Journal of Machine Engineering, Vol. 9, No. 1, 2009

rapid prototyping (RP),
3D printing, product development,
performance of rapid manufacturing

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INCREASING OF RAPID PROTOTYPING PERFORMANCE BY 3D PRINTING TECHNOLOGIES

Rapid prototyping (RP) is being recognised as a significant technology for future product development. One of the most effective RP technologies is 3D printing. A three dimensional object is created by layering and connecting successive cross sections of material. Therefore this new RP methodology is generally faster, more affordable and easier to use than any other additive fabrication technologies. This paper analyses performance of RP methods and compares these based on use-cases. Prototypes of casing type details have been created using different RP technologies. Productivity of product development process and 3D printing has been investigated. A problem in differences between physical prototypes compared to existing computer model (digital prototype) can be diminished by using comparative pre-testing. Case studies of increasing innovation capacity in development of casing type details have been analysed. In addition, suggestions for increasing innovation capacity and performance of rapid manufacturing have been made.

1. INTRODUCTION

Previous means of producing a prototype typically took man-hours, many tools and skilled labour. For example, after a new street light luminary was digitally designed, drawings were sent to skilled craftsmen where the design on paper was painstakingly followed and a three-dimensional prototype produced in wood by utilizing an entire shop full of expensive wood working machinery and tools. This typically was not a speedy process and costs of the skilled labour were not cheap. Hence, there was the need for developing a faster and cheaper process to produce prototypes. As an answer to this need, rapid prototyping (RP) was born in the late 1980s and was successfully used to produce models and prototype parts [1]. Since the late 1980s the rapid prototyping has evolved from a tool for making factory moulds and dies to a low-volume technique for making finished parts, even consumer product prototypes [2]. The rapid prototyping technologies are now

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evolving toward rapid tooling. The reasons for this extension are found in the need to further reduce the time-to-market by shortening not only the development phase, but also the industrialization phase of the manufacturing process [5].

Nowadays many different RP methods are available. In this study three different RP methods have been used in order to investigate which of these is more effective for rapid prototyping in product development process.

The challenge how to stay competitive in the market(s) is still a question mark for many enterprises. The products have various functional requirements, whereas product cost, quality and time-to-market are the main key-factors in product development. The product development cycle time for almost all products has steadily decreased over the years and the quality and cost relation has been getting better [6]. Enterprises using 3D prototypes have found that the opportunity for 3D printing enables them to produce three-dimensional “form-and-fit” concept models, which are primarily used for visualizing and communicating early product design. Such approach enables quick “print” and fast presenting the prototype to marketing people and to toolmakers. Therefore the rapid prototyping method – 3D printing shortens the product development time and accelerates the time to the market. Significant savings in cost and time can be achieved using rapid prototyping (RP) by manufacturing multiple parts in a single setup to achieve efficient machine volume utilization [4].

In this paper main 3D printing methods have been analysed for rapid manufacturing of housing type details. Comparative tensile strength analysis has been used for creating criteria.

2. THREE-DIMENSIONAL PRINTING TECHNOLOGIES

Three different RP machines used in case studies have been investigated and described in more detail. The following RP machines/technologies were investigated: Zprinter 310 based on Inkjet Printing Technology (IPT), Dimension SST 768 based on Soluble Support Technology (SST) and Formiga P 100 based on Plastic Laser Sintering Technology (PLST).

The IPT is based on the use of a vertically moving bed of powder onto which layer by layer of binder material is printed. When a layer is complete, a roller moves across the surface of the already built layer and deposits another layer of virgin powder. As each layer is added, the model’s form is built-up layer by layer within the powder bed [3]. Once complete, the build platform can be moved up and the model covered with the strengthening liquid and dried in dryer.

The SST is also printing layer by layer, but using melted wire instead. The difference is also in after-treatment following the printing process. In case of SST, designer removes the model from the 3D printer and places the model into an SST station. The SST station is an agitation system that utilizes hot water and a soap bath to automatically wash away the support structures. Therefore the final shape for the prototype will be given with the after-treatment in SST station. In case of inkjet printing the after-treatment means printed detail strengthening and drying process.

PLST involves fabrication of a physical model by the selective melting of powdered material layer by layer. The process uses a fine powder which is heated with a CO2 laser so that the surface tension of the particles is overcome and they fuse together. Before the powder is sintered, the entire bed is heated to just below the melting point of the material in order to minimize thermal distortion and facilitate fusion to the previous layer.

