

Using 3D Printing Technology in Prototype Production to Control the Dimensions of Complexly Shaped Products

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Prototype production is a key element in the process of developing a new product. The prototype is important both being the initial materialization of ideas and intentions related to the way the product is going to be designed, and also for the subsequent assessment of the technological solution. One of the technologies used in prototype production today is 3D printing. One of its advantages is quick adaptation to more complexly shaped prototypes, which makes it possible to come up with products which would be hard or even impossible to make in the past. The increasing availability of 3D printing equipment is making it all the more widely used. This paper was written to demonstrate the principles of the production of auxiliary gauges, which are used to check the dimensions of a more complexly shaped prototype. The possibilities of using 3D printing technologies in the conditions of an engineering company are also discussed. The conclusion of this paper focuses on the possibilities of integration between modern and classic technologies in piece and custom production.

Keywords: 3D Printing, Prototype Production, Auxiliary Gauges

1 Introduction

In today's resource-constrained environment, market pressure for new products is growing dramatically due to increasing access to worldwide markets. On the other hand, competition is growing dramatically as well. That is why companies are trying to overtake their competitors, launching new products which the market is not yet saturated with and thus securing their position on the market. [1]

However, the process of manufacturing a new product is a long and demanding journey where at the beginning we do not know whether the product will be fully functional and suit the customer's wishes. The manufacturing process is a complex chain, consisting of a series of links which are interconnected and thus the chain cannot be continued unless the previous link is fully functional. It is therefore necessary to divide the process into individual steps and continuously monitor and control the individual sub-sections so that the non-functioning part does not get farther along in the process. In addition to market research, where the main focus is to analyse the demand, i.e. whether or not the product will ever be attractive for customers, one of the most important steps in designing a new product is the construction of a prototype.

The term "prototype" is understood as at least one sample version of a machine, device, product, or program. Prototypes make it possible to test the functionality of a product being designed. It can be both an actual thing or a virtual version of it. Prototyping is an essential stage in the process of designing a new product, namely a checkpoint, a part of the design stage,

before the product enters production. This testing helps manufacturers avoid mass producing items which are not (fully) functional. Speaking of mass or large-scale production, this step has a decisive effect on the success or failure of the entire project. Nowadays, consumers only demand good quality products, which must meet not only their expectations, but also user parameters and legislative demands. Prototypes are tested for all physical, technical and aesthetic properties that the final product should have. Tests are performed on real or software created virtual prototypes.

Using virtual reality for testing reduces the cost of researching and analysing the physical and technological properties of a product. Today, these advanced technologies make it possible to speed up most time-consuming phases of the production process. Designers use virtual models instead of real prototypes and analyse them using different types of simulations, focusing on real-life conditions in which the product will have to operate. This process is supported by modern computer software. First, the designer creates a virtual model. The next phase is the preparation of a virtual simulation, the aim of which is to outline the real conditions of the object's use.

In addition to virtual prototyping, the production of real prototypes, where the actual object is produced in accordance with customer requirements and technical specifications. The prototype is a fully functional product that is manufactured according to technical specifications and customer requirements. The problem with prototypes is that there is no standardized

production process and machines and tools may not be readily available, which makes it a demanding technological process with high production costs. Without creating a real prototype, it is not possible to test the product and detect problems before mass production is started.

This paper describes the production of prototypes in a mechanical engineering company, using conventional sheet metal processing technology combined with modern 3D printing and modelling. The case study was carried out at LAKUM Group, which is an umbrella name for LAKUM-KTL, a.s., LAKUM-AP, a.s., LAKUM-GALMA, a.s. and Massag, a.s. located near Ostrava. This company combines advanced 3D printing and modelling technology with conventional processing technology to create unique prototypes for its customers. The company also deals with surface treatment, pressing and CNC metal processing.

2 Literature review

3D printing technology, referred to as Digital Manufacturing or Additive Manufacturing (AM) or Rapid Prototyping (RP) technology, is a modelling process that creates a reconstruction of a physical surface or object from a digital 3D model. This technology uses digital data. The data is processed using 3D graphics software (CAD) or other devices, such as a 3D scanner which can scan a physical object to create a virtual 3D model. The created 3D models of objects are further prepared using a postprocessor which is a software converter of data from CAD / CAM system into the data language of a particular 3D printing machine. The principle of 3D technology allows you to convert any virtual model to a physical model using 3D printing. [2,3,4,5,6,7]

