# Experiment on production time for model creation on small Fused Deposition Modeling device

Juraj Beniak, Peter Križan, Miloš Matúš, Ľubomír Šooš

***Abstract*—**The production time is one of very important parameters which can influence the whole economic profit in production process. Also in case of Rapid Prototyping we are interesting in time for which we are able to produce the prototype parts. The Rapid prototyping systems are also in many cases used as production device to produce the components for final use. For this reason we have prepared the experiment in which is measured the production time necessary for building of models with different settings. The aim of this article is to present how the production time changes depending on different settings of production process, and orientation. Specimens are produced on small Fused Deposition Modeling device with use of wired PLA (Polylactic Acid) plastic. This measured data are statistically evaluated and compared with tensile strength values of produced models.

***Keywords*—**Production Time, Rapid Prototyping, Fused Deposition Modeling, FDM, Layering.

## I. INTRODUCTION

There is on the market a lot of small devices which works with technology Fused Deposition Modeling (FDM). It is probably the most widespread Rapid Prototyping system which could be seen in the practice. The reason is probably that the patents regarding the basic of this technology is already expired. Also this technology use really easy available materials, which could be bought all over the word for low price. The technological principle of FDM is easy to design, manufacture and control.

This technique uses two materials – one for modeling and one for support. First, the model material is used to build the model. Second, the support material is used to build a support structure on the areas where the modeling material will overhang the rest of model [2]. This technique works on a principle similar to a fuse-gun [1]. The material is unspooled from the spool to the fuse-head, where it is melted and deposited on the working table. After the completion of the model, the support materials either broken away or dissolved in a special bath.

We can use basically two types of model material, which are ABS (Acrylonitrile Butadiene Styrene) or PLA (Polylactic Acid). Less then this we can see also materials as LayWoood what is the new extrusion material allows to print objects that look and smell like wood when finished. LayWood as a filament is made from 40% recycled wood that is combined with polymer binders allowing it to be melted and extruded like all of the other commercially available 3D filaments on the market today [3].

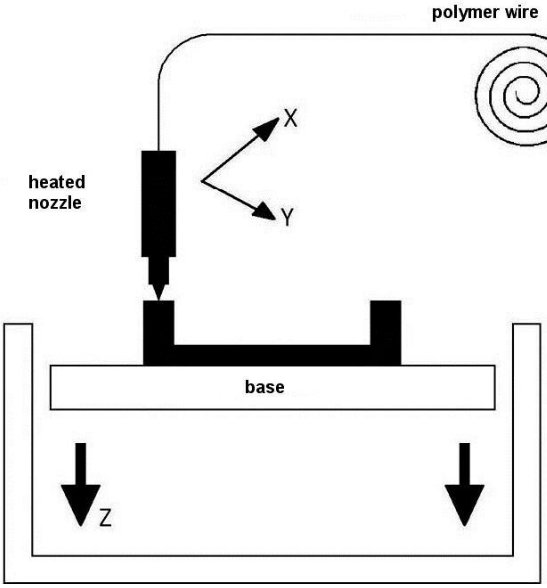

Fig. 1 FDM technology scheme [8]

The ABS filament as a constructional material is widely used in the industry, for example as an interior parts material. So it can be easy printed also parts for real use. It depends just what material properties or part surface is requires.

Juraj Beniak is with Institute of Manufacturing Systems, Environmental Technology and Quality Management, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. Nam. Slobody 17, 812 31 Bratislava, Slovak Republik (e-mail: juraj.beniak@stuba.sk).

Peter Križan is with Institute of Manufacturing Systems, Environmental Technology and Quality Management, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. Nam. Slobody 17, 812 31 Bratislava, Slovak Republik ((e-mail: peter.krizan@stuba.sk).

Miloš Matúš is with Institute of Manufacturing Systems, Environmental Technology and Quality Management, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. Nam. Slobody 17, 812 31 Bratislava, Slovak Republik ((e-mail: milos.matus@stuba.sk).