3. PROTOTYPING

Different prototypes were made by using the following RP technologies: IPT, SST and PLST. The objective was to compare the RP technologies based on the following criteria:

- uncertainty of arithmetic mean of printing results
- speed of printing
- quality of printing (need for mechanical after-treatment)
- preparatory works (e.g. 3D models created need to be carried into stereo lithography tessellation language (STL) model)
- physical properties of materials used choice of materials

The uncertainty of arithmetic mean of printing is one of the most important factors because of the dimensional problems with developed prototypes. In many cases it has occurred that the prototype made with 3D printing has differences in physical and virtual dimensions. Therefore the after-treatment is often necessary increasing the product development time could be increased. Consequently, in order to prevent such bottlenecks, it is necessary to know the uncertainty of arithmetic mean of printing. If designers know the possible deviation, they could change the dimensions of details in virtual prototyping process before printing and the after-treatment could be avoided. In that reason, the test prototypes were measured with coordinate measurement machine TESA Micro-Hite 3D and uncertainties of arithmetic mean of printing were made comparable for the used RP technologies.

3.1. CASE STUDY OF SMART DUST HOUSING PROTOTYPING

At first smart dust housings detail prototype was made. Distributed computing solutions based on miniature computing devices called ”smart dust” or motes were introduced in the beginning of the current century.

The sensors are integrated into small sized boards and equipped with small sized accumulators. Autonomous power supply and wireless communication interface makes the deployment of these systems simple, relatively cheap and fast. Integration with existing equipment is quite easy. To realise the network suitable for machinery workshop environment all smart dust pieces had to be protected with developed test housings.

The smart dust housing details were printed with Zprinter 310 (using IPT) and Dimension SST 768 (using SST). Those two printing technologies were compared.

The Dimension SST (Soluble Support Technology) produces the high-quality ABS models. The difference is that Dimension SST features an automated support removal process. The designer removes the model from the system and places the model into an SST station. An SST station is an agitation system that utilizes hot water and a soap bath to automatically wash away the support structures. There was no need for mechanical after-treatment. In addition, the coordinate measurement machine TESA Micro-Hite 3D was used for measurement dimensions (see Fig. 1) and determining the uncertainties of arithmetic mean of printing results.

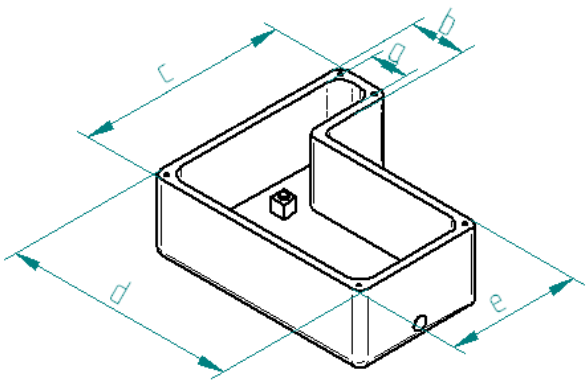

Fig. 1. Measured dimensions of “smart dust” in comparative 3D printing

The results are presented in the Table 1.

Table 1. Uncertainties of arithmetic mean of printing results in the case of “smart dust” in mm

Dimension ID	CAD dimension	Uncertainties of arithmetic mean of printing results	
		IPT	SST
a	13.0	0.06	0.01
b	19.0	0.33	0.10
c	72.0	0.32	0.81
d	80.0	0.22	0.03
e	46.0	0.31	0.91

It was turned out that the uncertainties of arithmetic mean of SST printing results were bigger in case of dimensions c and e. It makes reference to the circumstances that SST printing uncertainty is greater in one direction (c, e) printing and smaller in other direction (a, b, d).

In the time-saving point of view, the inkjet printing technology enabled to print the smart dust housing with 1 hour 10 minutes, SST printing with 3 hours 23 minutes.

3.2. CASE STUDY OF RFID READER HOUSING PROTOTYPING

The second case of the study concerns development of casing type details of Radio Frequency Identification (RFID) reader. The main goal of the device is to monitor (independently from process control) the real usage of machines, tools and half-finished products during manufacturing cycle. The aim is to improve the productivity and simplify the resource sharing.

Physical prototypes were made by 3D printing technology using the Zprinter 310 (using IPT) and Formiga P 100 (using PLST).

To make the prototype, all 3D models were created with Solid Edge and transferred into stereo lithography tessellation language (STL) model. That process enabled to transmit the Solid Edge models into the printers working programs for the 3D printing.

The uncertainties of arithmetic mean of printing were in both cases (IPT and PLST) investigated. Measured dimensions of RFID reader housing are shown in the Fig. 2 and the measuring results are presented in the Table 2.