3D printing technology is based on an additive process whereby material is gradually added to create a physical model, as opposed to conventional machine tools, where material is removed from a solid block until the desired shape remains. [4,8,9]

3D printing technology is an emerging digitized production technology that makes it possible to produce objects with a complex shape geometry at low cost, and also allows quick design of a number of prototypes. That is why this technology represents one of the most promising and revolutionary production options today. This technology has gained worldwide recognition and has attracted a lot of attention in recent years. [3,4,8]

3D printing technology is used primarily in industries such as agriculture, aviation, robotics, aerospace and automotive, but also in the health sector; in fields such as plastic surgery, orthopaedics and dentistry. [10]

Today, 3D printing technology is capable of producing fully functional components in a wide range of materials such as:

- Metals - metals are used in aviation, automotive industry or biomedicine because they have excellent properties and 3D printing allows for great precision and significantly lower weight of the manufactured parts. Aluminium, nickel, cobalt, stainless steel or titanium alloys are used. [2,9]
- Polymers - polymers are the most widely used material for 3D printing due to their availability and properties. Polymers such as PLA, ABS, PP, or PE are used. [2]
- Ceramics - ceramics are mainly used in dentistry, but in the future they will definitely find their place, together with concrete, as a practical material for the construction industry, due to its technological properties.[2]
- Composites - are used for their versatility, low weight and customizable properties. Examples of composite materials are carbon fibres reinforced with polymer composites and glass fibre reinforced polymer composites. [12]
- Smart materials - intelligent materials have the potential to change the geometry and shape of an object in response to external conditions. Examples are some shape memory alloys, such as nickel-titanium, which are used in biomedical implants for the application of microelectromechanical devices. [2]

Advantages of 3D printing

The advantage of 3D printing for the production process is that a wide range of materials can be used. This variety has helped promote applications in many manufacturing sectors. Future directions focus more on military applications, including on-site printing of spare parts. It also saves production time, shortens the time after which a product can be launched on the market, saves material and simplifies the workability of highly complex products. [13]

Disadvantages of 3D printing


The disadvantages are related to the environment, where printers consume large amounts of electricity and can also slow down the movement towards ending humanity's dependence on plastics. Another disadvantage is the legal problems that will have to be worked on, in order to protect the intellectual property of manufacturers. The last disadvantage is the initial investment in this technology, which is in the order of hundreds of thousands of crowns. [13]

3 Case study

The case study was realized in a real company environment. The production of measuring templates

(Model Test 1, Model Test 2) was carried out on a specific 3D printer using the given filament and predetermined printing parameters, see Tab. 1.

Tab. 1 Print parameters [14]

Printer		Fillamentum	
3D Printer Ultimaker S5		Ultimaker Tough PLA (black)	
Average print strings	2.850 [mm]	Type of material	PLA
Print volume	330 x 240 x 300 [mm]	Diameter of the filament	2.850 [mm]
Number of extruders	2	Recommended printing temperature	210-220 [°C]
Number of nozzles	2	Recommended platen temperature	60 [°C]
Nozzle diameter, head	0.250/0.400/0.600/ 0.800 [mm]		
Working temperature of the nozzle	180-280 [°C]		
Heating pad	20-140 [°C]		
Rated power	500 W		
Technology	FFF/FDM		
XYZ Resolution	6.900/6.900/2.500[μm]	CTE	[41 x 10-6 m/m·K]
Print parameters			
	Model Test 1	Model Test 2	
Print Speed	45 [m·s ⁻¹]	45 [m·s ⁻¹]	
Travel Speed	150 [m·s ⁻¹]	150 [m·s ⁻¹]	
Traver Jerk	30 [m·s ⁻¹]	30 [m·s ⁻¹]	
Printing Temperature	210 [°C]	210 [°C]	
Build Plate Temperature	60 [°C]	60 [°C]	
Quality Layer Height	0.100 [mm]	0.100 [mm]	
Printing Time	7.500 [hr.]	44 [min.]	
Nozzle diameter, head	4 [mm]	4[mm]	
Software			
Ultimaker Cura (preparation of 3D printing), Ultimaker Connect (3D print queue management)			

The first part of the study describes the process of manufacturing a control template using 3D printing. The first step is to create a 3D virtual template in CAD software. In this particular case, Autodesk Inventor software was used, among other software used are SolidWorks, Pro / ENGINEER, Catia or Solid Edge.

The designer creates a 3D model of the template directly on the given product model (B, C), which he creates in case he sells the products, or he makes drawings and receives the 3D models from the customer (A). The model is created directly on the product to check the given dimension. Process of manufacturing, see in Fig. 1.

