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Influence of Tumbling Bodies on Surface Roughness and Geometric Deviations by Additive SLS technology

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This research focusing on influencing the surface structure and its geometric deviations from the CAD model after various tumbling of bodies at constant parameters of the tumbling machine. The purpose of determining the actual effect on the resulting surface before and after the tumbling process, which tumbling body causes the selection of a larger grain or compaction of the surface layer. The research outputs are thermographic maps and geometric deviations measured using CAD models. The experimental line was at VŠB - TU Ostrava, with the help of the PROTOLAB 3D printing center, there was an experimental sample in your game. Measurement of access in the metrology laboratory on CMM Wenzel LH 65 X3Premium and optical heads Shapetracer II.

Keywords: 3D CMM, Optical scanning, Geometric deviations, Aditive Technology, Method S

1 Introduction

In the last decade, 3D printing has become a very popular and affordable means for realizing designs from the CAD software into a physical state [1].

3D printers that allow you to print from plastic can vary in the technology used when making the parts. The difference in the used printing technology often mean a different printer design, but also different applications of the printed parts. The printed parts may be different in mechanical properties, accuracy, size, consistency or even appearance. [8] [10]

3D printing may seem as a fast way to produce the designed parts. However, from an industrial point of view, especially in mass production it is much slower than injection moulding. The advantage of 3D printing is not the speed of production or low price, but the ability to produce prototypes, or in one-off production it is suitable for even very complex parts that cannot be produced by other methods. This applies for the parts whether they are only design parts or in the case where topology optimization is applied to stress-based structural design problems in parts.

The most frequent requirements for printed parts are optimal mechanical properties combined with the accuracy of functional surfaces. In order to determine whether a particular part is manufactured accurately, it is necessary to use both conventional measuring instruments, custom gauges and non-traditional measuring devices, that is mainly because of the complexity of the manufactured parts. A comprehensive evaluation of the surface topography of a shin guard is given by using a tumbling machine, which adjusts the shin guard's surface to appear visually smoother using selected tumbling bodies. Adjusting may mean a refinement of the surface layer, strengthening (compaction) of the surface layer and also the least suitable for us a change of geometric dimensions. In the process there is a rounding of the edges, a change in length, a change in angle, etc. From a process point of view, the goal of the tumbling bodies is: smoothing, polishing, deburring, rounding of the edges and precise final adjustment.

The surface topography is analysed from a qualitative point of view to evaluate the functionality and assembly of the surface [3]. Requirements for the final surface topography are most often determined for the following reasons: low noise, adhesion, anti-vibration, frictional heat transfer, abrasion resistance, surface appearance, etc [19]. It is not always necessary to produce a surface as gloss, if not needed. Each process operation makes production more expensive. It is always necessary to consult with the customer or with the production technologist. [6]

2 Experiment

Selective laser sintering (SLS) is a modern manufacturing technology that was created in the 1980s at the University of Texas in Austin's Department of Mechanical Engineering [2]. SLS has become one of the most advanced and promising production methods in the world [7] that is used today thanks to the invention of Carl Deckard [4] [18].

Print Creation

The SLS method was chosen because of the problematic and more complex structural elements used in the designed experiment. In this case, the removal of support is eliminated, as the surrounding of the tray serves as support for the printed part. The design of the printing process is assessed from the design point of view and the orientation of the model in the build chamber of the 3D printer. Today's possibilities allow printing surfaces at any angle without the use of supports, there is a direct dependence of a certain slope with deteriorated surface quality.

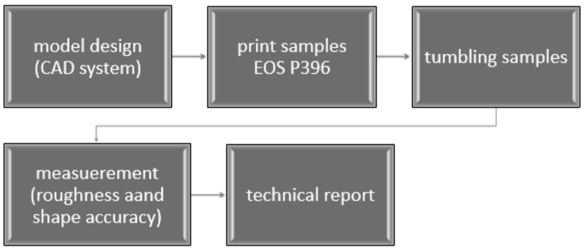


Fig. 1 *Proces flow diagram*

For the selected samples, we chose the EOS P396 printer, which prints using the SLS method. The samples were printed in a layer of 120 micrometres and in balance mode, see Figure 3. When assessing the shape of the models, the samples were printed in a vertical position in the build chamber, due to their specifications (raster designs and inscriptions). If a different orientation is chosen in the build chamber, eg. horizontal, certain deformations and higher geometric deviations from the original CAD model could occur. Incorrect selection of the orientation of the printed model in the build chamber further deteriorates the integrity of the surface of the printed part and prolongs the processing times for surface layer modifications [17].