Ľubomír Šooš is with Institute of Manufacturing Systems, Environmental Technology and Quality Management, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. Nam. Slobody 17, 812 31 Bratislava, Slovak Republik ((e-mail: lubomir.soos@stuba.sk)

The PLA filament is a new, biodegradable material, which is environmental friendly. Also the advantage of this material is, that their use for 3D printers is more easy then ABS. Require lower heating temperature of nozzle, the parts are not so predisposed for deformation and do not require table heating. There is also much more possible materials suitable for Fused Deposition Modeling. For example PolyCarbonate (PC), which have high stiffness and is widely used in the industry as a construction plastic. Nylon is tough and have some flexibility so it does not break easy. Is using for tubes, hoses, connectors and others. Different composite materials are applied based on PLA polymers with adding for example wood particles (LayWood), metallic particles, ceramic particles and many others combinations. Different materials are used for different applications and environmental conditions [10], [11].

## II. FACTORS SPECIFICATION

In the following paragraphs will be discussed the influence of selected factors to time necessary for part production by FDM technology. Production time is important from economical point of view. If we can decrease production time we can produce more parts, but it is necessary to compare it also with reference to other part properties. Because we can easy produce parts with sparse interior, but the strength of such part will be probably lower as in case of solid normal type of interior filling. Presented results are the part of complex research in this field and in this paper we will show the variety of production time for different production conditions [6].

In our research we selected four basic factors, which have been compared also in the frame of others experiments and measurements. These factors and their specified levels are shown in Table 1.

Table 1 Selected factors for experiment

| Factor | Level 1 | Level 2 |
|---|---|---|
| A – interior filling | 90% | 50% |
| B – filling shape | Perimeter line | Honeycomb |
| C – layer size | 0,125 mm | 0,25 mm |
| D – model orientation (X-Y) | 0 deg | 45 deg |

Fig. 2 Interior filling shape

We can see that all factors have two levels, which have been selected depending up device setting possibilities and knowledge obtained in previous experiments. In case of filling shape, there is many of possibilities, but we choose just this two basic (Fig. 2), otherwise the experiment grows to bigger size. Specific influence of filling shape is possible testing independently in separate experiment.

The perimeter line shape is the most use in the practice, is very easy to made and also very fast to produce. The honeycomb is much difficult as a shape, so we suppose also much longer time to produce such a shape.

Available small Fused Deposition Modeling device with applied nozzle with diameter 0,25mm enable to deposit layers and fibers with two thickness. This two values of layer thickness (0,125 mm and 0,250 mm) are shown in Table 1. If we want to use smaller or bigger layer thickness, we have to change also the nozzle diameter.

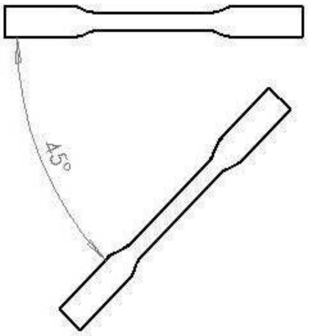

Fig. 3 Orientation of model in X – Y plane

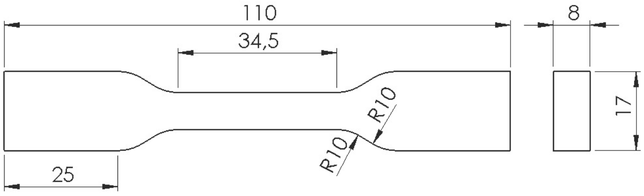

Fig. 4 Design of specimen suitable for tensile strength testing

Model orientation on the horizontal plane X – Y (Fig. 3) were specified in the previous experiments [7] as significant factor. So we add also this factor to the design of experiment. On the Fig. 5 and Fig. 6 we can see the plastic fiber orientation in different model position. The two orientations means changing of fiber direction with changing of layers in the model of produced specimen (Fig. 4). The specimens are designed for tensile test. The design and dimensions have been prepared with reference to ASTM D638 and ISO527-1 and adjusted for restrictions of available tensile test device, with maximal possible load force 5 kN.

The device on which was produced the specimens is small FDM 3D printer, where is possible to change the nozzles with different diameter to cover wider range of layer thickness. As a material were selected PLA (Polylactic Acid) polymer, because the PLA plastic is in the present time very popular, but not explored enough in the field of Fused Deposition modeling.

