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INVESTIGATION OF 3D PRINTING PARAMETERS AFFECTING THE IMPACT STRENGTH

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Abstract: The aim of this study is to investigate the effects of different types of 3D printing parameters on the impact strength, their standard deviations, and the printing time by using UNI EN ISO 180 unnotched specimens manufactured by FDM 3D printing technology. The investigated parameters are printing direction and infill density since they are key factors both in the 3D printing for fun and profit. Every specimen is made of PLA, which is the most basic material of the FDM printing technology by using the same 3D printer. In the study it plays a key role to find out whether a 3D printing parameter can be used to optimize the researched mechanical property within an economical framework or not. What is more, the possibly observable tendencies and crucial influential parameters will be analysed as well.
Keywords: PLA, 3D printing, additive manufacturing, impact strength

1. INTRODUCTION

The additive manufacturing, which is often mentioned as 3D printing, is one of the most dynamic and intensive developing manufacturing technologies.

3D printing has many different types just like SLS (Selective Laser Sintering), SLA (Stereolithography), and FDM (Fused Deposition Modelling) [1][2]. Besides, the 3D printers used to print different types of plastics. However, nowadays there are printers which are suitable to print different types of materials such as metals, ceramics, composites, concretes, and even biomaterials can be printed [2]. Among the 3D printers, which are appropriate to print different types of plastics, the 3D printers using FDM technology are one of the most common and the cheapest ones [3]. Out of the many advantages of 3D printing, the most important one is that almost any kind of complex shapes can be created by using this technology hence it creates the object layer by layer. Therefore, zero or almost zero waste is produced during the process making this technology extraordinarily favourable from the point of view of a waste management. There are a lot of factors affecting 3D printing, but their effect on the mechanical properties is often not properly known for us. This will not cause any problems if the product is a prototype or is produced for a purpose in which it is not exposed to any kind of mechanical impacts.

However, the effects of the printing parameters on the mechanical properties become a key factor if the 3D printed product is any kind of replacement part.

Thanks to the industrial spread of this technology, more and more scientific articles are published in connection with the effect of printing parameters on the mechanical properties during the last few years. Most of these scientific articles investigate their effects on tensile strength or yield strength [3][4][5]. Nevertheless, there are articles examining the printing parameters' effects on the impact strength [6] [7]. These articles concerning the impact strength are mainly related to notched specimens due to the drastic impact strength reduction caused by the stress collector place on the object. In several studies, the effect of infill density, infill pattern, print speed, printing temperature, layer height or other parameters on the impact strength was analysed [8][9]. In every study it was proven that the examined mechanical properties were influenced by the parameters used during the printing, but the degree of influence was different relating to every single parameter [10].

2. MATERIAL AND METHOD

The Polylactic acid or PLA is a biodegradable thermoplastic produced mostly from different types of grains containing a huge amount of starch. In 3D printing, PLA is one of the most common materials especially for hobby hence it has not only a reasonable price, but it can be printed easily without a special printing area. For this reason, it is very easy to work with it without any experience in 3D printing. This material is used especially for producing disposable products over and above in 3D printing, to create prototypes and a huge variety of hobby products. Due to its biodegradability, PLA is extremely advantageous in terms of waste management. It is important to mention that the research made in different scientifical areas pointed out that 3D printed PLA could be often a better choice than traditional technical plastics such as ABS [11].

For the measurements, a Galdabini Impact 25 impact testing machine (Fig.1.) was used. This precision measuring instrument makes it possible to measure to two decimal places and it gives the impact strength immediately if a standard specimen known by the machine is used saving time and preventing the faults caused by the calculation errors.

This measuring instrument has only a 5J hammer making it impossible to measure plastics specimen with higher impact strength. Despite the incorrect values caused by the low measuring limit, it is ideal to measure plastics like PLA. For the proper measurement of technical plastics like ABS, a bigger hammer would be necessary.

For the measurement UNI EN ISO 180 standard unnotched specimens were used (Figure 2), whose dimensions are 80×10×4mm. This type of specimens was chosen, because it is known by the Galdabini Impact 25 impact testing machine making the work faster and more precise. The unnotched type was chosen because the manufacturers test their material by using notched specimens. Nevertheless, in some cases, there is no stress collector on the product causing unnecessary material usage and oversizing if the impact strength measured on notched specimens is used for the designing. The proper impact strength value is especially important in cases when it is the key sizing aspect of the product. In most scientific articles about impact strength, notched specimens were used giving another reason to use unnotched specimens for this research.