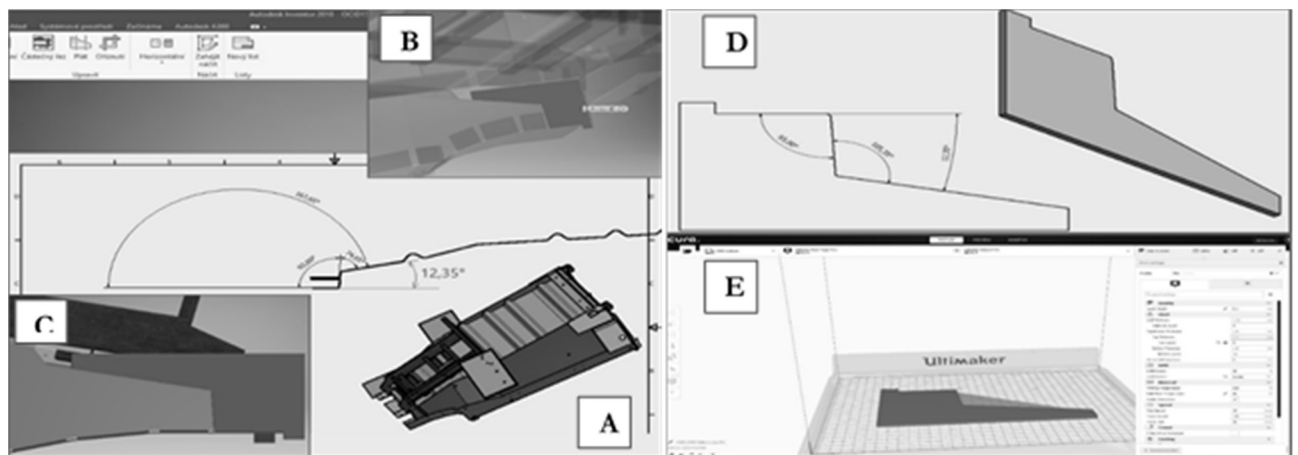


Fig. 1 Process of manufacturing

After creating a 3D template model in the CAD software, the model is transferred to the 3D printing preparation software. In this case, the Ultimaker Cura software is used. Other platforms used are Simplify3D or PrusaSlicer. Here the given 3D printing parameters

(E) are set, subsequently the printing is set, which is then converted to the printer language using the post-processor, and printing is launched. The printing parameters for the measurement templates are shown in Tab. 1. Process of 3D printing, see in Fig. 2.

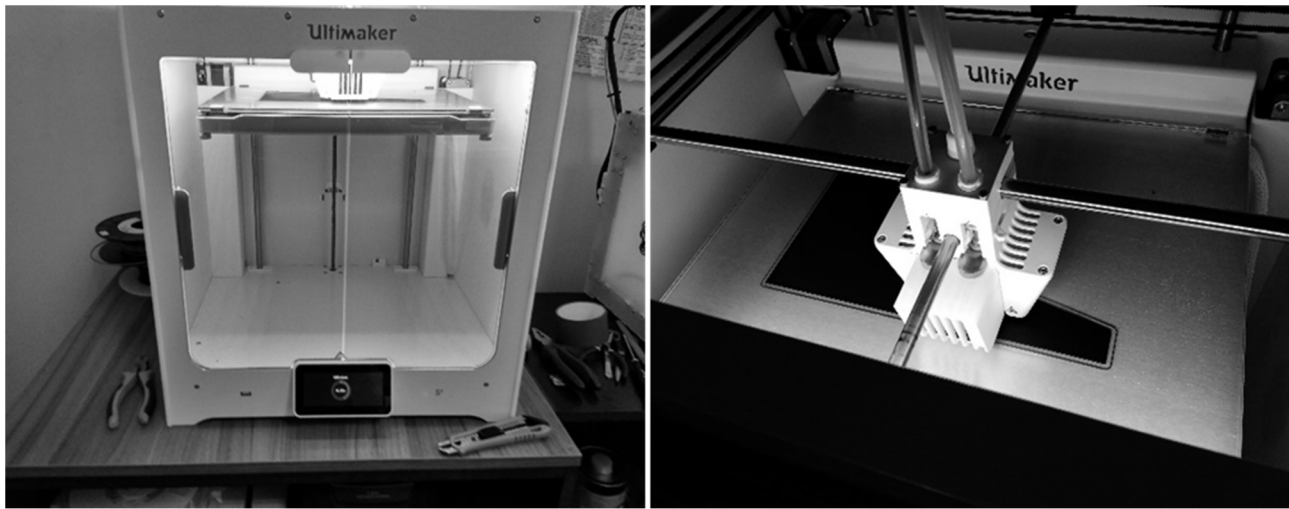


Fig. 2 Process of 3D printing

The printed models (Figure 3) are handed over to the factory where they check the complexity of dimensions which are difficult to measure with conventional measuring means. The Test 1 model is a template for checking the correct size of the product angle, see in