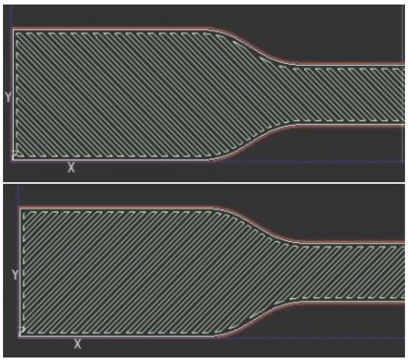

Fig. 5 Layer deposition for 0 deg orientation

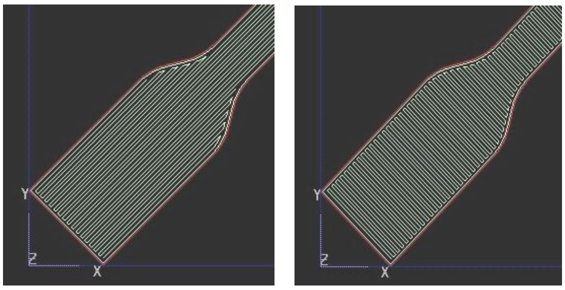

Fig. 6 Layer deposition for 45 deg orientation

## III. DESIGN OF EXPERIMENTAL PLAN

Depending on selected factors and their levels we prepared full factors experiment (complete experiment plan). This plan consists from all possible combinations of all factor levels. It is the simplest and the most comprehensive plan of experiment. Allows to estimate all parameters of regression model and easy find out influence and weight of most important factors and their interactions to measured parameters [4]. If we have in our case $k = 4$ factors and measurement will be realized on $h = 2$ levels and with accepted $q = 3$ repetitions, the total number of measurement will be $N_c = q \cdot h^k = 3 \cdot 24 = 48$ repetitions. The design of experiment is shown in Table 2.

Table 2 Design of experiment

| exp. | **A**<br>($x_1$) | **B**<br>($x_2$) | **C**<br>($x_3$) | **D**<br>($x_4$) |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 2 | 1 | 1 | 1 |
| 3 | 1 | 2 | 1 | 1 |
| 4 | 2 | 2 | 1 | 1 |
| 5 | 1 | 1 | 2 | 1 |
| 6 | 2 | 1 | 2 | 1 |
| 7 | 1 | 2 | 2 | 1 |
| 8 | 2 | 2 | 2 | 1 |
| 9 | 1 | 1 | 1 | 2 |
| 10 | 2 | 1 | 1 | 2 |
| 11 | 1 | 2 | 1 | 2 |
| 12 | 2 | 2 | 1 | 2 |
| 13 | 1 | 1 | 2 | 2 |
| 14 | 2 | 1 | 2 | 2 |
| 15 | 1 | 2 | 2 | 2 |
| 16 | 2 | 2 | 2 | 2 |

The measured value is the time necessary for part production. Measured values are displayed on Fig. 7. We can see in some experiments really significant difference where the gap is more than 700%.

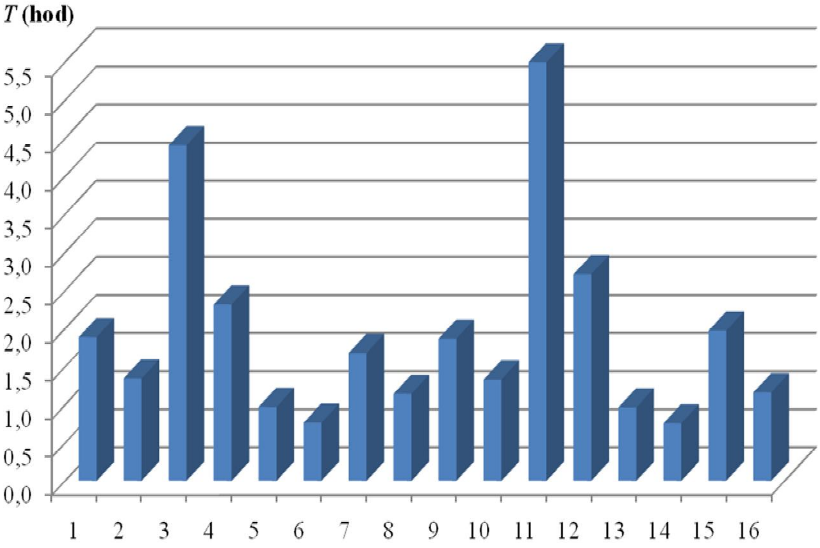

Fig. 7 Measured time necessary for model production

## IV. EVALUATION OF MEASURED DATA

The measured data have been evaluated by modern statistical methods. We used the ANOVA method as the base and for verification we used Students criterion and linear regression model.