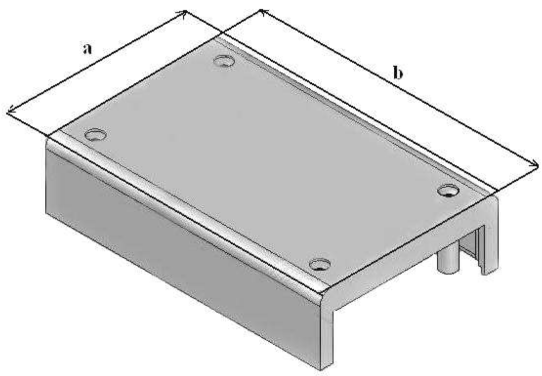

Fig. 2. Measured dimensions (a,b) of RFID housing in comparative 3D printing

It occurred that in case of Zprinter the uncertainty of printing was greater in both directions (a, b). Compared the Zprinter with Dimension SST 768, the first ones uncertainty was greater in directions a, b and d. It shows that the uncertainty of printing is mostly worst in case of Inkjet printing technology. It would be also interesting now to compare the PLST with SST and find, which of them could have the smallest uncertainties of arithmetic mean of printing results.

Table 2. Uncertainties of arithmetic mean of printing results in case of RFID reader in mm

Dimension ID	CAD dimension	Uncertainties of arithmetic mean of printing results	Dimension ID
		IPT	PLST
a	96	0.78	0.37
b	174	0.43	0.18

Comparison of the results of 3D printing technologies is presented in the Table 3. Obviously the printing time is smallest with Zprinter, it is not good idea to use it in case of high accuracy requirements because of the biggest uncertainties of arithmetic mean of printing results. As preparatory works were needed with all three printers, the most annoying after-treatment has been needed in the case of IPT. However, the PLST needs only the cooling after the printing process, any after-treatment was not needed.

Table 3. Comparison of RP technologies (IPT, SST, PLST)

Estimation criteria	3D Printing technology (including printer name)		
	Inkjet Printing Technology (Zprinter 310)	Soluble Support Technology (Dimension SST 768)	Plastic Laser Sintering Technology (Formiga P 100)
Uncertainties of arithmetic mean of printing results	Compared IPT with SST in one direction (a, b, d) the IPT uncertainties of arithmetic mean of printing results is bigger than another directions (c, e)		
	Compared IPT with PLST the IPT uncertainties of arithmetic mean of printing results is much bigger than in case of PLST		
Speed of printing	1 hour 10 minutes (smart dust housings detail) not including: - covering with glue - drying with compressed air	3 hours 23 minutes (smart dust housings detail) not including: - SST Station	
	30 minutes (RFID reader housings detail) not including: - covering with glue - drying with compressed air - mechanical treatment		8 hours and 6 minutes (RFID reader housings detail) not including: - cooling
Quality of printing	poor	good	excellent
Preparatory works	3D model into STL model; details optimal setting	3D model into STL model	3D model into STL model; check over of details
After-treatments	need for mechanical after treatment (polish and file of details)	SST Station for automatically wash away the support structures	-
Cost of prototype	low	low	high
Cost of printer	low	average	high
Choice of materials	Fine powder and special glue (Cyanoacrylate (Z-Bond 101))	Fine powder and molten polymer	Fine powder

4. TENSILE STRENGTH ANALYSIS

The physical properties of the materials used in three-dimensional printing were unknown. Several tests were conducted to find out the modulus of elasticity, elongation, tensile strength of the material and how infiltrating the part with z-Bond resin affects these properties. Physical properties of the part depend on the level of attrition on the printing head, bonding material, orientation of the part during printing and how the part is post processed. The shape shown on Fig. 3 of the test specimen was identical to the ones used in steel or aluminium tensile tests [7]. Twenty test specimens were printed on b Zprinter 310 (IPT) and Formiga P 100 (PLST). The test specimen printed using IPT were divided into four groups. First group of test specimen was orientated in an upright position and had no post processing. Second group was orientated horizontally and had no post processing. Third group was oriented in an upright position but were infiltrated with z-Bond resin. Fourth group was orientated horizontally and were also infiltrated with z-Bond resin. Test specimen printed using PLST were divided into 2 groups because they do not need post processing. First group was oriented in an upright position and the second group was positioned horizontally.