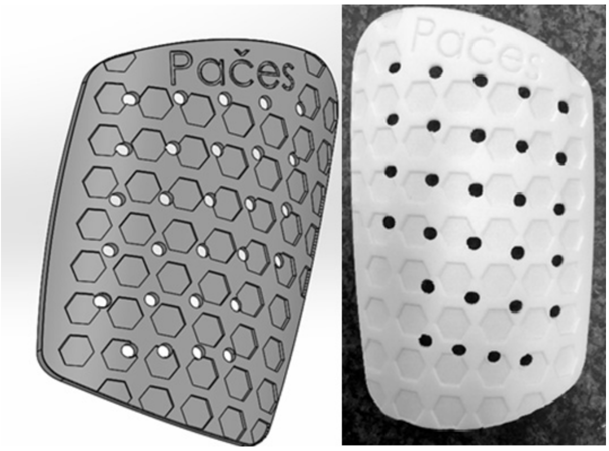
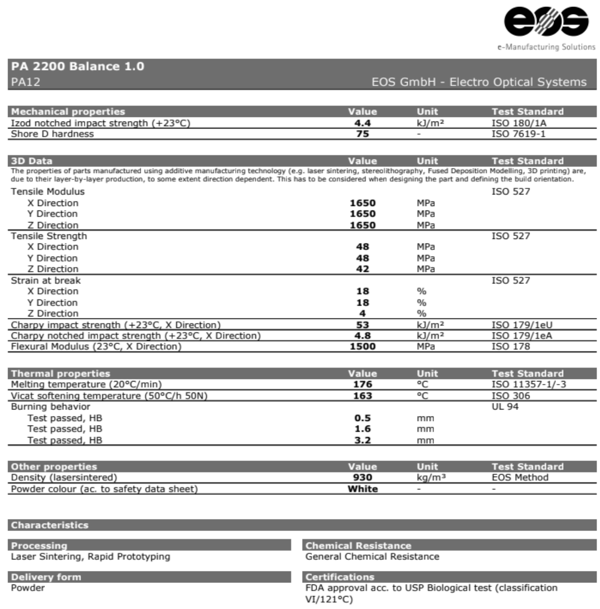


Fig. 2 *Protector 3D model is on left size and next size is models printed by SLS technology*

The material for the samples used was the PA 12 (Polyamide 12), which guarantees excellent mechanical and thermal properties and resistance to various chemicals. This material has a balanced profile of given properties (strength, stiffness). In addition, this material is a strong alternative to plastics, which have proved their worth in plastic injection molding, since we wanted to replace the molding or injection molding of protectors (large-scale production) by 3D printing according to a precise model, i.e. the human shin.

Tab. 1 *Material properties PA12*

Typical mechanical properties	
Train module	1650 MPa
Tensile strength	48 MPa
Elongation at break	18 %
Thermal properties	
Melting temperature (20°/min)	176 °C
Dimensional stability temperature (1.80 MPa)	70 °C
Dimensional stability temperature (0.65 MPa)	154 °C



e-Manufacturing Solutions

PA 2200 Balance 1.0
PA12 EOS GmbH - Electro Optical Systems

Mechanical properties	Value	Unit	Test Standard
Izod notched impact strength (+23°C)	**4.4**	kJ/m²	ISO 180/1A
Shore D hardness	**75**	-	ISO 7619-1