The measurements were done in every case at room temperature to make possible comparisons of the results in the future. During the measuring process, the specimen supported at both ends was hit in the middle by the hammer of the Charpy breaking the specimens and making it possible to determine the value of impact strength correctly.

Figure 1. Galdabini Impact 25 impact testing machine

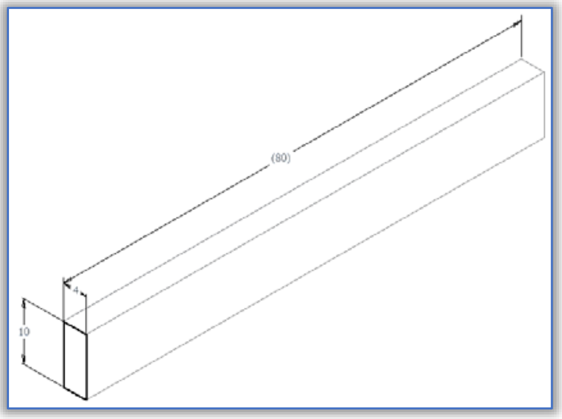

Figure 2. The model of specimen used for the measurements

The 3D printed PLA specimens were produced by using a Creality CR-10S Pro V2 3D printer. This printer provides a very reliable printing due to its built-in self-levelling and filament break detection module. Due to its excellent printing quality and favourable price, this 3D printer is one of the best middle class FDM printers on the market.

The essential Gcodes for the printing were created by the software Ultimaker Cura 4.4 allowing the modification of a huge amount of 3D printing parameters. The Gcodes with different infill density, layer height, and printing direction were made by using this software. For the printing, 3DJake EcoPLA was used with a layer height of 0,2 mm, a printing temperature of 200 °C, and a build plate temperature of 50 °C.

3. RESULTS

— Printing time

Printing time is one of the most crucial features of 3D printing, because in most cases it determines the price of print and that is why the number of products could be produced with this technology economically. The printing time is affected by many factors just like the impact strength. These aspects are among others the infill density (Figure 3) and in some cases the printing direction, because especially complex geometries require so-called support and the incorrectly chosen printing direction can extremely increase the amount of necessary support material and printing time.

The printing time was almost the same for the specimens printed on their 4×80mm and 10×80mm side, while the printing direction 4×10mm doubled this time.

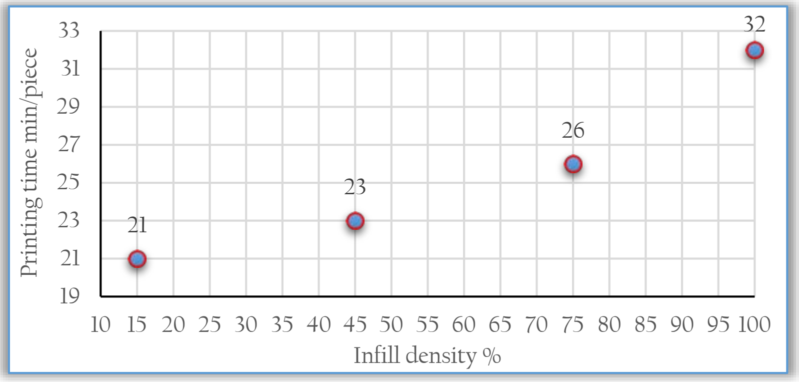

Figure 3. Printing time influenced by the infill density

— 3D printing direction's effect on the impact strength

The printing direction is an important factor as well, hence the appropriately chosen printing direction can reduce both the printing time and the amount of material used as support. However, it can significantly influence the mechanical properties of the product. That is why it is important to decide before the printing what kind of stresses the part must resist and according to it, choose the proper printing direction. In this study, 3 printing directions were investigated (Figure 4). They were created by printing the specimen on its sides with different surfaces.

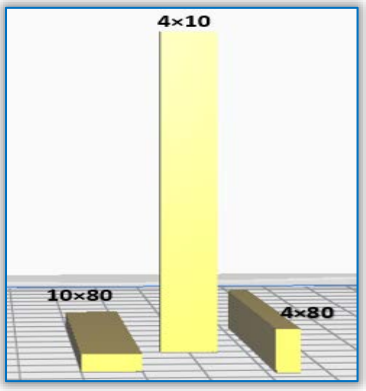

Figure 4. The used printing directions in 3D printing environment

These printing directions' effect on the impact strength were examined by using 100% infill density for every specimen. The examined printing directions were side 4×10mm (Figure 5, Table 1), side 4×80mm (Figure 6, Table 2) and side 10×80mm (Figure 7, Table 3).

