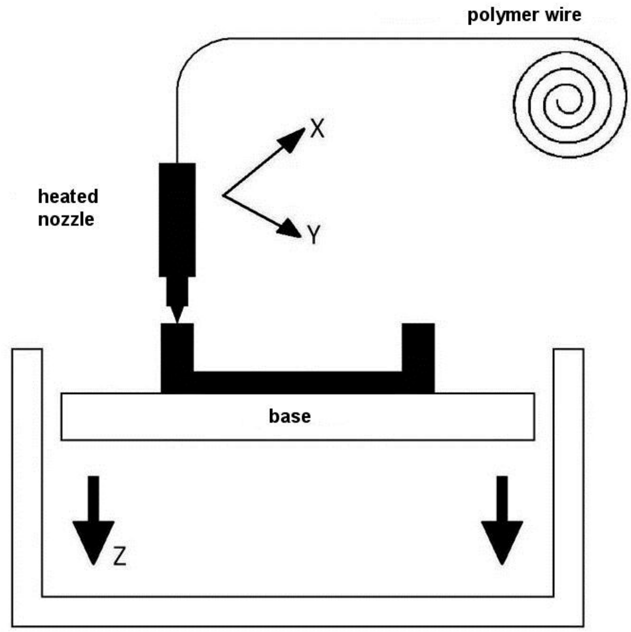

Fig. 2 Basic principle of Fused Deposition Modeling (FDM) method

Fig. 3 Stratasys Dimension SST 768

Table 1 Basic technical parameters of Stratasys SST 768

Printer dimensions [mm] (L x W x H)	686 x 914 x 1041
Printer weight [kg]	136
Working space [mm] (X x Y x Z)	203 x 203 x 350
Production space [mm] (X x Y x Z)	200 x 200 x 250
Layer thickness [mm]	0,254 or 0,33
Resolution [mm]	X axis – 0,1 Y axis – 0,1 Z axis – 0,5
Build material	ABS
File format	STL

B. 3D printing (PolyJet)

3D printing is very often used rapid prototyping method. The principle is very similar to 2D printing process of inkjet pointer. The injected material is a polymer which after cooling forms the required layer or binder which bonds powder particles. PolyJet Technology is a new Rapid Prototyping process that provides a quick turnaround for smooth, fully cured parts. The process consists only of UV bulbs and photopolymer materials. PolyJet machines fully cure each layer of super fine UV photopolymer and support materials as eight jetting heads precisely deposit the product. Support material is easily separated from the part by either a water jet or hand and brush. No special baths or extra finishing treatments are needed. The small-footprint, exceptionally cost effective system uses a completely clean process, making it ideal for standard office environments. The materials are deposited in layers as fine as 0,016 mm thick (optionally 0,032 mm). [6-8]

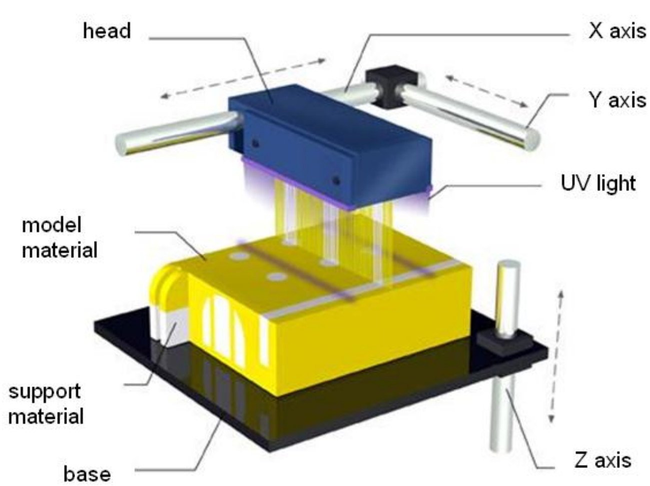

Fig. 4 Basic principle of 3D printing method (PolyJet)