Fig. 3. The Test 2 model is a gauge for checking the size of the radius, see in Fig. 3. Both models were checked on a 3D coordinate measuring instrument Zeiss.

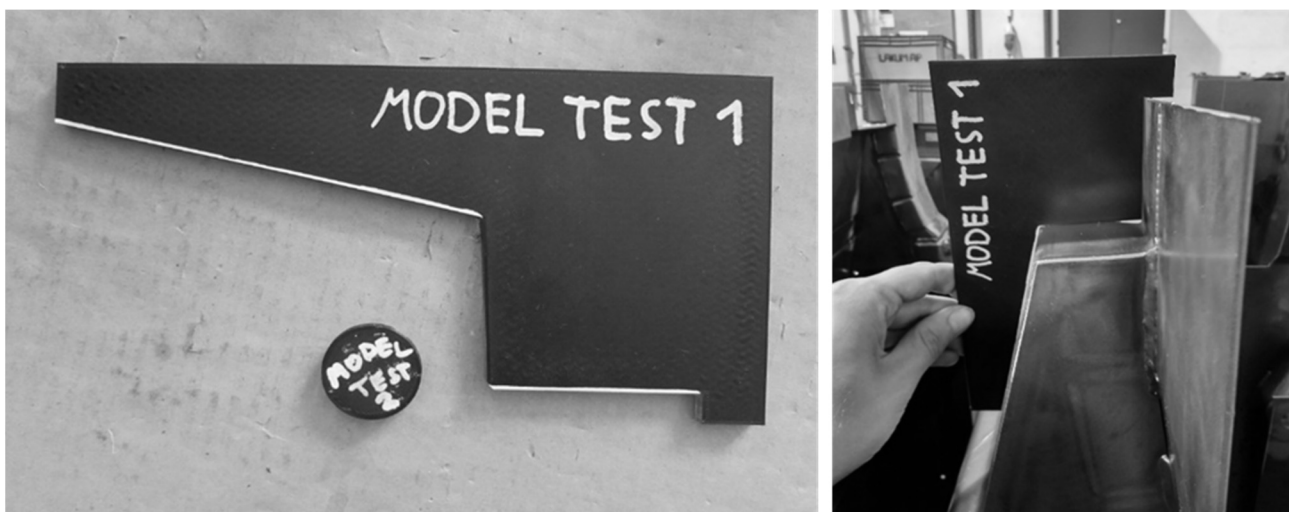


Fig. 3 Model test 1, Model test 2

The second part of the study evaluates the accuracy of 3D printing. Accuracy is evaluated based on the control measurements of the printed templates. The inspection was carried out using a 3D coordinate measuring device Zeiss DURAMAX, calibrated according to DIN EN ISO 10360. The measurement was carried out by the touch probe measurement method. For Model Test 1, the angle size was measured 10 times, and measurements were made comparing the variations in the distance between the points of the

actual model and the virtual model. This measurement consists of 23 points that were distributed over the model area. From the measured points the deviation of the actual shape of the measured object from the ideal shape (virtual template) is determined. This measurement was performed 10 times. In the second Test 2 model, the pore size was checked 10 times and the circularity deviation was measured 10 times. The averages were calculated from the measured values.