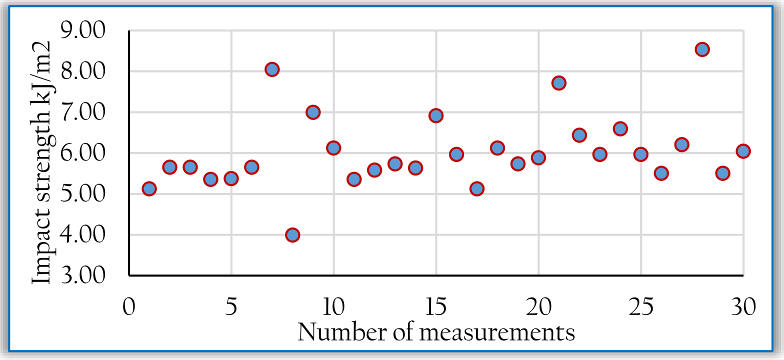

Figure 5. The results of specimens printed on their 4×10 mm side

Table 1. The results of specimens printed on their 4×10 mm side

The results of specimens printed on their 4×10 mm side [kJ/m²]					
PLA-S4×10-1	5,12	PLA-S4×10-11	5,35	PLA-S4×10-21	7,71
PLA-S4×10-2	5,65	PLA-S4×10-12	5,58	PLA-S4×10-22	6,43
PLA-S4×10-3	5,65	PLA-S4×10-13	5,73	PLA-S4×10-23	5,96
PLA-S4×10-4	5,35	PLA-S4×10-14	5,63	PLA-S4×10-24	6,59
PLA-S4×10-5	5,37	PLA-S4×10-15	6,91	PLA-S4×10-25	5,96
PLA-S4×10-6	5,65	PLA-S4×10-16	5,96	PLA-S4×10-26	5,5
PLA-S4×10-7	8,04	PLA-S4×10-17	5,12	PLA-S4×10-27	6,2
PLA-S4×10-8	3,99	PLA-S4×10-18	6,12	PLA-S4×10-28	8,53
PLA-S4×10-9	6,99	PLA-S4×10-19	5,73	PLA-S4×10-29	5,5
PLA-S4×10-10	6,12	PLA-S4×10-20	5,88	PLA-S4×10-30	6,04

