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To cite this article: A Baier *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **400** 022010

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Studies on optimization of 3D-printed elements applied in Silesian Greenpower vehicle

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Abstract. The paper presents the process of optimization of 3D printing method used to fabricate elements for Silesian Greenpower electric racing vehicle. The bolide has been developed by students of the Silesian University of Technology in Gliwice, Poland as an interfaculty students' project. The main purpose of the work was to optimize 3D printing process parameters, such as printing temperature, layer height, and cooling rate, for further body part's manufacturing for Silesian Greenpower electric vehicle. To achieve that, static tensile tests were carried out in order to analyze data collected from the sensors. Samples used for the tests were made out of polylactide (PLA). Influence of following parameters of 3D printing process has been inspected: printing temperature, layer height and cooling rate. 56 specimens have been fabricated in order to compare the influence of each of the parameters on the tensile strength and Young's modulus of the specimens and hence – parts made for SG electric car. Tests were carried out in compliance with EN ISO 572-2:2012 norm. Results of the tensile test research have been analyzed and discussed and conclusions have been presented in the following article.

1. Introduction

Silesian Greenpower is students' interfaculty project which focuses on design and construction of the electric racing vehicle. There are two main components of the car which are designed in Siemens NX software: the aluminum frame and the body. Shape and dimensions of some elements of the frame (shown in figure 1) such as roll bar are specified by the regulations of Greenpower formula races. The shape of the body is unrestricted and each of the teams designs it on their own. The shape of Silesian Greenpower Bullet SGR car has been designed in Siemens NX and calculated in ANSYS software. It has a bullet shape due to its best aerodynamic properties. In this particular case, aerodynamic drag represents 70 percent of all the frictions that are the consequences of car motion [4]. The main restriction is imposed by the organizers, the power source and type of the motor driving the car, which increases competition level and equalize the chances of teams [6]. Each of the electric cars taking part in Greenpower races is equipped with the same electric motor. The motor is powered by two 12 V batteries with a capacity of 36 Ah each [4]. The main goal is to drive as many laps as possible in a certain amount of time.



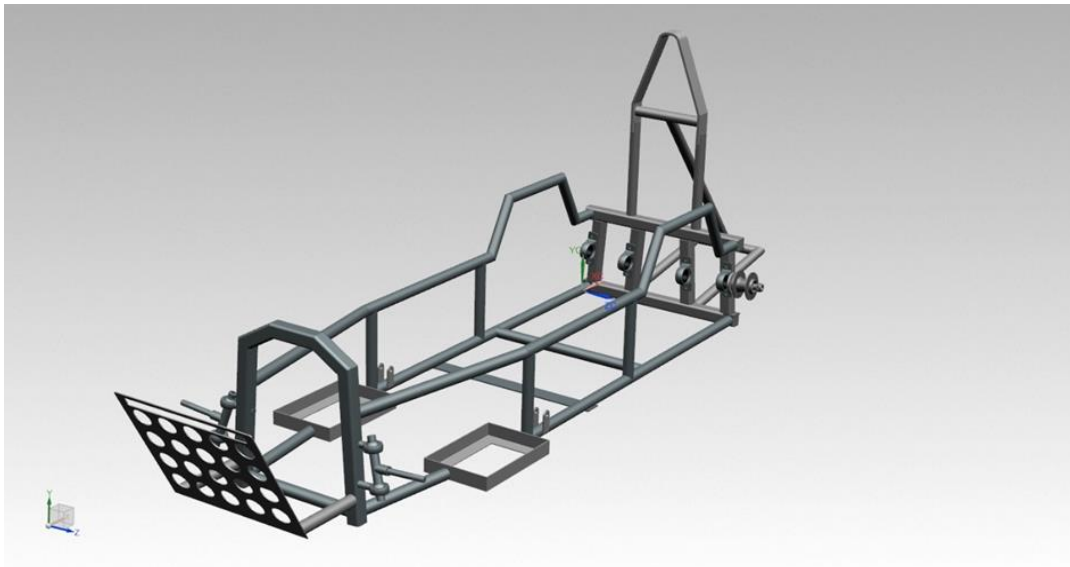


Figure 1. The model of the frame of Silesian Greenpower electric vehicle.