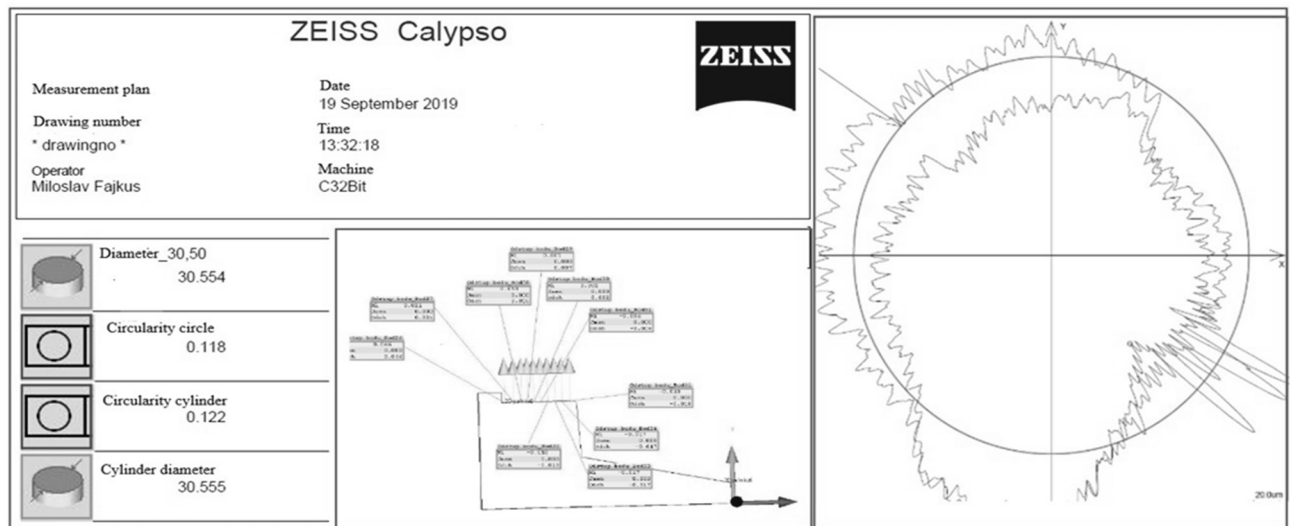


Fig. 4 Measurement using 3D Zeiss system

Tab. 2 Measured values Model Test 1

Measurement results Model Test 1										
Points	Deviations of the actual shape of the measured template from the ideal template shape									
	Measurement 1 – 10 [mm]									
1	-0.014	-0.017	-0.018	-0.016	-0.018	-0.017	-0.018	-0.017	-0.015	-0.016
2	0.001	-0.003	-0.003	-0.001	-0.004	-0.003	-0.004	-0.003	-0.006	-0.001
3	0.016	0.011	0.010	0.014	0.010	0.011	0.009	0.011	0.012	0.009
4	0.010	0.008	0.007	0.010	0.007	0.008	0.007	0.009	0.007	0.011
5	0.009	0.006	0.005	0.009	0.005	0.007	0.005	0.006	0.005	0.005
6	0.010	0.007	0.007	0.009	0.007	0.008	0.007	0.007	0.008	0.009
7	0.004	0.001	0.001	0.004	0.001	0.002	0.001	0.001	0.001	0.003
8	0.006	0.003	0.003	0.005	0.003	0.004	0.003	0.004	0.003	0.003
9	0.004	0.001	0.001	0.006	0.001	0.002	0.001	0.002	0.003	0.002
10	0.009	0.006	0.006	0.008	0.006	0.007	0.006	0.006	0.008	0.007
11	0.017	0.017	0.016	0.009	0.016	0.007	0.016	0.017	0.016	0.019
12	0.027	0.085	0.084	0.019	0.084	0.018	0.084	0.085	0.030	0.048
13	0.096	0.066	0.065	0.086	0.065	0.085	0.064	0.021	0.067	0.068
14	0.073	0.021	0.021	0.068	0.020	0.066	0.020	0.011	0.023	0.066
15	0.023	0.010	0.008	0.023	0.010	0.021	0.009	0.006	0.009	0.009
16	0.013	0.007	0.006	0.014	0.006	0.012	0.005	0.002	0.008	0.012
17	0.009	0.002	0.002	0.009	0.002	0.007	0.002	-0.005	0.001	0.002
18	0.004	-0.006	-0.005	0.004	-0.006	0.003	-0.006	-0.011	-0.002	0.001
19	-0.004	-0.010	-0.011	0.004	-0.011	-0.004	-0.012	-0.018	-0.008	-0.004
20	-0.009	-0.017	-0.019	-0.003	-0.019	-0.009	-0.019	-0.017	-0.016	-0.012
21	-0.016	-0.018	-0.017	-0.008	-0.018	-0.017	-0.018	-0.018	-0.017	-0.018
22	-0.015	-0.015	-0.018	-0.016	-0.019	-0.016	-0.008	-0.008	-0.007	-0.015
23	-0.016	-0.006	-0.008	-0.015	-0.008	-0.017	-0.012	0.006	-0.007	0.006
Average of measured deviations 0.007 [mm]										
Nominal angle value 12.35 [°]										
Angle size measured	12.336	12.297	12.296	12.297	12.339	12.296	12.340	12.297	12.347	12.336
Angle deviation	-0.014	-0.053	-0.054	-0.053	-0.011	-0.054	-0.010	-0.053	-0.003	-0.014
Diameter of the measured angle magnitudes [°]					Average measured deviations [°]					
12.318					-0.032					

Fig. 4. shows the measurement protocol using the Zeiss 3D system and a table of measured values when checking the Model Test 1 template, see in Tab. 2.