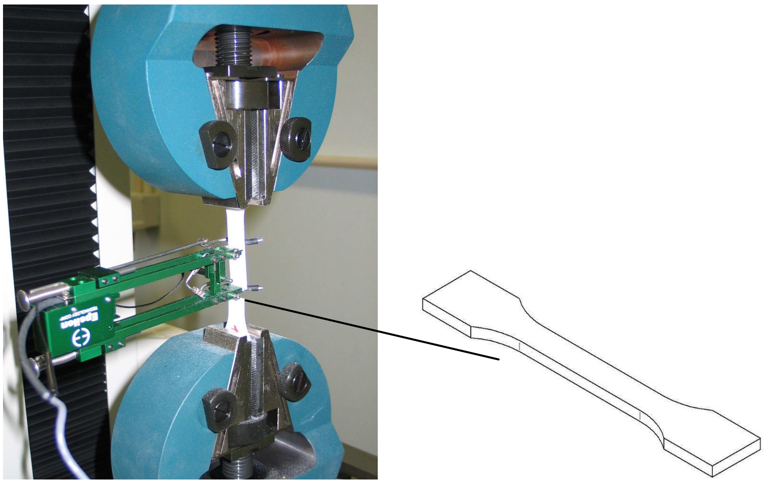

Fig. 3. The test specimen and its measurement set-up

Knowing the tensile strength of the material allows calculating stress values in the printed part. This in turn would mean the possibility to add or remove material from less stressed places of the part thus optimizing the printing process and the part itself. The results varied greatly between the different groups of test specimen.

The groups printed using IPT that had post processing with z-Bond resin (groups 3 and 4) had higher tensile strength. The average tensile strength was higher by 5.7 MPa (825%) then the groups with no post processing. Elongation was higher in groups 3 and 4, by 0.45 % (325%). As result shows, part orientation during printing and post processing are essential.

The groups printed using PLST had no post processing so they can only be compared with the first two groups of IPT. Tensile strength of materials is substantially higher, on average 50.8 MPa (4700%) and elastic elongation by 13.1% (on average), that is 130 times higher then on IPT.

Table 4. Test results

	IPT			PLST		
	Force (N)	Tensile strength (MPa)	Elastic elongation (%)	Force (N)	Tensile strength (MPa)	Elastic elongation (%)
	Upright positioning, no post processing					
Average	21.3	0.591	0.109	2025	50.6	9.80
	Horizontal positioning, no post processing					
Average	58.2	1.617	0.091	2210	53.2	16.63
	Upright positioning, post processed					
Avarage	271.1	7.532	0.261			
	Horizontal positioning, post processed					
Average	218.4	6.066	0.391			

Comparing groups with post processing, group three had better results then group four. The reason for it is that group 3 specimens had more layers. Resin infiltrates deeper into the part between the layers, thus creating a stronger part. The downside of more layers is that the surface roughness in higher and in some cases unusable because the part has to look esthetic and presentable. This can be resolved by sanding the surface but this in turn will reduce the accuracy of the part.

The tests show that most of the IPT part's strength comes from the resin. The level of resin infiltration depends on the powder and positioning of the part. Resin infiltrates deeper into the part, when it is positioned upright in the building area. This means, by right positioning and taking into account the resins properties, modifications to the parts can/should be made.

PLST on the other hand had more consistent results. Tensile strength was affected but not by much by changing the orientation of the parts. Elastic elongation was lower on the parts in upright position because the pulling force was perpendicular to the layers direction.

5. CONCLUSION

Case studies have realized by investigating 3D printing technologies. Based on investigation of IPT, SST and PLST rapid prototyping technologies, the following implications have been done.

First of all, it is possible to avoid the differences between physical prototypes compared to existing computer model (virtual prototype). In order to avoid the situation, that the printed 3D detail is not the same as it was expected. It is good to know the uncertainty of arithmetic mean of printing results. It gives for the designers and engineers the possibility to minimize the details dimensions before the printing process.

It is possible to save the time in product development phase, if the printing time of prototype and the preparatory and after-treatment works could be known before the prototyping. It is really important to know, how much time is going on to the preparatory and after-treatment works. On the assumption of that designers and engineers could know, which of those printing technologies they could prefer.

It is possible to make preliminary calculation for prototyping, in case the developers could know what is the price of printer and prototype; which materials are needed for 3D printing; how available are these materials in markets.

Positioning the parts during printing (IPT) affects greatly the physical properties of the parts. Upright positioning with post processing increases the maximum tensile strength about eight times and elastic elongation about three times.

Using PLST, positioning the parts affects only the elastic elongation. It is increased about two times by positioning the part horizontally compared to upright positioning. The tensile strength and elastic elongation are substantially higher in PLST then in IPT.

ACKNOWLEDGEMENT

This research was supported by the Estonian Ministry of Education and Research Project SF0140113Bs08.

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