Based on the results obtained during analysis of occurrence of the aerodynamic Kammback effect conditions that should be fulfilled for shape for occurrence of this effect were specified. On this basis, the shape of the vehicle of Silesian Greenpower Race Team, SG2014 Bullet was modeled. The dimensions of the vehicle, length limit, were specified in the rules of races organized by Greenpower Education Trust. Length limit is 2800 mm [7]. The shape of Silesian Greenpower Bullet SGR car has been shown in figure 2.

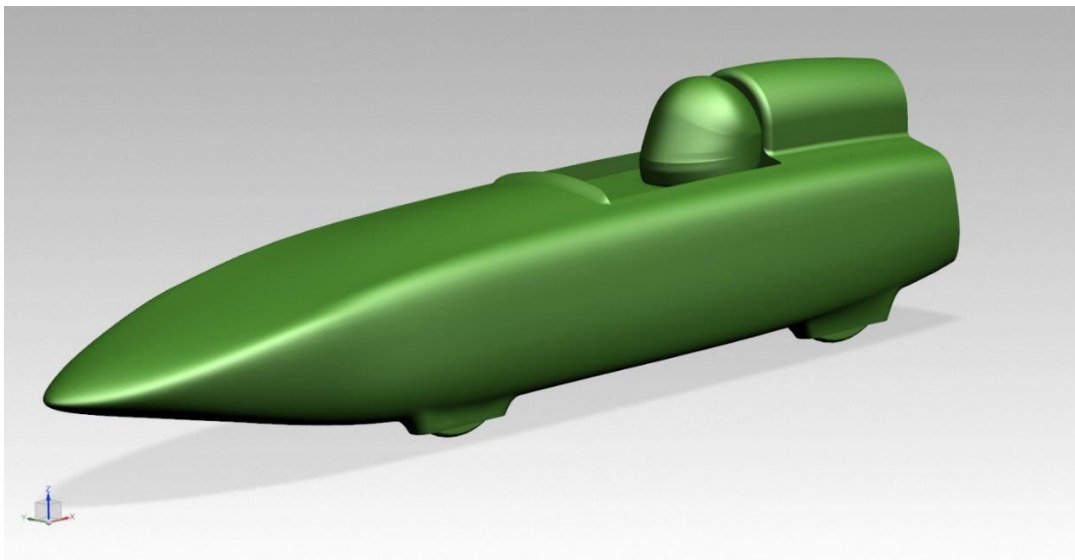


Figure 2. The model of the body of Silesian Greenpower bolide.

1.1. 3D printing

Additive manufacturing is relatively new technology, which has been invented in the 1980s and developed dynamically in last two decades [[1]].

All 3D printing processes offer advantages and disadvantages. The type of 3D printer chosen for an application often depends on the materials to be used and how the layers in the finished product are bonded [8]. 3D Printing is a member of a group of layer manufacturing techniques which have the primary distinguishing feature of creating parts by the controlled addition (rather than subtraction) of material [11]. The three most commonly used 3D printer technologies are: selective laser sintering (SLS), thermal inkjet (TIJ) printing, and fused deposition modeling (FDM) [8]. FDM technology is the most popular manufacturing technology used on the market. In FDM thermoplastic material is pressed through the nozzle to form the modeled shape [[2]].

The 3D printer used to fabricate test specimens was made by 3DGence and had a 0.5 mm nozzle.

Some parts of the Silesian Greenpower vehicles are 3D-printed – fairing and mirror casing (shown in figure 3 and 4). This method allows customizing the shape of an element and its manufacturing.

