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INVESTIGATION OF THE HIDDEN POTENTIAL IN 3D PRINTING MATERIAL POLYLACTIC ACID KNOWN AS PLA

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Abstract: The aim of this study is to investigate the effect of different additives on the average impact strength and on its standard deviation of the in FDM 3D printing widely used polylactic acid (PLA) by using UNI EN ISO 180 unnotched specimens. During the study, PLA based printing materials were investigated containing different types of additives. All specimens were produced by using the same printing parameters to prevent their impact strength modifier effect. The purpose of the research was to determine the extent to which the value of average impact strength, and its standard deviation can be influence using different additives. In the study it plays a key role to find out whether an additive can be used to optimize the researched mechanical property or not. Furthermore, to prove that there is a great, hidden potential in development of printing materials with different additives.
Keywords: PLA, 3D printing, additives, additive manufacturing, impact strength

1. INTRODUCTION

Nowadays, 3D printing is one of the most dynamic and fastest developing manufacturing technologies being considered by many people to be just one of the technologies that will determine the future. However, the phrase 3D printing became a collective concept since there are many different 3D printing processes. If we only want to differentiate the processes according to the used raw material, there are 3D printing processes for plastics (FDM, SLS, SLA), for metals (DMLS), for ceramics, for biomaterials etc [1].

The aim of all these processes is to use the advantages provided by the 3D printing e.g., the possibility of implementing complex geometries and the reduction of waste [2]. By the expansion of 3D printing, there is a user demand not only for newer and newer 3D printing processes but for printing materials for the existing processes that are as perfect as possible, and which can meet as many expectations as possible [3]. This progress is well exemplified by the fact that year after year newer and better printing materials are developed, which, of course, require very different printing conditions [4]. These conditions demanded by the different printing materials are especially conspicuous in FDM 3D printing technology, which is a popular process for both the hobby and the industrial 3D printing [5]. While some printing materials, called filaments, can be printed at a relatively low temperature and in open printing space, others require extremely high temperature and enclosed space [6]. This results a huge difference between 3D printers for hobby purpose and industrial 3D printers both in performance and in price. These differences largely divide the manufacturers as some manufacturers develop material exclusively for industrial purpose and often make special 3D printers for them, while the others try to satisfy the demands of every participant on the market. The latter tends to optimize the PLA being the most basic material of FDM 3D printing by using different additives can be noticed [7][8].

Its reason is that PLA has extremely favourable properties for 3D printing as it can be printed at a relatively low temperature (190°C<), and it demands neither a closed printing space nor a special printing surface so it can be a compatible printing material for almost every FDM 3D printer. The purpose of the use of additives is to associate favourable mechanical and other properties to the favourable printing properties [9]. Many studies have been made in connection with the impact strength of PLA, but they have basically examined the effect of different printing parameters [10][11] and not the effect of different additives [12].

2. MATERIAL AND METHOD

Polylactic acid known as PLA is a biodegradable thermoplastic made of cereals containing high amount of starch. Thanks to its biodegradation, PLA is advantageous in the point of waste management. Furthermore, PLA has many favourable properties in the in terms of 3D printing. It can be printed at relative low temperatures, and it is a non-toxic material making this material suitable even for educational purposes.

During the measurements PLA filaments containing different types of additives were tested. Some of them were only in test phase, while the others are already on the market.

— Material1

The first measured material was a common PLA, which can be found on the market as Filaticum PLA. This material was made for hobby use meaning that it can be printed easily, and it demands neither a special 3D printer nor special printing circumstances.

— Material2

The second material was only in experimental phase. It was a PLA containing ceramic additives in hope of an improvement in the mechanical properties of the material, while providing the favourable printing properties of the polylactic acid meaning that it can be printed easily with any kind of FDM 3D printer.

— Material3

The third material was a PLA containing impact-resistant plasticizer to improve its mechanical strength especially its impact strength, while keeping the favourable printing properties of the polylactic acid. During the study, the final test of this material was made. Right now, it can be found on the market with the name of Filaticum PLA High Impact.