3D Data	Value	Unit	Test Standard
The properties of parts manufactured using additive manufacturing technology (e.g. laser sintering, stereolithography, Fused Deposition Modelling, 3D printing) are, due to their layer-by-layer production, to some extent direction dependent. This has to be considered when designing the part and defining the build orientation.			
Tensile Modulus			ISO 527
X Direction	**1650**	MPa	
Y Direction	**1650**	MPa	
Z Direction	**1650**	MPa	
Tensile Strength			ISO 527
X Direction	**48**	MPa	
Y Direction	**48**	MPa	
Z Direction	**42**	MPa	
Strain at break			ISO 527
X Direction	**18**	%	
Y Direction	**18**	%	
Z Direction	**4**	%	
Charpy impact strength (+23°C, X Direction)	**53**	kJ/m²	ISO 179/1eU
Charpy notched impact strength (+23°C, X Direction)	**4.8**	kJ/m²	ISO 179/1eA
Flexural Modulus (23°C, X Direction)	**1500**	MPa	ISO 178

Thermal properties	Value	Unit	Test Standard
Melting temperature (20°C/min)	**176**	°C	ISO 11357-1/-3
Vicat softening temperature (50°C/h 50N)	**163**	°C	ISO 306
Burning behavior			UL 94
Test passed, HB	**0.5**	mm	
Test passed, HB	**1.6**	mm	
Test passed, HB	**3.2**	mm	

Other properties	Value	Unit	Test Standard
Density (lasersintered)	**930**	kg/m³	EOS Method
Powder colour (ac. to safety data sheet)	**White**	-	-

Characteristics

Processing	Chemical Resistance
Laser Sintering, Rapid Prototyping	General Chemical Resistance
Delivery form	**Certifications**
Powder	FDA approval acc. to USP Biological test (classification VI/121°C)

Fig. 3 *Samples Printing Parameters*

After printing, the parts the tumbling device was used to soften the surface layer, remove imperfections after printing, round the edges, and smooth as much as possible and prepare the surface for subsequent surface treatment by painting.

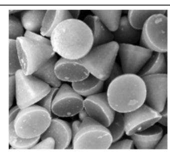
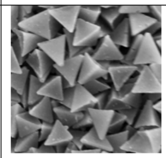
Type	*XS 12 K*	*XS 10 P*	*GP 3X10 A/C*
Image			

Fig. 4 *Bodies used for tumbling*

To smooth and eliminate imperfections after printing, three different types of plastic tumbling bodies from Walther Trowal, were used. These tumbling bodies are adapted for tumbling of plastics. Uniform conditions were set for tumbling parts of the selected tumbling bodies, the tumbling time was set to 25 min and speed of 300 rpm. The previous conditions were chosen so that after pulling the samples out of the tumbling device, the parts would seem sufficiently smooth visually and by touch.

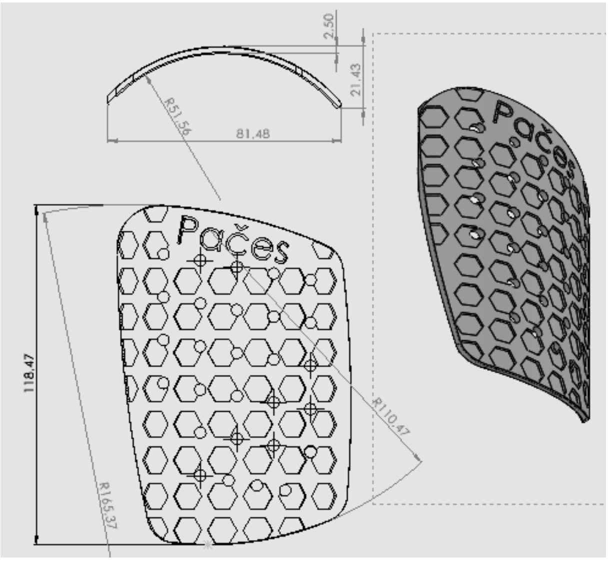


Fig. 5 *Protector model*

3 Surface Roughness Measurement

Roughness measurement was performed on an Alicona InfiniteFocus device, which is used to check the microstructure and surface topography. The device is contactless and it is based on an optical method by focusing the image at a local point. The device captures the topography of the surface, including integrated shape measurement, both 2D (parameter R) and 3D (parameter S). The output of the measurement is a clear and illustrative graphic processing 3D surface roughness parameter Sa - arithmetical mean height of a surface and Sz - parameter is defined as the sum of the largest peak height value and the largest pit depth value within the definition area.