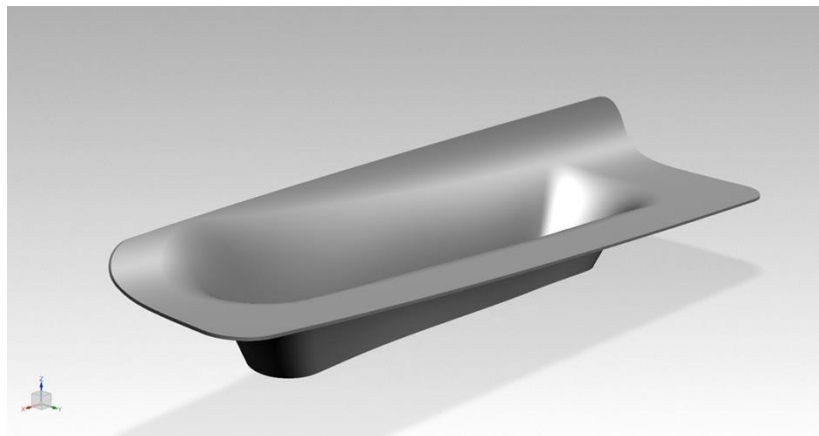


Figure 3. The model of the fairing for back wheels of SG electric vehicle.

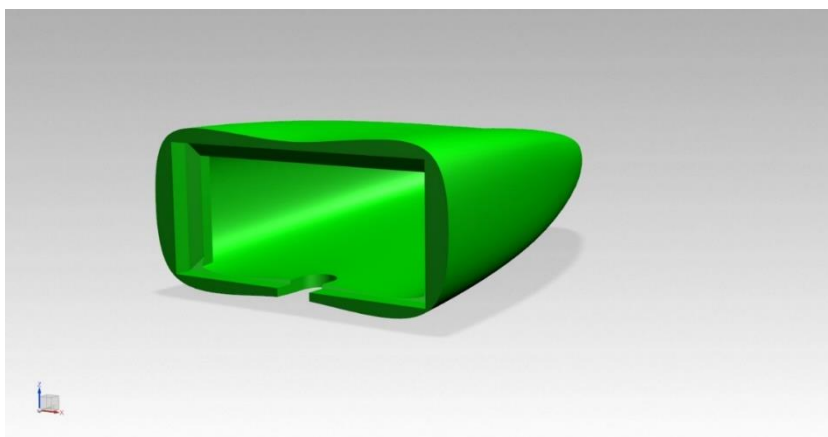


Figure 4. The model of the mirror case.

This case study covers the process of preparation of polylactide specimens with different parameters of the 3D printing process. Parameters inspected during further tests were printing temperature, layer height and cooling rate.

1.2. Tensile tests

Tensile tests measure the force required to break a plastic sample specimen and the extent to which the specimen stretches or elongates to that breaking point. Such tests produce stress-strain diagrams used to determine tensile modulus. The resulting test data can help specify optimal materials, design parts to withstand application forces, and provide key quality control checks for materials. [3]

1.3. Material - PLA

A material used for the tensile test specimens was polylactide – PLA. Polylactic acid is proving to be a viable alternative to petrochemical-based plastics for many applications [9]. PLA is biodegradable and bioactive thermoplastic polyester. It can be made by fermentation of starch-containing agricultural products like potato (waste), rice and alike. The degradation time is 18 to 24 months. PLA copolymer is a blend with glycolide/lactide ratio of 85/15 which has a moderate crystallinity and a degradation rate. [5]. Solid free form fabrication methods, such as 3D printing, can produce complex-shaped articles directly from a CAD model [10].

PLA's basic mechanical properties have been shown in table 1. The material used in 3D-printing process was polylactide (PLA) and was manufactured by 3DGence.

Table 1. Mechanical properties of PLA [5].

Mechanical property	Minimum value	Maximum value	Unit
Density	1210	1430	kg/m ³
Elongation	1.5	380	%
Tensile strength	10	60	MPa
Young's modulus	350	2800	MPa

2. Preparation of specimens and test process

Test objective was to inspect the influence of following parameters of 3D-printing: temperature of printing, layer height and cooling rate on properties of the final product – Young's modulus and tensile strength.