Tab. 2 shows the measured values from the Model 1 Test Control Measurement. The calculated diameter

of the measured deviations of the actual shape of the measured template from the ideal shape of the template was 0.007 mm. The calculated diameter of the measured angle magnitudes was 12.318 °, when the nominal angle value was 12.35°.

Tab. 3 Measured values Model Test 2

Measurement results Model Test 2			
Tracking number	Measured values	Measured deviations	Circularity deviation
1	30.554	0.054	0.118
2	30.555	0.055	0.119
3	30.554	0.054	0.119
4	30.554	0.054	0.118
5	30.550	0.050	0.118
6	30.551	0.051	0.117
7	30.551	0.051	0.118
8	30.555	0.055	0.118
9	30.554	0.054	0.119
10	30.550	0.050	0.118
Nominal value means [mm]			Diameter of measured roundness variations [mm]
30.500			
Average measured evaluation [mm]			0.118
30.553			
Average of measured deviations [mm]			
0.053			

For the Model 2 control, the average value of 30.553 mm diameter was calculated from the measurements. The nominal diameter was 30.500 mm. The

average circularity deviation from the measurements was calculated to be 0.118 mm.

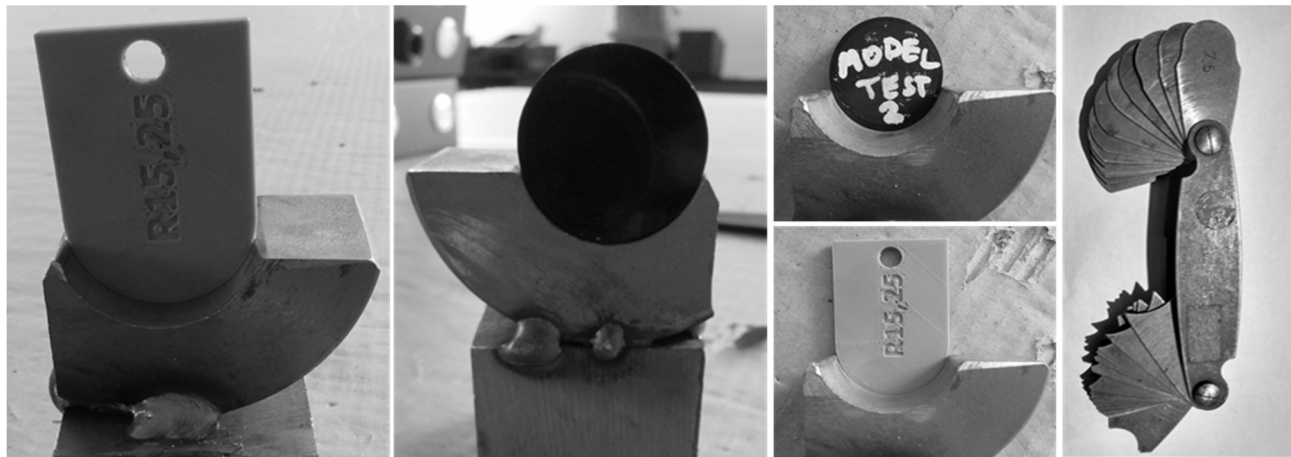


Fig. 5 Check gauges

Final dimensional precision is very important here. In 3D printing, this is about very precisely adjusting the position of the X, Y and Z axes, positioning them with the use of stepper motors. XYZ Resolution Ultimaker S5 is 6.900 µm, 6.900 µm, 2.500 µm. Another thing that needs to be taken into consideration is that the material will change its dimensions depending on

changes in temperature (thermal expansion or shrinkage). In the data sheet for the PLA material, thermal expansion coefficient is stated to be $41 \times 10^{-6} \text{ m/m} \cdot \text{K}$ [15] and the difference in temperature between the production and measurement process is not big. For this reason, in Model Test 2, elongation of the 15.250mm long material is only within thousandths, so these molds are quite accurate when measuring

small parts. it can be said that 3D printing technology is very accurate and can be used to print size control templates or to print non-standard radius check gauges as shown in Figure 5.