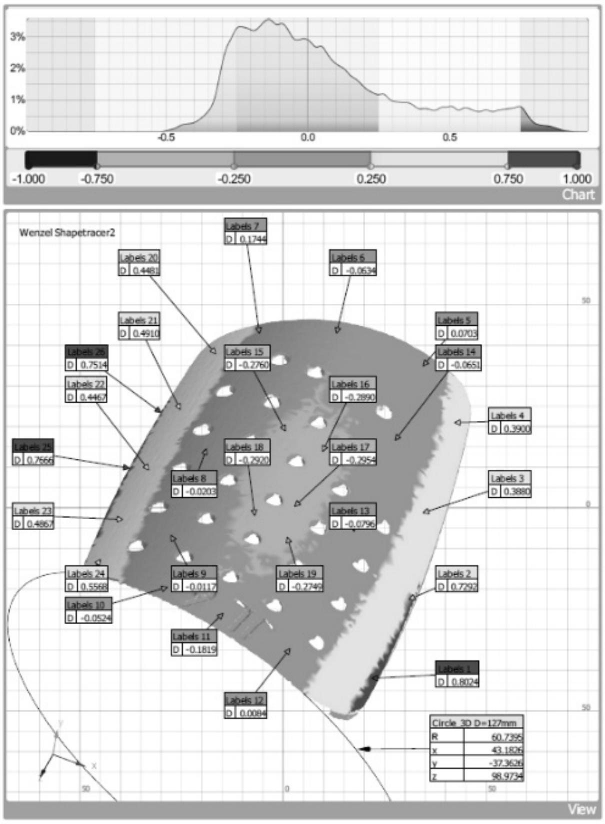


Fig. 6 *Without tumbling, shape deviation evaluation protocol*

Tab 2 *Surface Roughness*

Num.	Types	Sa [μm]			Sz [μm]		
1.	No Tumbling	22.33	17.95	16.39	119.93	122.39	108.33
2.	XS 12 K	6.55	6.59	5.08	133.86	124.46	86.49
3.	XS 10 P	6.58	4.86	4.86	104.97	126.67	126.12
4.	GP 3X10 A/C	15.07	13.09	12.42	147.25	138.54	147.25

Four samples were used to measure roughness, where each sample was treated with a different type of tumbling body. All tumbling processes took place under constant conditions and are therefore expressed as constants and aspects that do not affect the measurement. Every component was measured at 3 locations from which the arithmetic value was expressed. Eavery site was measured 10 times, the extreme values of the analysis were retained.

Tumblers type GP 3X10 A / C have the worst results in the analysis of surface roughness Rz. This surface roughness is higher than before the surface treatment by the tumbling method. Therefore, in terms of surface roughness, I do not recommend the use of a tumbling body type GP 3X10 A / C to smooth the surface.