— Material4

The fourth PLA based material was a close relative of the third one. The only different between them was that this printing material contained less impact-resistant plasticizer. The aim of this development was to create a printing material, which can be printed as easy as the first material, while it is softer than the third one. The final test of this material was made during this study as well, and it already can be found on the market as Filaticum PLA Advanced PRO.

— Material5

The fifth examined PLA based material was in experimental phase and it contained both impact-resistant plasticizer and ceramic additives. The aim of this development was to improve the mechanical properties of the PLA and to eliminate the problems caused by the stiffness and low softening temperature of the material, while keeping its advantageous printing properties.

— Measuring method and printing parameters

For the measurements, a Galdabini Impact 25 Charpy machine was used, which was equipped with a 5J hammer. This machine provided ideal circumstances for the testing of the specimens because its hammer was suitable for the testing of materials with low impact strength [10].

During the study, UNI EN ISO 180 unnotched specimens were used, which are prisms with 80×10×4 mm long sides. This type of specimen was chosen because most of the studies were made by using notched specimens but there can be cases when there is not any stress collector place on the part. That is why, it is important to know how the materials will behave without a stress collector place.

For the printing a CraftBot2 FDM 3D printer was used, which was equipped with an extruder having a 0.4 mm nozzle size. For the creation of the G-code CraftWare slicer was used. All specimens were printed out by using the same G-code to provide the same printing parameters and conditions for every investigated material. The specimens were printed with the printing parameters of 0,3 mm layer height to provide a balance between the printing speed and the resolution [13]. To provide good mechanical properties, 3D Triangle grid infill pattern with 45% infill density. The specimens were printed on their 80×10 mm side by using 215 °C printing temperature and 60 °C bed temperature by using a printing speed of 50mm/s.

3. RESULTS

— Effect of impact-resistant plasticizer additive

As it was mentioned before, the difference between material3 and material4 is the amount of impact-resistant plasticizer additive. That is why, it can be interesting how the amount of the additive influences the impact strength and its standard deviation.

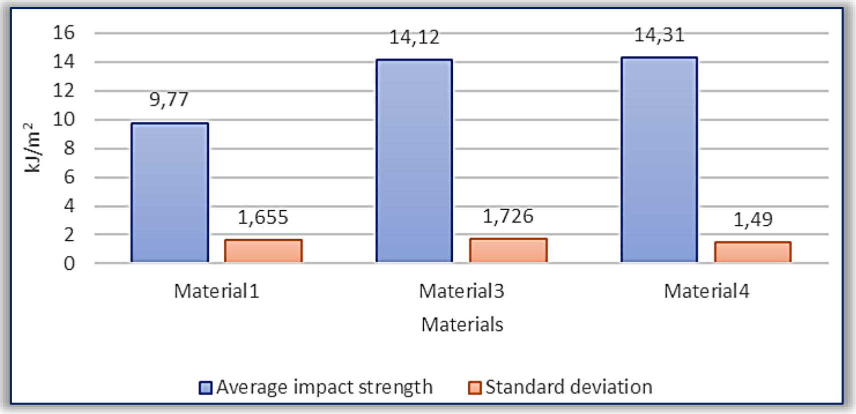

Figure 1 – The effect of impact-resistant plasticizer additive

As shown on figure1, material4 performed better, which is surprising since it contained less impact-resistant plasticizer additive. In the case of average impact strength, the difference between material3 and material4 is within the measurement error limit because it is less than 2%. However, the by 10% lower standard deviation measured on material4 is significant. Compared with material1, it can be determined that the use of impact-resistant plasticizer additive improved the average impact strength by 40% and the standard deviation by 10% in the case of material4. The figure also shows that the overuse of impact-resistant plasticizer additive leads to worse impact strength and standard deviation.

— Effect of ceramic additive

As it was mentioned before a PLA containing only ceramic additive was examined.