Fig. 5 OBJET EDEN 250

Table 2 Basic technical parameters of Objet Eden 250

Printer dimensions [mm] (L x W x H)	870 x 735 x 1200
Printer weight [kg]	280
Working space [mm] (X x Y x Z)	260 x 60 x 200
Production space [mm] (X x Y x Z)	250 x 250 x 200
Layer thickness [mm]	HQ (High Quality): 0,016 HS (High Speed): 0,032
Resolution [dpi]	X axis – 600 Y axis – 300 Z axis – 1600
Build material	VeroWhite
File format	STL or SLC

III. EXPERIMENT

The mechanical properties, surface quality of prototypes and final cost with time of part building have been tested in comparison of both methods. Two machines has been used for the testing sample preparation: Stratasys Dimension SST 768

(FDM method) and Objet Eden 250 (3D printing method – PolyJet).

A. Mechanical properties – tensile test

Five different methods have been used for the tensile testing sample production: 3D printing, injection molding (ABS) and three types from FDM (with horizontal, vertical and longitudinal orientation of layers).

A tensile test of the samples has been done by the standard CSN EN ISO 572-2 on the testing equipment tensile tester ZWICK 1456 (Fig. 6). The best mechanical properties in tensile test can be seen on samples produced by 3D printing method, see Table 3.

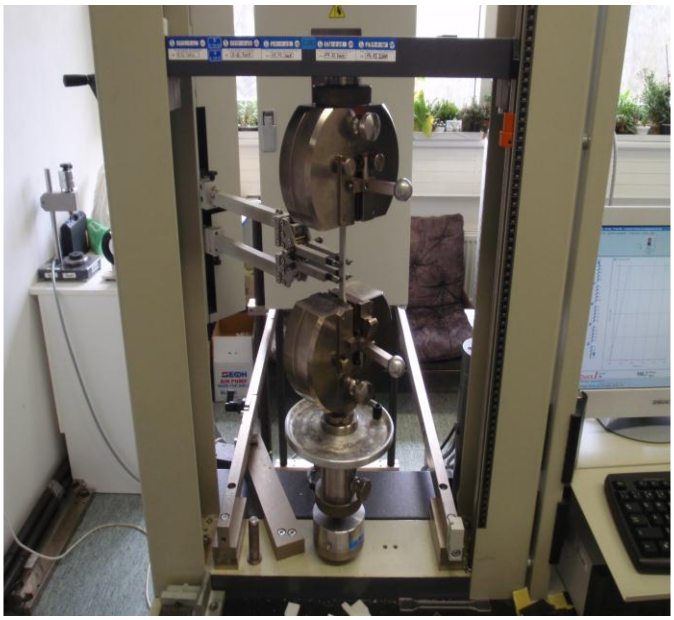

Fig. 6 Tensile tester ZWICK 1456

Fig. 7 Testing sample (for tensile tests) production (3D printing - PolyJet)

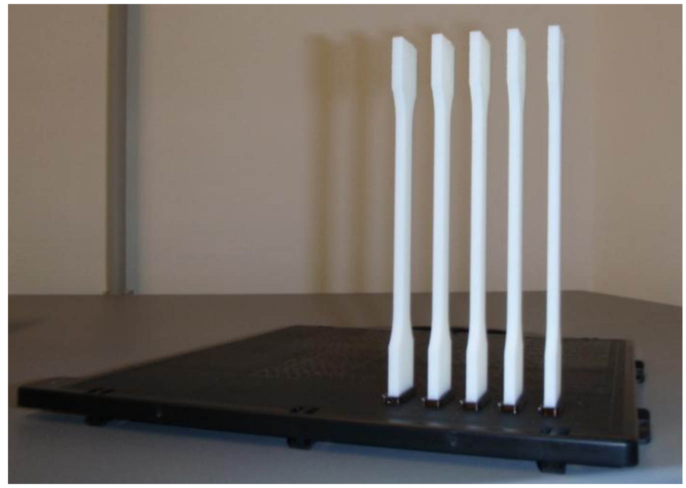

Fig. 8 Testing sample (for tensile tests) production (FDM – vertical position)