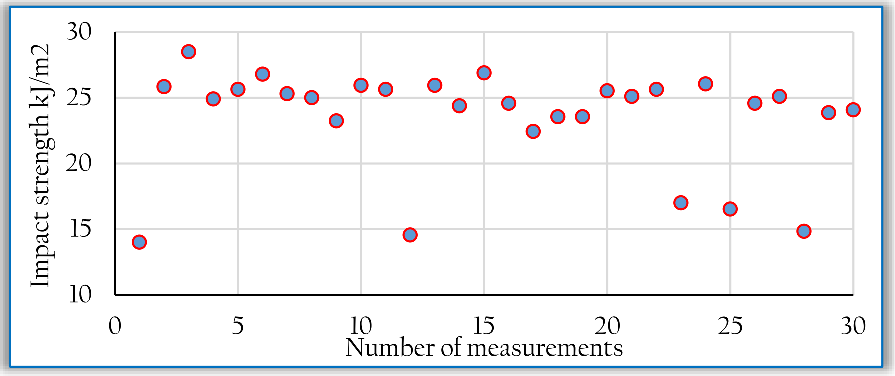

Figure 6. The results of specimens printed on their 4×80 mm side

Table 2. The results of specimens printed on their 4×80 mm side

The results of specimens printed on their 4×80 mm side [kJ/m²]					
PLA-S4×80-1	14,01	PLA-S4×80-11	25,63	PLA-S4×80-21	25,1
PLA-S4×80-2	25,84	PLA-S4×80-12	14,56	PLA-S4×80-22	25,63
PLA-S4×80-3	28,49	PLA-S4×80-13	25,94	PLA-S4×80-23	17
PLA-S4×80-4	24,9	PLA-S4×80-14	24,38	PLA-S4×80-24	26,05
PLA-S4×80-5	25,63	PLA-S4×80-15	26,89	PLA-S4×80-25	16,53
PLA-S4×80-6	26,79	PLA-S4×80-16	24,58	PLA-S4×80-26	24,58
PLA-S4×80-7	25,31	PLA-S4×80-17	22,43	PLA-S4×80-27	25,1
PLA-S4×80-8	25	PLA-S4×80-18	23,55	PLA-S4×80-28	14,84
PLA-S4×80-9	23,24	PLA-S4×80-19	23,55	PLA-S4×80-29	23,86
PLA-S4×80-10	25,94	PLA-S4×80-20	25,52	PLA-S4×80-30	24,07

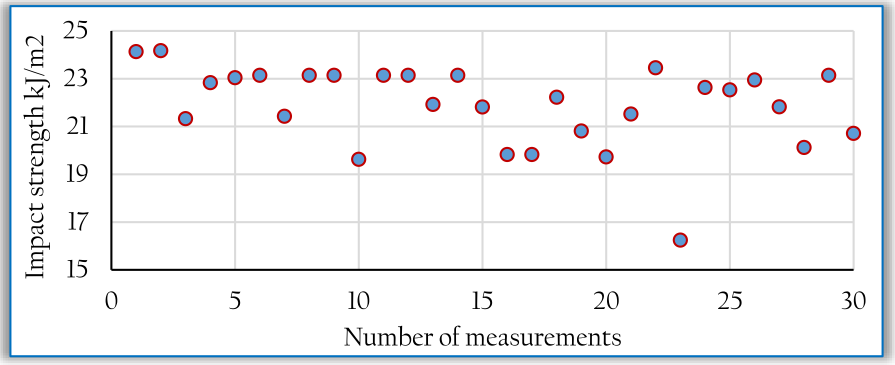

Figure 7. The results of specimens printed on their 10×80 mm side

Table 3. The results of specimens printed on their 10×80 mm side

The results of specimens printed on their 10×80 mm side [kJ/m²]					
PLA-S10×80-1	24,13	PLA-S10×80-11	23,14	PLA-S10×80-21	21,52
PLA-S10×80-2	24,17	PLA-S10×80-12	23,14	PLA-S10×80-22	23,45
PLA-S10×80-3	21,32	PLA-S10×80-13	21,92	PLA-S10×80-23	16,24
PLA-S10×80-4	22,83	PLA-S10×80-14	23,14	PLA-S10×80-24	22,63
PLA-S10×80-5	23,04	PLA-S10×80-15	21,81	PLA-S10×80-25	22,53
PLA-S10×80-6	23,14	PLA-S10×80-16	19,82	PLA-S10×80-26	22,94
PLA-S10×80-7	21,42	PLA-S10×80-17	19,82	PLA-S10×80-27	21,82
PLA-S10×80-8	23,14	PLA-S10×80-18	22,22	PLA-S10×80-28	20,12
PLA-S10×80-9	23,14	PLA-S10×80-19	20,81	PLA-S10×80-29	23,14
PLA-S10×80-10	19,62	PLA-S10×80-20	19,72	PLA-S10×80-30	20,71

As the results have shown, earlier printing direction has a significant influencing effect on the impact strength of the 3D printed part (Figure 8). Especially if the mechanical impact came from thread direction, in this case the impact strength of the specimen decreased to a fraction of the impact strength measured on the specimens produced with the two other directions.

If the product is made by using 3D printing, it is necessary to consider the possible impacts already during the designing process of the product to prevent the impact strength reduction caused by thread direction.

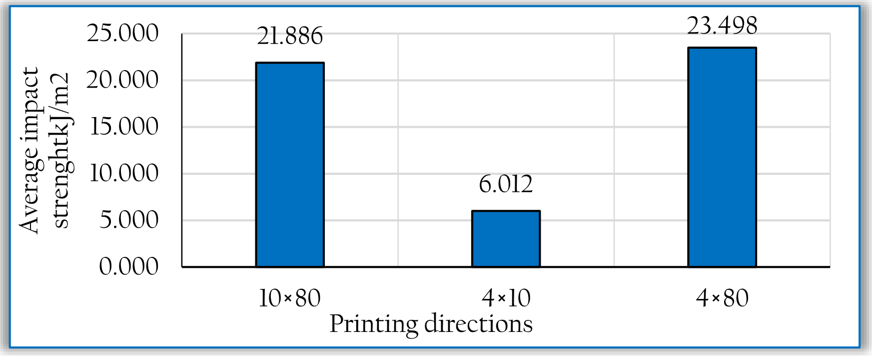

Figure 8. The average impact strength measured on the different printing directions

The printing direction influences not only the average value of impact strength but its standard deviation (Figure 9), too. The highest standard deviation was measured on the specimens with the highest average impact strength while the lowest standard deviation was examined on the specimens with the lowest average impact strength. This can be explained by the number of layers which had to must-be broken.