The third part of the study is devoted to the use of these auxiliary templates in practice, to control dimensions in the production of prototype products.

Figure 6 shows the manufacturing process of the prototype sleeve. The production of the sleeve begins with the development of the sleeve shape (B) from a metal sheet by means of a punching centre (A). Thereafter, the sleeve is successively formed by means of a conventional press brake into a final shape (C).

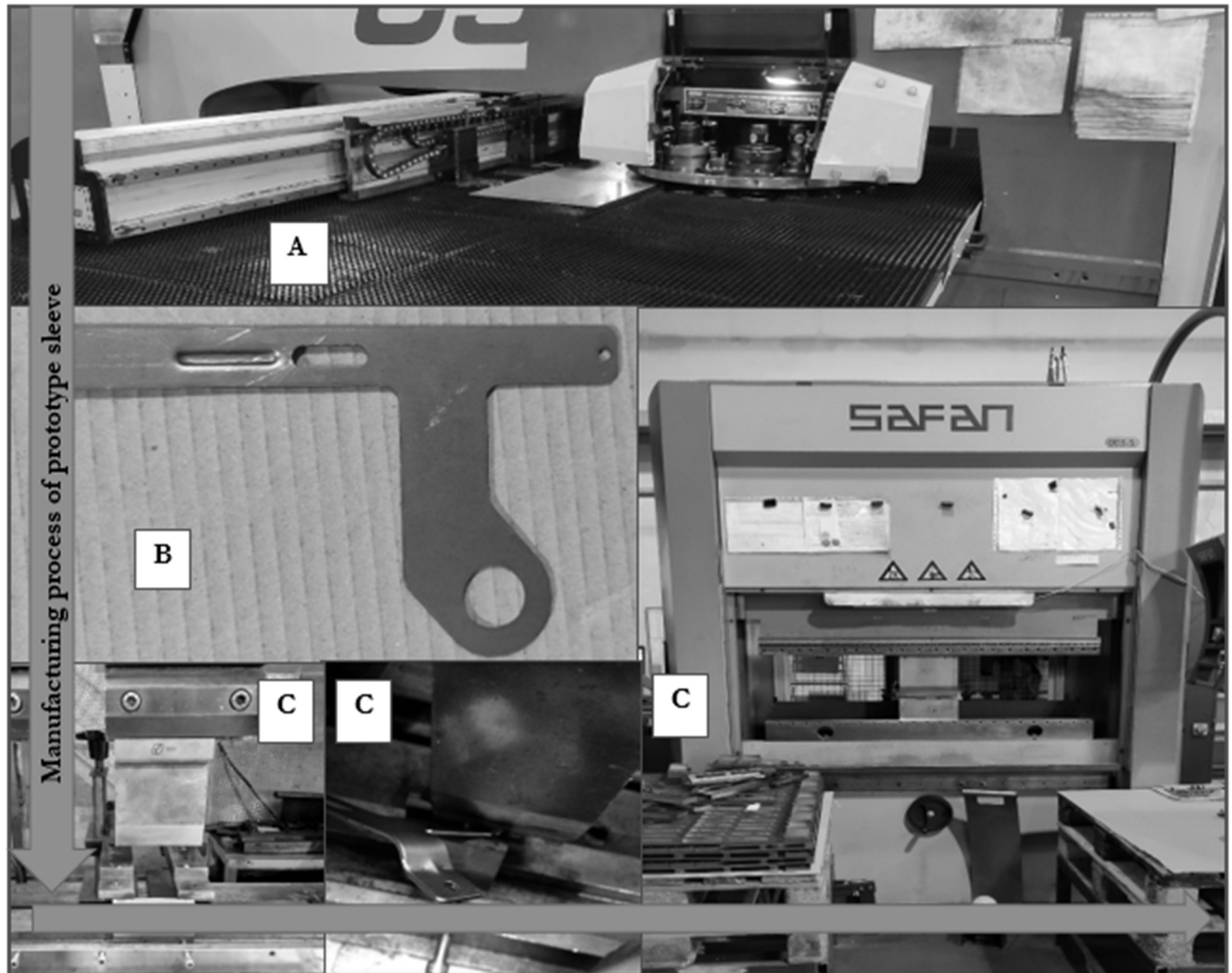


Fig. 6 Manufacturing process of prototype sleeve

3D templates serve as control gauges for complex product shapes. Here, for example, it is the radius or

correct bending angle, see in Fig. 7.