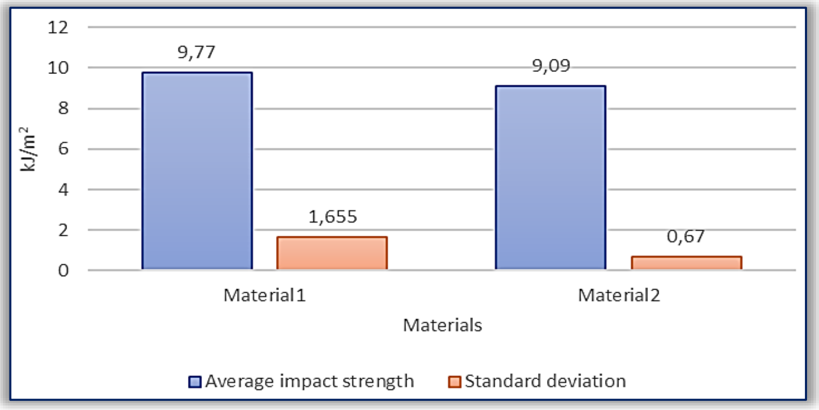

Figure 2 – The effect of ceramic additive

As shown on figure 2, the use of ceramic additive did not bring a positive result in terms of average impact strength since its use slightly reduced the average impact strength compared to the average impact strength of the basic PLA. However, it reduced the standard deviation of the impact strength by almost 60% compared to the value of the basic one.

— Combined effect of impact-resistant plasticizer and ceramic additives

Presenting the results of printed materials containing different additives, it has already become apparent that there are different degrees of difference in both the average impact strength and the standard deviation for each additive.

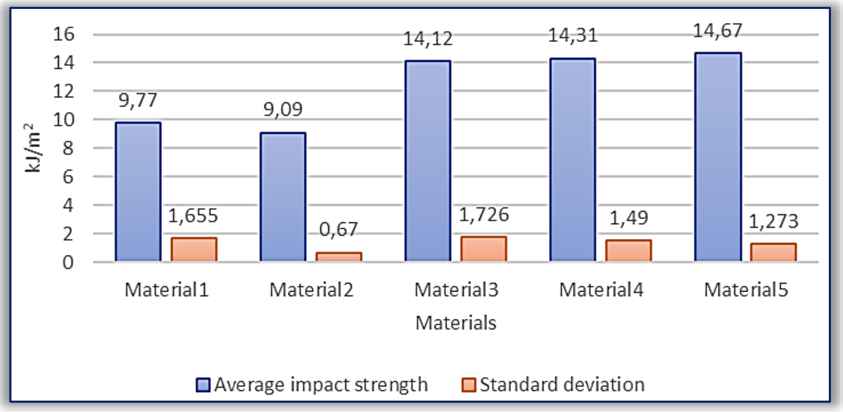

Figure 3 – The combined effect of impact resistant plasticizer and ceramic additives

As shown on figure 3, the use of additives improved the average impact strength and its standard deviation almost in every case. The only exceptions were material2 in terms of average impact strength and material3 in terms of standard deviation. Regarding average impact strength, the most optimal material was material5 containing both ceramic and impact-resistant plasticizer additives improving the average impact strength by 50%. However, the use of impact-resistant plasticizer significantly improved the average impact strength in general. This is well demonstrated by the fact that the second and third highest average impact strength were produced by material3 and material4 containing only impact-resistant plasticizer. However, in the case of specimens containing only ceramic additive, a reduction in average impact strength was observed. As for the standard deviation, the use of only ceramic additives brought the best result with an about 60% reduction in it. As it was mentioned previously, the use of impact-resistant plasticizer additive improved the standard deviation only until a given amount. Comparing material2 and material5, it can be noticed that the combined use of ceramic and impact-resistant plasticizer additive significantly improved the average impact strength, but the value of standard deviation also doubled.

4. CONCLUSION

After the measurements, it can be determined that the use of different additives can extremely influence both the average impact strength and its standard deviation. Furthermore, it can be established that the use of additives is not only suitable to influence the mechanical characteristics, but it can easily change other properties of the material too. During the measurements, several trends could be observed. The most important one was that the overuse of impact-resistant plasticizer debase both the average impact strength and its standard deviation.

In addition, another important inference is that individual additives alone can have a completely different effect on the properties of the printing material than in combination with other additives. In total, it can be determined that it is worth adding different additives to printing materials because the printing materials can be modified on an extremely wide scale by using proper additives.

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