On the Fig. 8, Fig. 9, Fig. 10 and Fig. 11 we can see graphic illustration weight of each factor level, how the change of factor level effects the measured value. If the gap between two points if bigger so the influence of the factor change is higher.

From presented graphic illustration and also from ANOVA results we can see that the most significant influence have factor C, what is the layer size (layer thickness). The second most significant is Factor B, what is the shape of interior filling. Next is factor A, which present the percentage of interior filling by material.

From this presented results we can easy state that the time for model production is highly depended on layer height. If we produce the same part with layer thickness 0,125 mm it takes much more time than when we produce the same part with layering 0,25 mm.

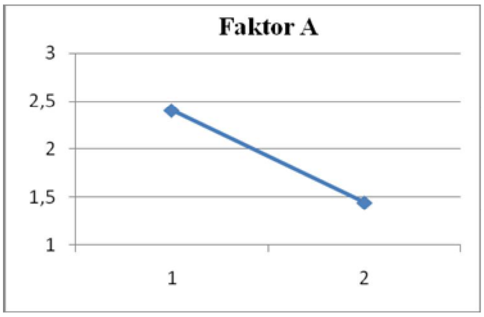

Fig. 8 Effect of factor A

The next reason is complication of interior filling shape. If we use just simple lines, the printing head can run with high speed and extrude the plasticized material. But if we want to use as filling shape honeycombs, which are much more difficult, the tool have to inscribe the shape of hexagon. This is not possible to do in so high speed as in case of simple lines.

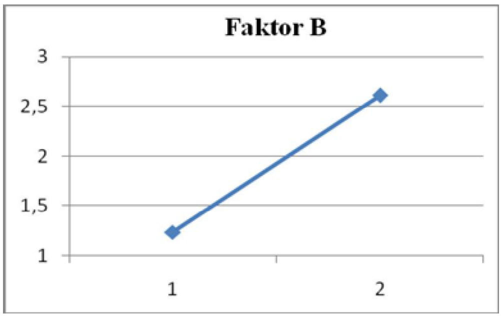

Fig. 9 Effect of factor B

The reason is total number of layers from which the part consist. When we use small layer thickness there is necessary use more number of layers instead of bigger layer thickness. The printing head need to do longer path and there is also necessary longer positioning of building platform in vertical direction.

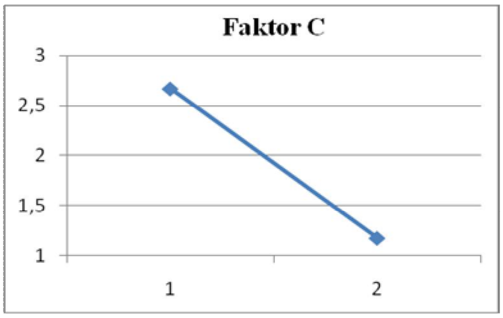

Fig. 10 Effect of factor C

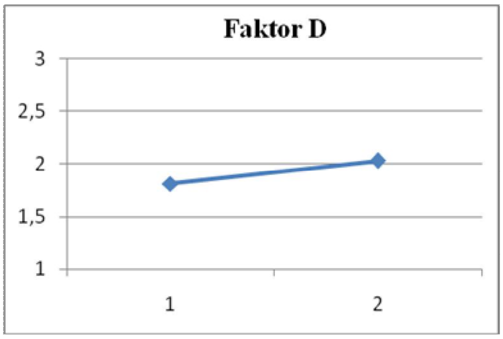

Fig. 11 Effect of factor D

Also if are this two disadvantageous factors meet with high volume of interior filling (Factor A), we reach extreme high time necessary for part production. This situation is visible in the Fig. 4 experiment number 3 and 11.