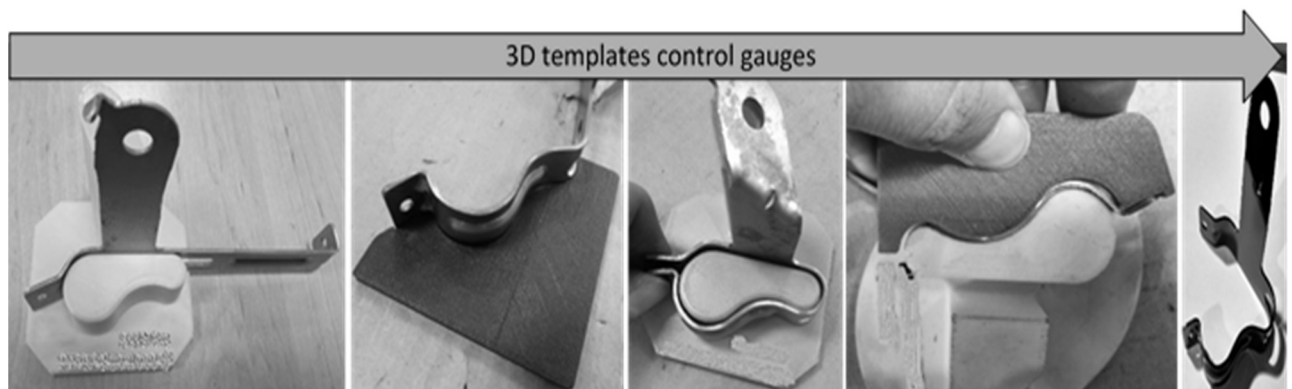


Fig. 7 3D templates control gauges

The prototyping itself uses a printed 3D model (product) as a model. This allows us to see the finished product in its actual size and shape, which then helps us technologically plan the sequence of individual bends so that we are able to produce the prototype under the given conditions, see in Fig. 8. Figure 9 shows the computer models of these 3D templates.

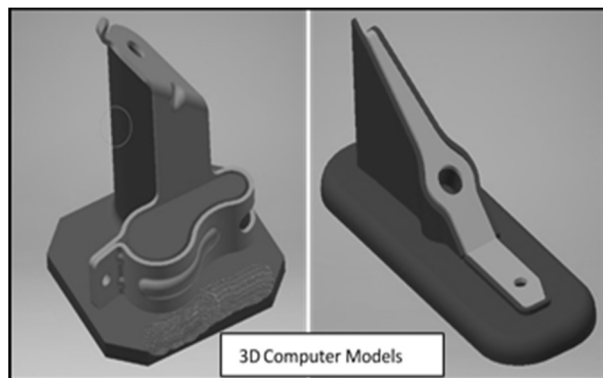


Fig. 8 Computer models 3D templates

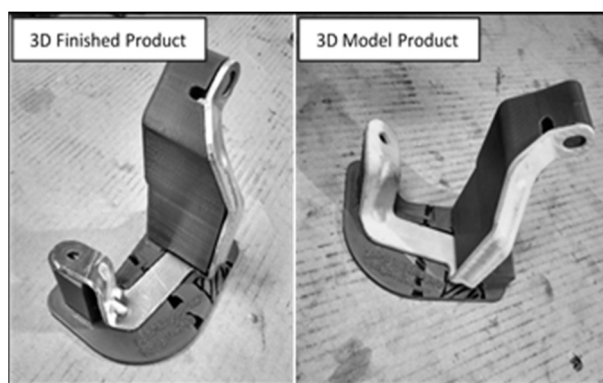


Fig. 9 3D model (product)

4 Conclusion

The case study was focused on 3D printing technology and its use in prototype production. The first part was devoted to the process of 3D template production using 3D printing in real conditions. The second part was focused on checking the accuracy of the produced template using 3D printing. It has been found that 3D printing allows us to produce precise shape and size products.

Based on testing model measurement results, and considering both the dimensional precision of a given 3D printer and PLA printing string qualities, it may be concluded that with the given dimension, and keeping the production parameters, very high precision is achieved and the molds can be used as relatively precise gauges.

From the above it is evident that modern 3D printing technology represents the possibility and suitability of integration of modern production technologies in the conditions of single or custom production, which leads to the reduction of costs necessary for the

production of prototypes and also the possibility of wider use in practice.

The results of the case study showed the practical use of 3D printing technology in the conditions of engineering prototype production. The combination of conventional sheet metal processing technology and modern 3D printing technology creates unique prototypes without which the physical and mechanical properties of future products could not be tested.

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