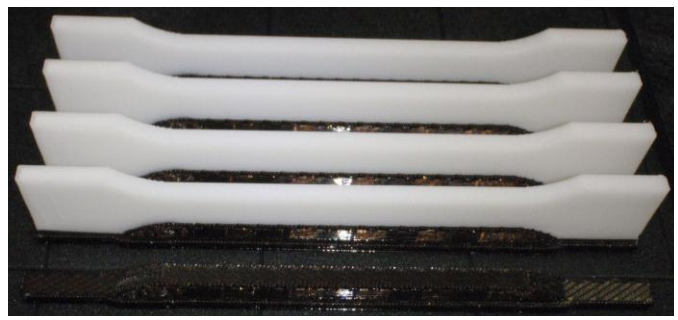

Fig. 9 Testing sample (for tensile tests) production (FDM – longitudinal position)

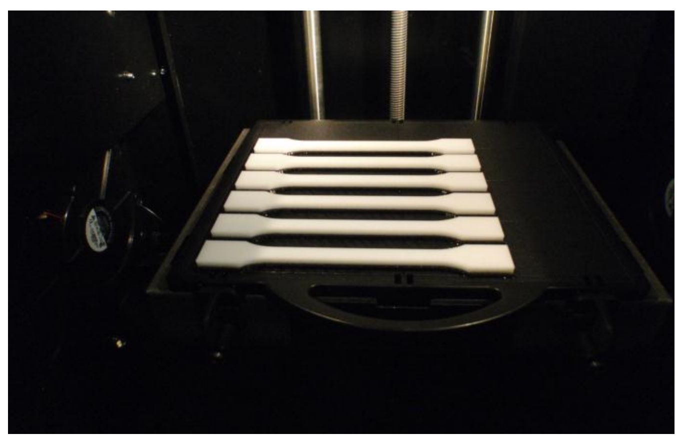

Fig. 10 Testing sample (for tensile tests) production (FDM – horizontal position)

The best results can be seen on samples prepared by 3D printing (PolyJet) technology where does not matter on the direction of the printed sample. In the case of samples prepared by FDM technology has the best results horizontal position (Fig. 10) of the testing samples.

Fig. 11 Testing sample (for tensile tests) production (Injection molded by Arburg Allrounder - ABS)

Table 3 Tensile test results

Method of sample preparation	σ [MPa]	A [%]	E -modulus [MPa]	Rb [MPa]
3D printing	1,37	5,75	1836	33,96
Injection molding	0,64	2,75	2302	26,31
FDM – horizontal	0,40	2,98	1774	20,03
FDM– longitudinal	0,49	2,71	1271	10,22
FDM – vertical	0,21	1,53	1631	19,31

B. Mechanical properties – impact test

Five different methods have been used for the impact testing sample production (same as for testing test): 3D printing, injection molding (ABS) and three types from FDM (with horizontal, vertical and longitudinal orientation of layers).

Fig. 12 Impact tester CEAST Resil Impactor Junior

An impact test of the samples has been done by the standard CSN EN ISO 148-1 on the testing equipment Charpy hammer CEAST Resil Impactor Junior (Fig. 12). The best mechanical properties in inpact test can be seen on samples produced by 3D printing method, see Table 4.

Table 4 Impact test results

Method of sample preparation	F_{MAX} [N]	F_B [N]	A [kJ/m^2]	e_B [mm]
3D printing	361,70	13,26	4,49	0,90
Injection molding	611,41	34,16	24,10	3,45
FDM – horizontal	384,80	34,16	14,15	2,85
FDM– longitudinal	444,03	103,98	22,81	4,35
FDM – vertical	119,23	0,84	0,79	0,41

C. Total costs production and time consumption

The special parts designed for this test has been used (Fig. 13 and Fig. 14). The comparison of both methods is described in the table 4 and table 6. There is shown differences between clear time printing, other time (calibration, pre-heating, part cleaning, etc.) and costs of part production (material, machine time, etc.) in percentage.