The factor D influence also this time, but not so much like previous mentioned 3 factors.

We have also compared this measured production time for each experiment with previously measured tensile strength values [7]. The measurement have been done on universal testing device Inspekt Desk 5kN with maximum possible loading 5 kN. All the measured data are online recording in the computer database and can be later used for evaluation and comparison.

Also for this measurement we have prepared full factor experiment with four factors and with two levels for each factor. So there is also 16 experiments (Table 1, Table 2). As comparison we are presenting the important values of tensile strength on Fig. 12. The most important for us are the maximum values of tensile strength. We can see that there does not exist any regularity that the specimen with highest tensile strength value is produced with longest production time.

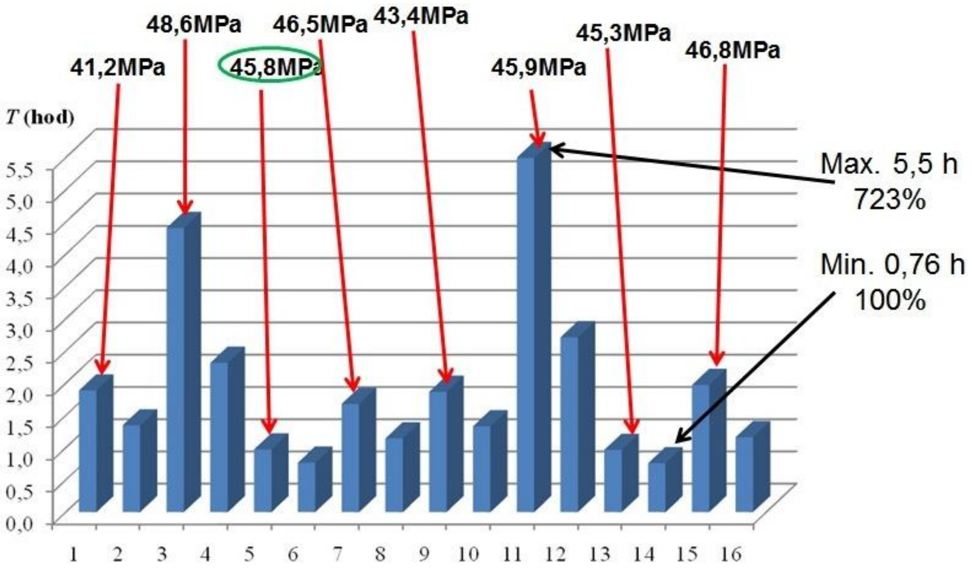

Fig. 12 Comparison of Production time with Tensile strength

## V. LINEAR REGRESSION MODEL

For processing of measured data we can use also regression analysis. This is suitable for exact specification of coefficients, which presents the weight of investigated factors. For this we selected empirical model of experiment:

$$\hat{\boldsymbol{y}} = \varphi\,(\boldsymbol{x},\boldsymbol{\beta}) + \boldsymbol{s} \qquad (1)$$

Where $\boldsymbol{x}$ is vector of selected factors, $\boldsymbol{\beta}$ is vector of unknown parameters and $\boldsymbol{s}$ is vector of errors. Its parameters are estimated from empirical data by regression analysis methods. The model (1) can be replaced by power law series [5]:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum\sum \beta_{ij} x_i x_j + \ldots + \beta_{12\ldots k} x_1 x_2 \ldots x_k \qquad (2)$$

where $\beta i$ parameter is estimated from empirical data and where $\beta_{12}$ to $\beta_{12\ldots k}$ present correspondent interactions between two to $k$ factors.

For simplicity we take linear regression:

$$T = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + b_{1,2} x_1 x_2 + b_{1,3} x_1 x_3 + b_{1,4} x_1 x_4 + b_{2,3} x_2 x_3 + b_{2,4} x_2 x_4 + b_{3,4} x_3 x_4 + b_{1,2,3} x_1 x_2 x_3 + b_{1,2,4} x_1 x_2 x_4 + b_{2,3,4} x_2 x_3 x_4 + b_{1,2,3,4} x_1 x_2 x_3 x_4 \qquad (3)$$

In formula (3) are $b_0$, $b_1$, $b_2$, $b_3$ ..., point estimation $\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$ , ... .