To compare each of the printing parameters, 8 types of specimens were made. In total, 56 samples were printed – 7 of each type. Parameters inspected were: temperature of the printing, layer height and cooling rate. Properties of each type and its values were shown in table 2. The number of outlines remained the same for all of the specimens. The diameter of the filament was 1.75 mm. Table temperature was 65°C.

Table 2. Properties of specimens.

Type	1	2	3	4	5	6	7	8
Printing temperature [°C]	220	220	220	220	185	185	185	185
Layer height [mm]	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1
Cooling rate [%]	50	50	100	100	50	50	100	100

Samples for the static tensile test were modeled in compliance with PN-EN ISO 572-2:2012 standard. The measuring section of the specimen according to the norm is 75 mm (± 0.5 mm) long, 10 mm (± 0.2 mm) wide and 4 mm (± 0.2 mm) thick. The average width, thickness and cross-section area were shown in table 3. Length of the measuring section accepted for test purpose was 75 mm for all specimens. The shape of the specimen (type 1A) was shown in figure 5.



Figure 5. The shape of the specimen – type 1A.

Table 3. Average width, thickness and cross-section area of specimens.

Type	1	2	3	4	5	6	7	8
Width [mm]	10.21	10.09	10.15	10.02	10.02	9.98	10.03	10.08
Thickness [mm]	4.11	4.14	4.04	4.04	3.90	3.99	3.90	3.96
Area [mm ²]	41.96	41.79	41.02	40.49	39.03	39.81	39.10	39.93

2.1. Test

The test was carried out in compliance with PN-EN ISO 572-1:2012 standard. A machine used for the test was Zwick Roell Z050. Pre-load applied on the specimen was 2 MPa. Test speed was 0,008 1/s. The test stand was presented in figure 6. 56 specimens have been inspected.



Figure 6. Test stand with installed specimen– Zwick Roell Z050.

3. Results

The average test result for each of the 8 series were presented in table 4. Stress-strain diagram for Series 5 has been presented in figure 7.

Table 4. Average test results for each series.

	Young's modulus E [MPa]			Tensile strength Rm [MPa]			Maximum force Fm [kN]			Elongation Agt [%]		
	\bar{x}^a	s^b	v^c	\bar{x}	s	v	\bar{x}	s	v	\bar{x}	s	v
1	1050	295	28.1	55	1	2.46	2.32	0.06	2.46	5.14	0.29	5.65
2	925	267	28.91	57	1	1.61	2.39	0.04	1.61	5.57	0.29	5.18
3	1207	136	11.29	56	2	3.87	2.28	0.09	3.87	5.09	0.80	15.77
4	1274	19	1.52	47	4	9.10	1.89	0.17	9.10	3.90	0.29	7.53
5	721	61	8.52	29	2	5.14	1.14	0.06	5.14	4.48	0.70	15.58
6	1232	23	1.84	48	2	4.22	1.91	0.08	4.22	3.96	0.21	5.38
7	781	60	7.62	29	4	14.22	1.14	0.16	14.42	4.21	0.87	20.61
8	1198	92	7.66	48	1	2.26	1.92	0.04	2.26	4.28	0.22	5.12

^aArithmetic average.

^bStandard deviation.

^cPercentage relative deviation.

It can be seen, that Young's modulus varies between of 721 – 1274MPa with the percentage relative deviation in the range of 1.52 – 28.91 % - 2 out of 8 results are more than 25 %, therefore, these results obtained for Young's modulus are not accurate. However, each of the results is in the range of the reference value for PLA. Maximum forces applied vary between 1.14 – 2.39 kN. Percentage relative deviation for tensile strength is between 1.61 – 14.22 %, so results are accurate.