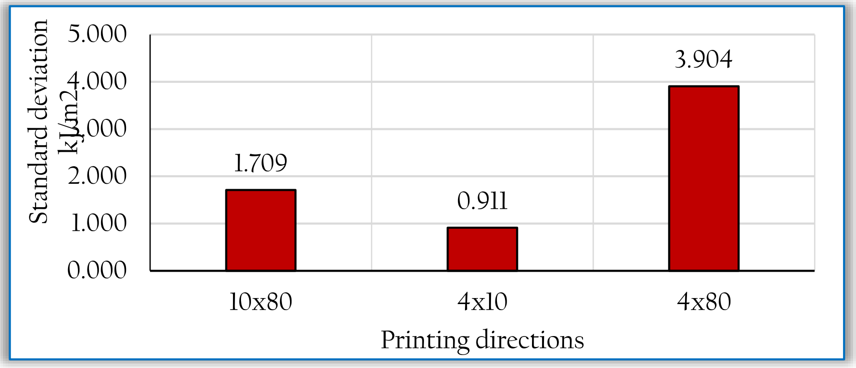

Figure 9. Standard deviation of the different printing directions

— **The infill density's effect on the impact strength**

With the infill density used during the printing process, the printing time, and the amount of material required for printing can be reduced materially. It can be used to create a time- and cost-efficient production. However, the infill density influences not only the material requirement and printing time, but the mechanical properties and the impact strength of the part as well. It is especially important to mention, that the infill pattern used to the given infill density is chosen by the slicer if it is not selected manually. It can lead to mechanical not optimal properties. During the designing of a product, it must be balanced how important its appropriate mechanical properties are. If the part is not exposed to mechanical stresses, it is suggested to use a lower infill density to make the production of the part more economical.

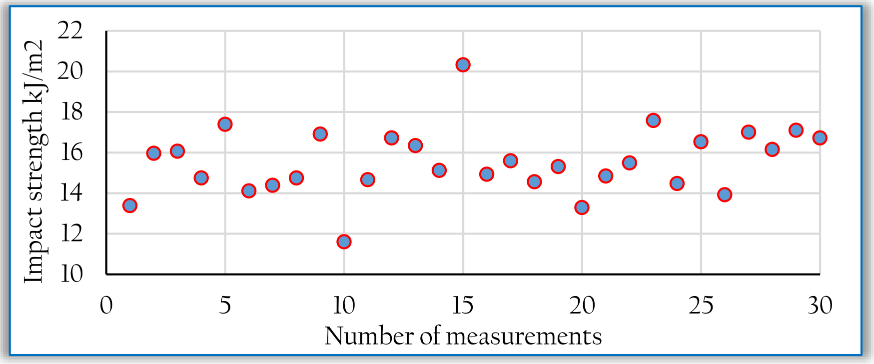

Figure 10. The results of the specimens printed with 15% infill density

Table 4. The results of specimens printed with 15% infill density

The results of specimens printed with 15% infill density [kJ/m^2]					
PLA-ID15-1	13,38	PLA-ID15-11	14,66	PLA-ID15-21	14,84
PLA-ID15-2	15,96	PLA-ID15-12	16,72	PLA-ID15-22	15,49
PLA-ID15-3	16,06	PLA-ID15-13	16,34	PLA-ID15-23	17,58
PLA-ID15-4	14,75	PLA-ID15-14	15,12	PLA-ID15-24	14,47
PLA-ID15-5	17,39	PLA-ID15-15	20,32	PLA-ID15-25	16,53
PLA-ID15-6	14,11	PLA-ID15-16	14,93	PLA-ID15-26	13,92
PLA-ID15-7	14,38	PLA-ID15-17	15,59	PLA-ID15-27	17
PLA-ID15-8	14,75	PLA-ID15-18	14,56	PLA-ID15-28	16,15
PLA-ID15-9	16,91	PLA-ID15-19	15,31	PLA-ID15-29	17,1
PLA-ID15-10	11,6	PLA-ID15-20	13,29	PLA-ID15-30	16,72