Verification of each coefficient is made independently. For this verification can be used Student criterion. When using the full factors experiment or repeated measurements, the determining intervals are the same for all coefficients.

The coefficient $b_0$ can be calculated as follows :

$$b_0 = \frac{\sum_{i=1}^{k} \bar{y}_i}{k_c} \qquad (4)$$

where $k_c$ is number of experiments, $y_i$ is arithmetic average of measured values.

Calculation of coefficients $b_1$, $b_2$, $b_3$, $b_4$:

$$b_u = \frac{\sum_{i=1}^{k} x_{ui} \bar{y}_i}{k_c} \qquad (5)$$

where $u = 1, 2, 3, 4$ is number of factors

$i = 1, 2, \ldots k_c$ is number of experiments ($k_c$=16)

For coefficients $b_{12}$, $b_{13}$, $b_{14}$, $b_{23}$, $b_{24}$, $b_{34}$, for interactions of two factors is:

$$b_{uv} = \frac{\sum_{i=1}^{k} x_{ui} x_{vi} \bar{y}_i}{k_c} \qquad (6)$$

For coefficients $b_{123}$, $b_{124}$, $b_{234}$, for interactions of three factors is:

$$b_{uvw} = \frac{\sum_{i=1}^{k} x_{ui} x_{vi} x_w \bar{y}_i}{k_c} \qquad (7)$$

where $w = 1, 2, 3$ is number of factors, $w \neq u \neq v$.

For coefficients $b_{1234}$, for interactions of four factors is:

$$b_{uvwz} = \frac{\sum_{i=1}^{k} x_{ui} x_{vi} x_{wi} x_{zi} \overline{y}_i}{k} \qquad (8)$$

$z = 1, 2, 3, 4$ is number of factors, $z \neq w \neq u \neq v$

By determination of above mentioned coefficients and by substitution to linear regression mode (3) we reach mathematical formula which describe the behaviour of our system in the frame of experiments.

$$T = 1{,}92 - 0{,}4818\, x_1 + 0{,}6872\, x_2 - 0{,}7465\, x_3 + 0{,}4091\, x_4 - 0{,}2957\, x_1 x_2 + 0{,}2622\, x_1 x_3 - 0{,}0602\, x_1 x_4 - 0{,}3755\, x_2 x_3 + 0{,}1153\, x_2 x_4 - 0{,}0721\, x_3 x_4 + 0{,}1793\, x_1 x_2 x_3 - 0{,}0608\, x_1 x_2 x_4 - 0{,}0745\, x_2 x_3 x_4 + 0{,}0263\, x_1 x_2 x_3 x_4 \qquad (9)$$

Absolute value of coefficients means the weight of correspondent factors and its interactions. It means how the factors or mutual interactions of factors influence the final value of monitored parameter, which in our case is the time necessary for part production.

When we see the mathematical model (9) and the values of coefficients, we can state the same result what is noticeable and graphical illustrated on Fig. 5 to Fig. 8. The factor C (layer thickness) with coefficient value 0,7465 is most significant. Then follow factor B (shape of interior slicing) with coefficient value 0,6872. This two factors are the most significant and most important in relation to realized experiment.

As we mentioned before, in this field was realized many experiments where we measured for example the tensile strength of produced samples from PLA material [7]. The maximum measured value was 48,63 MPa. This specimen was produced 4,41 hours, what is really long time. But if we take the specimen which was produced 0,97 hours, its tensile strength is 45,81 MPa. This value is just little bit lower then the maximum, but what is important the production time is more than 4 times shorter. If we think about the production and productivity, it is really important to make this process effective. We can see that by the optimal setting of FDM Rapid Prototyping device can be influenced the production process but also the final result which we reach. So the operator of this device have to have enough of information and experiences for proper setting of FDM machine.