Values of tensile strength are in the range of 29 – 57 MPa. Percentage relative deviation is the same as of maximum force for the corresponding series since tensile strength value is derived from force value. Most of the results of tensile strength are on the higher end of reference value range – 6 out of 8 results are above 45 MPa with the upper limit of 60 MPa. On the contrary, results of the elongation value are on the very low end of reference range with the value between 3.90 – 5.57 %.

Highest Young's modulus value and lowest relative standard deviation represented Series 4 – fabricated with higher printing temperature and cooling rate and lower layer height. On the contrary – the lowest Young's modulus value represented Series 5 and 7 – below 800 MPa. Both of these series were fabricated at lower printing temperature - 185°C.

It can be seen that the highest tensile strength values were obtained for Series 2 and 3 – respectively 57 and 56 MPa. Both series were manufactured at higher printing temperature - 220°C, while the lowest value stands for Series 5 and 7. It can be concluded, that printing temperature has a significant impact on properties of the final item.

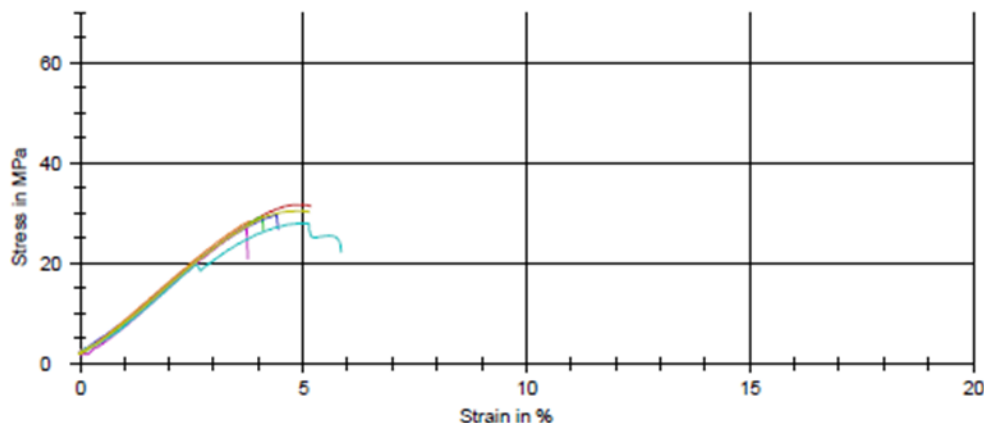


Figure 7. Series 5 stress-strain diagram.

4. Conclusions

The impact of the cooling rate is smaller at lower printing temperatures.

At lower printing temperatures, layer height is very significant. Smaller layer height provides better connection of the outline with the filling, and of the filling itself.

Printing at higher temperatures allows obtaining higher tensile strength. This property of an item – high tensile strength – is crucial for manufacturing high-quality and durable pieces for the Silesian Greenpower electric vehicle – e.g. mirror case.

At higher printing temperature and lower layer height, the higher cooling rate influences fragility of the material – lowers tensile strength significantly. The material is cooled down too rapidly whereby individual strokes did not connect enough with each other.

Low printing temperature and high layer height cause a decrease in tensile strength by almost half, also the outline of the specimen is not well connected with the filling.

Influence of 3D-printing parameters on Young's modulus value could not be determined.

Annotation

Artykuł został napisany w ramach realizowanego projektu „Elektryczny bolid SilesianGreenpower - międzywydziałowy projekt studentów Politechniki Śląskiej” na podstawie umowy o dofinansowanie nr: MNiSW/2017/119/DIR/NN2 z dnia 18.12.2017r. zawartej pomiędzy MNiSW a Politechniką Śląską. Projekt jest realizowany w ramach projektu pozakonkursowego o charakterze koncepcyjnym pt. „Najlepsi z najlepszych 2.0” w ramach Programu Operacyjnego Wiedza Edukacja Rozwój współfinansowanego ze środków Europejskiego Funduszu Społecznego (numer wniosku o dofinansowanie POWR.03.03.00-00-P009/16)

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