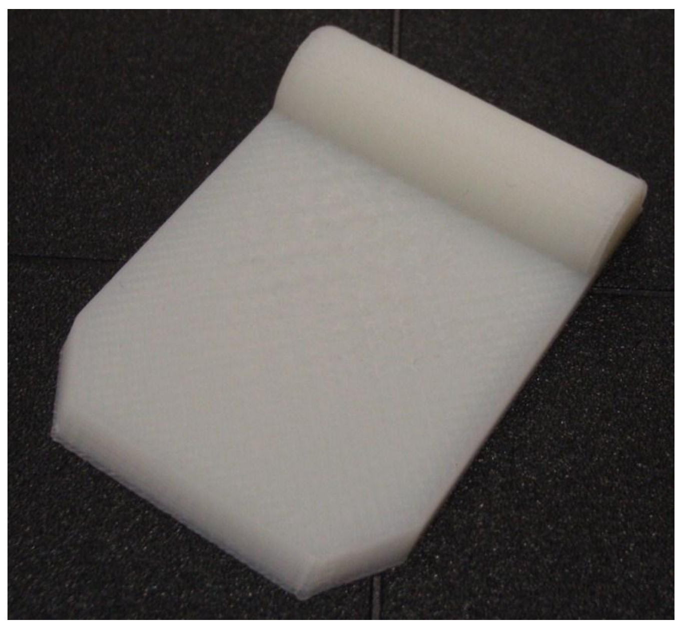

Fig. 13 Special testing part

Table 5 Total costs production and time consumption

Method of part reparation	Print time [min:s]	Other time [min:s]	Total time [min:s]	Cost [%]
3D printing	35:12	06:28	41:40	100
FDM	22:00	29:07	51:07	106,6

The FDM method is faster in case of one model production because of bigger building layer (FDM – 0,254 mm vs. 3D printing – 0,032 mm). On the other hand the 3D printing method is faster in case of more than one part production if the lay in one row on the working plate (width of the printing head). Total costs for the testing parts production was similar in both cases.

Table 6 Time needed for multi part production

Number of models	OBJET EDEN 250 [h:min:s]	DIMENSION SST 768 [h:min:s]	Time diff. [h:min:s]
1 model	0:35:00	0:22:00	-0:13:00
3 models	0:42:00	1:06:00	+0:24:00
5 models	1:24:00	1:51:00	+0:27:00

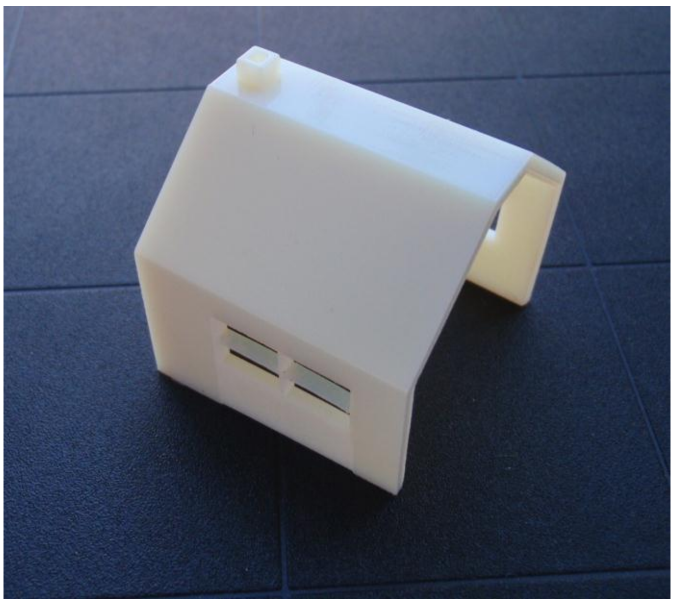

Fig. 14 Special testing part - house

The FDM method is faster in case of one model (model of house) production because of bigger building layer (FDM – 0,254 mm vs. 3D printing – 0,032 mm). Similar results as in the previous case. On the other hand the 3D printing method is faster in case of more than one part production if the lay in one row on the working plate (width of the printing head). Total material costs for the testing parts production was similar in both cases.