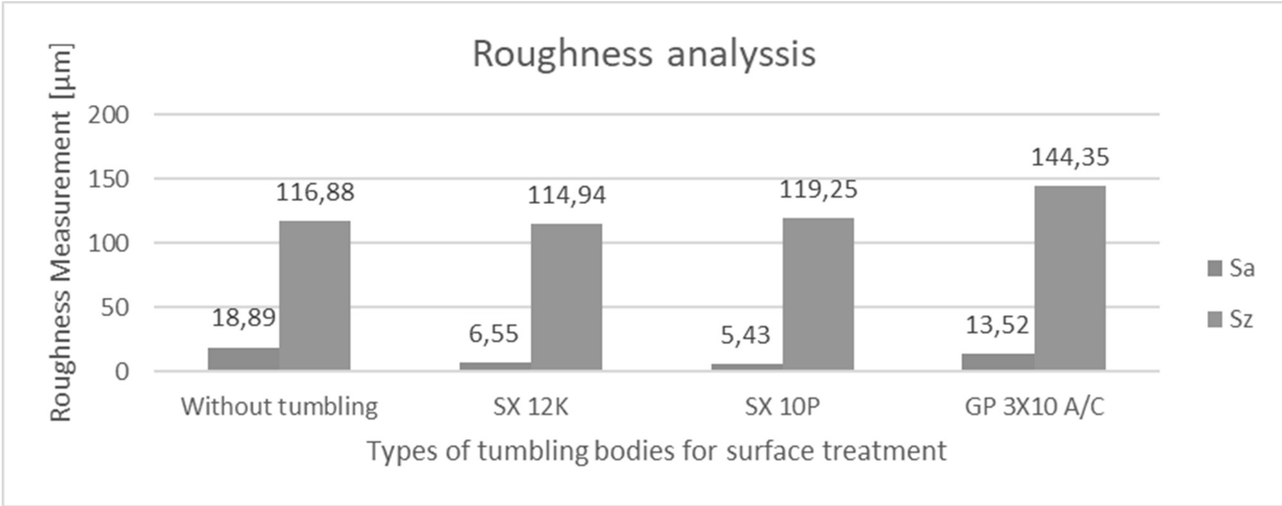


Fig. 6 *Roughness Analysis*

4 Measurement of geometric deviations of the shape

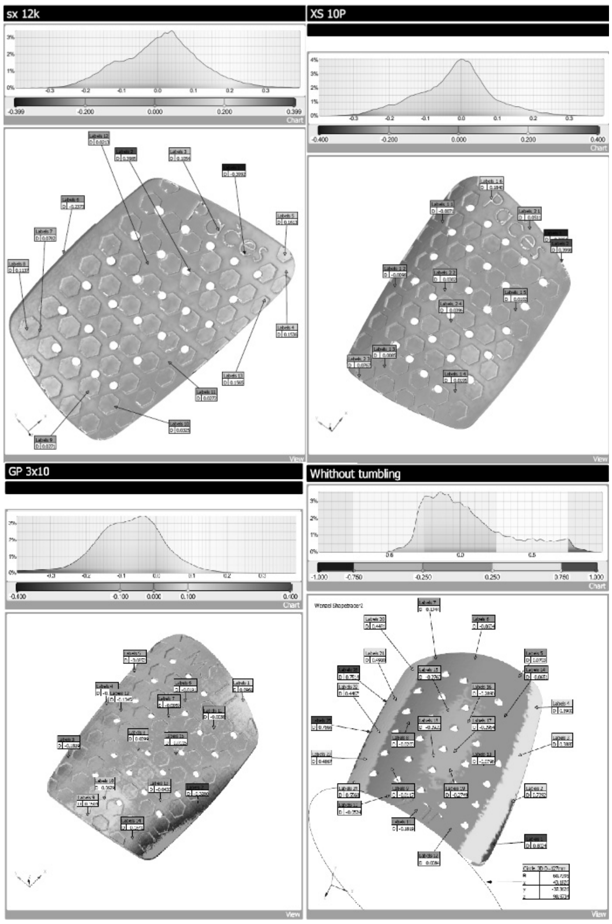


Fig. 7 *Thermographic evaluations of geometric deviation of measured samples*

The measurement was performed on a 3D coordinate measuring machine Wenzel LH 65 X3Premium, using an optical head Sheapetracker II. All measurements were performed with a constant scanning of a set of points. The Best Fit method was used to fit the set of points to the CAD models, the entire outer surface was scanned to evaluate the geometric deviation from the CAD model. The individual effects of tumbling bodies on the surface geometry were investigated. A thermographic map of the distance of deviations from the nominal shape was used for a clear evaluation.

5 Conclusions

Our result was a comparison of the CAD model from the printed samples. The roughness parameters and shape deviation from the CAD model were evaluated. Shape accuracy is directly related to surface quality. At the same time, the sample without tumbling had the largest shape deviations, where the variance of the shape deviation is 1.097 mm, and the difference in angle + 2 ° 67‘12 “compared to the CAD model.

The best result is the sample SX10P, which had the smallest roughness parameter Ra and at the same time the smallest variance of the shape deviation after filtering out the imperfections of the triangulation of the continuity of the set of points to the value of 0.398 mm. This sample was most similar to the CAD model.

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