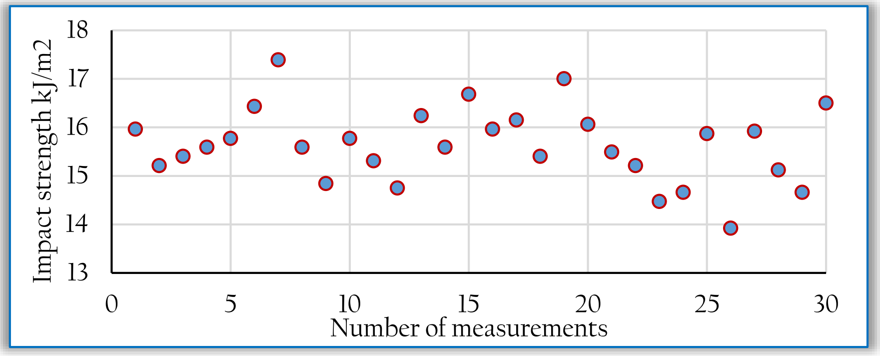

Figure 11. The results of the specimens printed with 45% infill density

Table 5. The results of specimens printed with 45% infill density

The results of specimens printed with 45% infill density [kJ/m^2]					
PLA-ID45-1	15,96	PLA-ID45-11	15,31	PLA-ID45-21	15,49
PLA-ID45-2	15,21	PLA-ID45-12	14,75	PLA-ID45-22	15,21
PLA-ID45-3	15,4	PLA-ID45-13	16,24	PLA-ID45-23	14,47
PLA-ID45-4	15,59	PLA-ID45-14	15,59	PLA-ID45-24	14,66
PLA-ID45-5	15,77	PLA-ID45-15	16,68	PLA-ID45-25	15,87
PLA-ID45-6	16,43	PLA-ID45-16	15,96	PLA-ID45-26	13,92
PLA-ID45-7	17,39	PLA-ID45-17	16,15	PLA-ID45-27	15,92
PLA-ID45-8	15,59	PLA-ID45-18	15,4	PLA-ID45-28	15,12
PLA-ID45-9	14,84	PLA-ID45-19	17	PLA-ID45-29	14,66
PLA-ID45-10	15,77	PLA-ID45-20	16,06	PLA-ID45-30	16,5

During the study, the infill density's effect on the impact strength was measured on 10×80mm specimens. Its reason is that some infill density and infill pattern is not available for narrow 3D printed products. Therefore, the printing direction 10×80mm was chosen hence there were not such complication during their slicing.

During the investigation, specimens with 15% (Figure 10, Table 4), 45% (Figure 11, Table 5), 75% (Figure 12, Table 6) and 100% (Figure 7, Table 3) infill density were used. The infill pattern for 15% and 45% infill density were cubic and lines for the 75% and 100% infill density.