Table 7 Total costs production and time consumption - house

Method of part reparation	Print time [h:min:s]	Other time [h:min:s]	Total time [h:min:s]	Cost [%]
3D printing	4:52:02	0:33:36	5:22:38	100
FDM	2:35:10	3:06:50	5:42:00	104

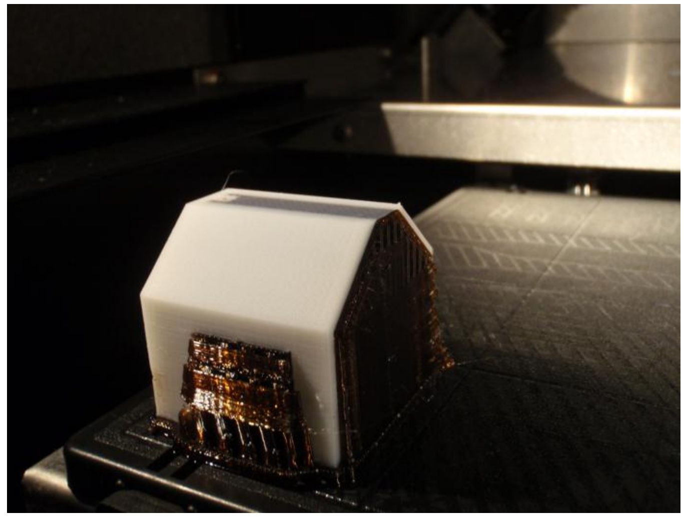

Fig. 15 Special testing part – house after building including support material (the darker one)

Table 7 Time needed for multi part production - house

Number of models	OBJET EDEN 250 [h:min:s]	DIMENSION SST 768 [h:min:s]	Time diff. [h:min:s]
1 model	4:52:00	2:35:00	2:17:00
3 models	5:18:00	8:01:00	2:43:00
5 models	6:01:00	13:23:00	7:22:00

Software of both machines are intuitive, easy to use and user friendly. The name of the control software is Catalyst in case of Dimension SST 768 (FDM) and Objet Studio in case of Objet Eden 250 (3D printing – Polyjet) – example can be seen on Fig. 16 and Fig. 17.

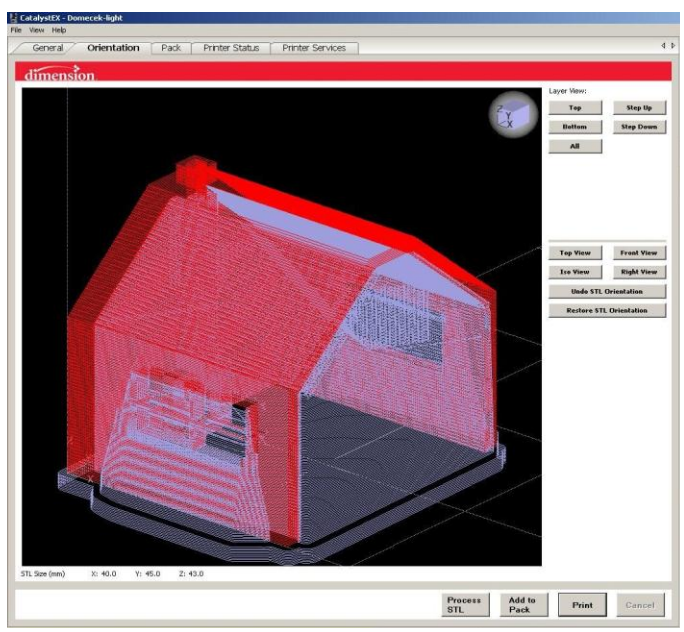

Fig. 16 Working desktop of SW (FDM)

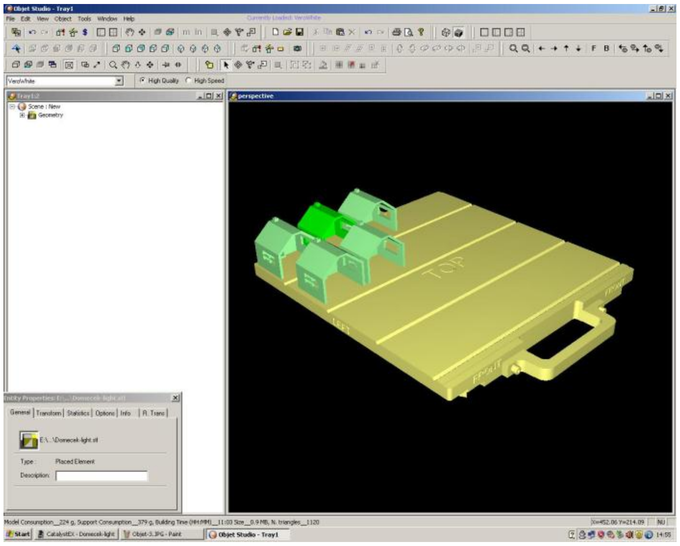

Fig. 17 Working desktop of SW – 5 models (3D printing)