## VI. CONCLUSION

As we see from results presented in this paper the same part can be produced with different time and this time values are in some cases very different. The minimum time is about 45 minutes, but the longest time is more than 5,5 hour. This depends just from FDM machine settings and positioning of model in the machine workspace. So before we start with producing of model, we have to know what we are expecting from prepared part, what should be the quality and also the mechanical properties. Also the operator should have some experiences regarding of machine settings, to know how to set the best parameters, how to orient the model and what layer thickness to use for best result.

Another result of this paper is model production time comparison with tensile strength, measured on prepared specimens. We can easy recognize that the high tensile strength values could be achieved also with short production time. There is no any dependence between production time and tensile strength. But we can recognize what have to be the device settings and model orientation to achieve the acceptable values and final part quality.

In our department we made many experiments to monitor mechanical properties of produced parts with reference to important factors. Following this experiments results we have been able to prepare mathematical models for example for calculation of tensile strength of produced parts.

In this field are available different experiments where are measured different parameters of produced parts as surface roughness [9], dimensions accuracy and also different use of models in challenging environment .

## ACKNOWLEDGMENT

The research presented in this paper is an outcome of the project No. APVV-0857-12 “Tools durability research of progressive compacting machine design and development of adaptive control for compaction process” funded by the Slovak Research and Development Agency.

## REFERENCES

[1] D. T. Pham, S. Dimov, “Rapid Prototyping, A time compression tool”, Manufacturing Engineering Centre, Cardiff University.

[2] C. K. Chua, K. F. Leong, , C. S. Lim, “Rapid Prototyping, Principles and Applications”, Nanyang Technological University, Singapore, World Scientific Co. Pte. Ltd, 2003, ISBN 981-238-117-1.

[3] R. Walters, “Laywood filament lets you 3D print with wood”, Available in: http://www.geek.com

[4] E. Jarošová, “Navrhování experimentů”. Česká společnost pro jakost, 1997

[5] R. Grofík, J. Kubíček, J. Hrubý, J. Dufek, B. Kába, R. Zeipelt, “Štatistika”, *Edícia Ekonomika poľnohospodárstva*, Príroda, 1987

[6] J. Lipina, P. Kopec, V. Krys, “Implementation of Polycarbonate Material Mechanical Properties of Rapid Prototyping into System Creo”, Laboratory Verification of the Results, *INES 2014, IEEE 18th International Conference on Intelligent Engineering Systems,* July 3-5. 2014, Tihany, Hungary, ISBN 978-1-4799-4615-0

[7] J. Beniak, “The factors affecting the production process of models by FDM device”, *Habilitation thesis, Slovak University of Technology*, 2014, ISBN 978-80-227-4300-6

[8] M. Stanek, D. Manas, M. Manas, J. Navratil, K. Kyas, V. Senkerik, A. Skrobak, “Rapid Prototyping Methods Comparison”; *Recent Researches in Circuits and Systems*, 2012, ISBN: 978-1-61804-108-1

[9] R. Udroiu, L. A. Mihail, “Experimental determination of surface roughness of parts obtained by rapid prototyping”, *Recent advances in circuits, systems, electronics, control and signal processing*, 2009 ISBN: 978-960-474-139-7, ISSN: 1790-5117

[10] S. Daneshmand, R. Adelnia, S. Aghanajafi, “Comparison between FDM Model and Steel Model as Wind Tunnel Testing Models”; *Proceedings of the 6th WSEAS International Conference on Robotics, Control and Manufacturing Technology*, Hangzhou, China, April 16-18, 2006 (pp36-41)

[11] E. Hnatkova, P. Kratky, Z. Dvorak, “Production of anatomical models via rapid Prototyping”; *International journal of circuits, systems and signal processing*, Volume 8, 2014, ISSN: 1998-4464

**Juraj Beniak** is an Assoc. Prof. on Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. He received the MSc. and PhD. degree on the same faculty. Currently work as university teacher on Institute of Manufacturing Systems, Environmental Technology and Quality Management. Published 3 books: Systems of Rapid Prototyping, Reliability analysis of screw briquetting press and CAx systems – Computer aided education. Doing the research in the field of Rapid Prototyping, Reverse Engineering, Computer Aided systems, Shredding machnines and others. Joined the training program for CNC and CAD systems in Taiwan. Participating on different national and international research projects.