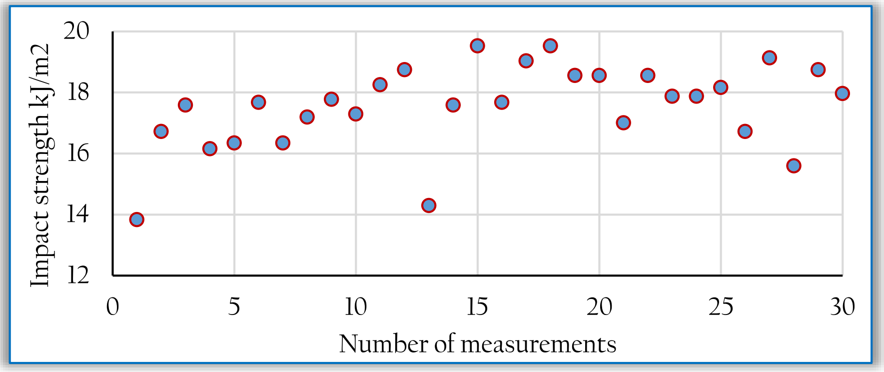

Figure 12. The results of the specimens printed with 75% infill density

Table 6. The results of specimens printed with 75% infill density

The results of specimens printed with 75% infill density [kJ/m^2]					
PLA-ID75-1	13,83	PLA-ID75-11	18,25	PLA-ID75-21	17
PLA-ID75-2	16,72	PLA-ID75-12	18,74	PLA-ID75-22	18,55
PLA-ID75-3	17,58	PLA-ID75-13	14,29	PLA-ID75-23	17,87
PLA-ID75-4	16,15	PLA-ID75-14	17,58	PLA-ID75-24	17,87
PLA-ID75-5	16,34	PLA-ID75-15	19,52	PLA-ID75-25	18,16
PLA-ID75-6	17,67	PLA-ID75-16	17,67	PLA-ID75-26	16,72
PLA-ID75-7	16,34	PLA-ID75-17	19,03	PLA-ID75-27	19,13
PLA-ID75-8	17,19	PLA-ID75-18	19,52	PLA-ID75-28	15,59
PLA-ID75-9	17,77	PLA-ID75-19	18,55	PLA-ID75-29	18,74
PLA-ID75-10	17,29	PLA-ID75-20	18,55	PLA-ID75-30	17,96

The results show that the increment of infill density increases the value of the impact strength (Figure 13). The standard deviation did not show any tendency (Figure 14), but the lowest value was measured on specimens with 45% infill density. The reason can be found in the stable internal structure provided by this infill density. In the case of the infill pattern, the increment of infill density increased the standard deviation. However, it must be mentioned, that specimens with higher impact strength show higher standard deviation in general. Therefore, a lower scale for infill density would be better to show the possible tendencies.

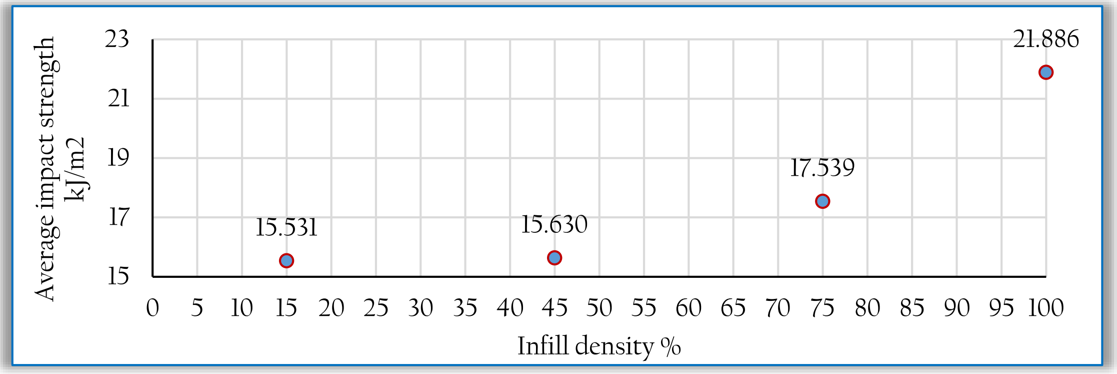

Figure 13. The infill densities effect on the average impact strength

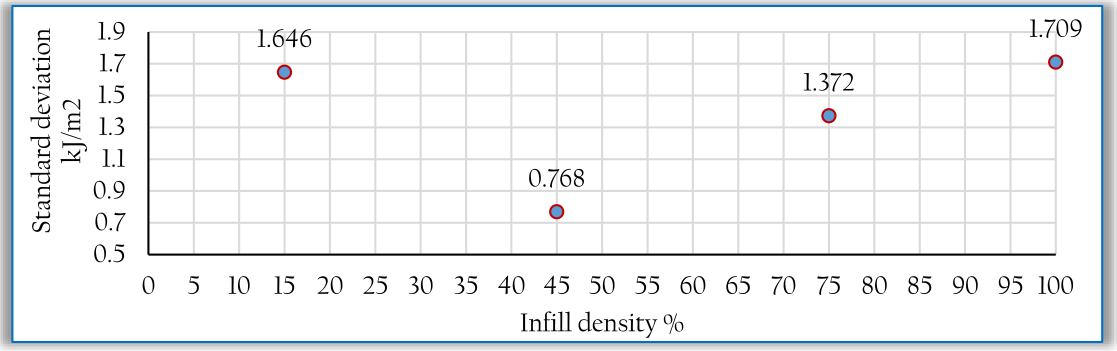

Figure 14. The infill densities effect on the standard deviation

4. CONCLUSION AND FUTURE WORKS

Based on the measurement results, it can be determined that all the examined parameters influence the impact strength and its standard deviation. At the printing direction, thread direction must be mentioned because it drastically influences the values of the impact strength. If the direction of the impact and the thread direction are not the same, the values of impact strength move within the margin of error.