D. Surface quality

Final surface quality of prototypes is one of the most important factors which can approach prototyped part to real part. It is specifying by the maximum layer thickness an orientation of part to base during its production (3D print layer: 0,016 mm; FDM layer: 0,254 mm). The next figure (Fig. 19) shows the difference between final surface quality of the testing part (without any finishing technology, just after support material removal). Photos has been done by special optical device ProScope HR BODELIN. The zoom of both photos is 30 times.

Fig. 18 Optical device ProScope HR BODELIN

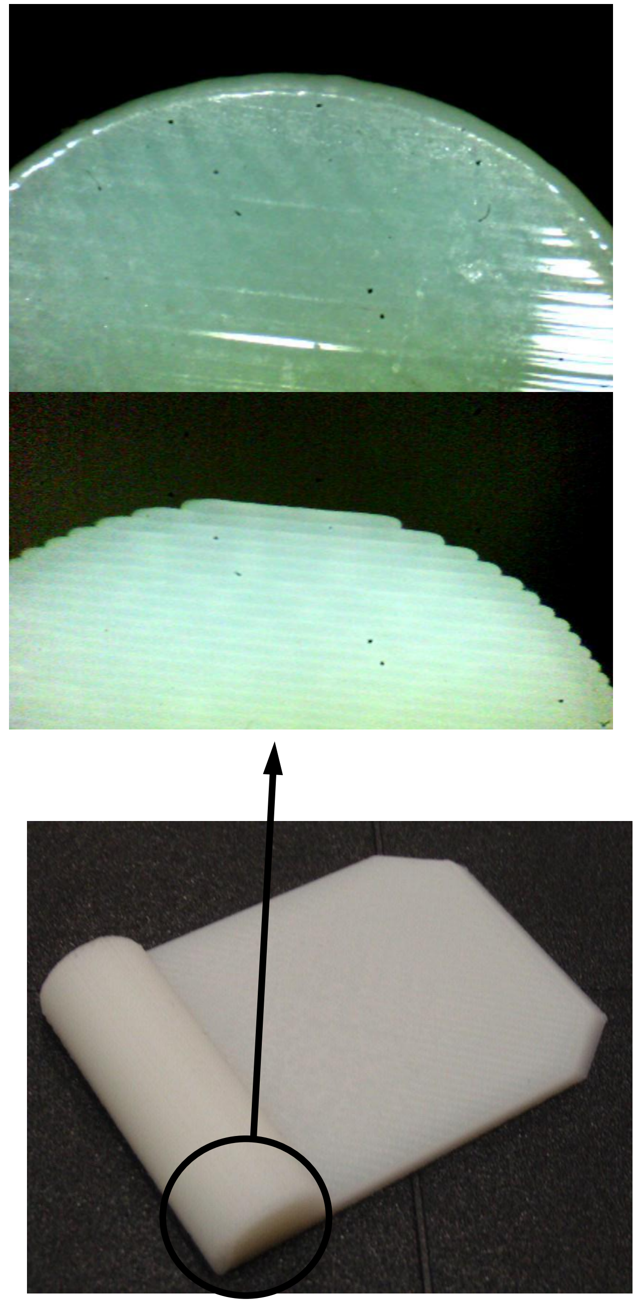

Fig. 19 Testing sample – upper from 3D printing, below – from FDM

IV. CONCLUSION

Rapid prototyping method is very useful tool which can accelerate the way of product from the idea to market. Generative principle of rapid prototyping methods enables to produce parts of any geometry. These processes are practically unlimited in their ability to form complex shapes, they can produce both positives (parts) and negatives (dies and molds). The final conclusion of differences between mentioned methods is better for 3D printing because of shorten time, lower costs and better surface quality of part. On the other hand there are higher purchase costs of machine.

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