The tendencies, which can be noticed in the case of standard deviation, are caused by the lower average impact strength and the different accuracy of the specimens' internal structure. It must be mentioned that in case of impact strength specimens changing the printing direction was a good way to improve the mechanical properties. However, in case of complex shaped products printing direction can influence the printing time much better than the impact strength due to the additional support material consequently this parameter is not always suitable to increase the impact strength economically.

Finally, there is another tendency which can be noticed showing that the increment of the infill density increases both the impact strength and the printing time. However, in this case the value of impact strength can be raised more economically. In the view of standard deviation, the 45% infill density is the most stable out of the researched ones, which can be explained with the formation of a stable internal structure.

References

[1] J. R. C. Dizona, A. H. Espera Jr., Q. Chena, R. C. Advinculaa, Mechanical Characterization of 3D-printed Polymers, Additive Manufacturing, Vol. 20, 2018, pp. 44-67
[2] N. Shahrubudina, T. C. Leea, R. Ramlana, An Overview on 3D Printing Technology: Technological, Materials, and Applications, Procedia Manufacturing, Vol. 35, 2019, pp. 1286-1296
[3] G. Ćwikła, C. Grabowik, K. Kalinowski, I. Paprocka, P. Ociepka, The Influence of Printing Parameters on Selected Mechanicalproperties of FDM/FFF 3D-printed Parts, IOP Conference Series: Materials Science and Engineering, Vol. 227, 2017, pp. 1-10
[4] A. J Qureshi, S. Mahmood, W. L .E Wong, D. Talamona, Design for Scalability and Strength Optimisation for Components Created tThrough FDM Process, Proceedings of the 20th International Conference on Engineering Design (ICED 15, Milan, Italy, 27-30 July, 2015, pp. 255-266
[5] K. G. J. Christiyan, U. Chandrasekhar, K. Venkateswarlu, A Study on the Influence of Process Parameters on the Mechanical Properties of 3D Printed ABS Ccomposite, IOP Conference Series: Materials Science and Engineering, Vol. 114, 2016, pp. 1-8
[6] A. K. Sood, R. K. Ohdar, S. S. Mahapatra, Parametric Appraisal of Mechanical Property of Fused Deposition Modelling Processed Parts, Materials and Design, Vol. 31, 2010, pp. 287-295
[7] L. Wang, D. J. Gardner, Effect of Fused Layer Modeling (FLM) Processing Parameters on Impact Strength of Cellular Polypropylene, Polymer, Vol. 113, 2017, pp. 74-80
[8] M. Samykano, S. K. Selvamani, K. Kadirgama, W. K. Ngui, G. Kanagaraj, K. Sudhakar, Mechanical Property of FDM Printed ABS: Influence of Printing Parameters, The International Journal of Advanced Manufacturing Technology, Vol. 102, 2019, pp. 2779-2796
[9] S. Wang, Y. Ma, Z. Deng, S. Zhang, J. Cai, Effects of Fused Deposition Modeling Process Parameters on Tensile, Dynamic Mechanical Properties of 3D Printed Polylactic Acid Materials, Polymer Testing, Vol. 86, 2020
[10] D. Popescua, A. Zapciua, C. Amzab, F. Baciuc, R. Marinescud, FDM Process Parameters Influence over the Mechanical Properties of Polymer Specimens: A review, Polymer Testing, Vol. 69, 2018, pp. 157-166
[11] N. Yanar, M. Son, E. Yang, Y. Kim, H. Park, S-E. Nam, H. Choi, Investigation of the Performance Behavior of a Forward Osmosis Membrane System Using Various Feed Spacer Materials Fabricated by 3D Printing Technique, Chemosphere, Vo. 202, 2018, pp. 708-715
[12] Y. Song, Y. Li, W. Song, K. Yee, K.-Y. Lee, V. L. Tagarielli, Measurements of the Mechanical Response of Unidirectional 3D-printed PLA, Materials and Design, Vol. 123, 2017, pp. 154-164

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