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DEVELOPMENT OF SOFTWARE FOR IDENTIFICATION OF FILAMENTS USED IN 3D PRINTING TECHNOLOGY

Abstract

The aim of the work was to develop a computer program that allows identification of polymer materials that are used in 3D printing technology. The computer program was made using the algorithm that concerns the method of thermal polymer degradation. Filament samples were prepared for this purpose and then set on fire. The collected data on the flammability of polymers was used in an algorithm that can make a decision to identify the name of the polymer. The software can be used to identify polymer prints used for 3D printing technology. The computer program supports the process of recycling plastics and supports ecological work.

1. INTRODUCTION

At present, plastics belong to one of the most popular construction materials. Their mechanical, physical and chemical properties make it possible to use polymers in many industrial sectors. Over the last years, there has been a large increase in the production of plastics materials, which is associated with their increased use, causing the displacement of other production materials (Klepka, 2014; Wittbrodt, Glover, Laureto, Anzalone, Oppliger, Irwin & Pearce, 2013).

Thanks to its numerous advantages, such as the ease of forming products with complex shapes, chemical resistance and high mechanical strength in relation to low density, plastics have found application in additive printing technology (Garbacz & Dulebova, 2013).

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Low production costs of input production materials and ease of access to polymer filaments led to the development of 3D printing technology (Pearce et al., 2010).

3D printing is carried out by applying a thermoplastic material pressed through the nozzle. The nozzle is heated to the plasticizing temperature of the given material. The material flow is limited by a nozzle that moves automatically. In this way, the model is produced layer by layer. The requirement to obtain an acceptable product is to choose the right polymer filament and technological parameters that apply to it (Garbarczyk, Józefowic & Rybarczyk, 2014). Identification of the polymeric material is important not only due to the selection of material for the production of the product, but also due to its identification in the recycling process (Błędzki & Kardasz, 1998). Therefore, an attempt was made to develop software for the identification of filaments used in 3D printing technology (Korga & Flis, 2018).

2. PROBLEMATICS ON POLYMER FILAMENT IDENTIFICATION

There are many methods to identify polymers, but they are mainly expensive laboratory methods. Therefore, one of the most popular methods for identifying polymers is the use of recycling marks (Broniewski, Kapko & Płaczek, 2000). This method was introduced by the Ministry of the Environment in accordance with art. 17 section 2 of June 27, 1997 on waste. Markings of polymer products using recyclable marks enabled the development of the so-called Material recycling. It is a process that uses polymer waste instead of input polymers to produce materials. This type of recycling allows you to reduce the consumption of oil, emissions of harmful compounds for the environment and energy consumption. The disadvantages of the process are psychological barriers, public opinion, quality of processed plastics, ecology and gas emissions (Okamoto, 2003; Mroziński, 2010). Unfortunately, in most cases, products obtained using 3D printing technology are not marked with recycling marks, which makes their identification difficult. The problem of identifying filaments and polymer prints can be solved by using the thermal decomposition method. It consists in observing changes in chemical properties of the polymer as a result of providing an elevated temperature value for the analyzed polymer (Błędzki & Faruk, 2006; Wróblewska-Krepsztul, Michalska–Pożoga, Szczepiński & Szczepiński, 2017).

The use of the thermal decomposition method of polymers gives the possibility of sorting and segregating which results in obtaining more materials that can be recycled. The complexity of the thermal decomposition process of polymers causes some difficulties regarding the analysis of many observed factors. The use of computer aided systems may be a great facilitation of the decision making process regarding the identification of a polymer (Rosato, Rosato & Schott, 2010).

3. POLYMER IDENTIFICATION USING THE THERMAL CUTTING METHOD

Before starting the process of burning polymers, the samples were collected on the basis of markings placed on them by the manufacturer. Analyzing the current scientific and research work and review of available literature dealing with the subject of polymer identification, they were identified and then cleaned and subjected to fire tests (Przygodzki, Włochowicz & Janowska, 2007).

Tab. 1. Identification of polymers based on thermal decomposition of the sample

The name of the filament	View of prepared filament samples	The initial temperature of the sample [°C]
Ultra PET		20
PETG		20
PLA		20
ABS		20
Rubber		20

The sample was placed in the holders, keeping it in the flame of the burner until it was ignited. The sample was slowly heated to observe all occurring phenomena. During the test, characteristic features of the burning sample were recorded, for example: the color of the flame, the smell of smoke, the ease of smoking and the self-extinguishing process.

3.1. Preparation and characterization of samples on the form polimer filaments

In order to carry out the research process, a set of polymer samples in the form of a filament was prepared. All prepared samples were produced by one manufacturer – Spectrum Premium 3D Filaments. The samples were taken from the manufacturer's hermetically sealed packaging, therefore no purification process was carried out. Samples prepared for testing have the same length and diameter. A set of filament samples is shown in Table No. 1.

3.2. Thermal decomposition processes of polymeric filaments

The research process using the thermal polymer decomposition method was carried out on previously prepared samples. A butane burner was used to trigger the filament burning process. The combustion of samples took place in the environment. The flame temperature of the burner was 1150 °C. The view of burned filament samples is shown in table 2.

On the basis of observations of the combustion process of samples, information on the behavior of the polymeric material in the flame environment was collected. The collected data was used to build the algorithm of the program enabling the decision-making processes concerning the identification of polymeric materials.

Tab. 2. Identification of polymers based on thermal decomposition of the sample

The name of the filament	View of filament samples subjected to a fire test	Flame temperature (gas burner – butane) [°C]
Ultra PET		1150
PETG		1150
PLA		1150
ABS		1150
Rubber		1150

4. DEVELOPMENT OF THE PROGRAM FOR POLYMER PLANT IDENTIFICATION

The repeatability of the occurrence of flammability characteristics, which are found in the literature as tabular data, makes it difficult to identify the polymer with the highest probability. Therefore, an attempt should be made to develop software that would allow the identification of polymers in the analysis of similar material properties of incinerated polymers (Rabek, 2013).

This type of software analyzing the flammability characteristics allows to determine the material from which the filament or product was made (Matuana, Park & Balatinecz, 1998). Identyfications of the material has shown in the table 3.

Tab. 3. Identification of polymers based on thermal decomposition of the sample

Type of material	Behavior of the material after smoking in a flame	Look and the color of the flame	Odor/smoke	Plastic changes during heating
ULTRA PET (Polyethylene terephthalate)	After burning, it burns further	Steming, yellow with a blue center, drips with burning drops	Similar to the smell of burned paraffin	It melts very easily, loses its turbidity, is neutral
PETG (polyethylene terephthalate with admixture of glycol)	After burning, it burns further	It does not burn and it does not choke	The smell of vinegar	Decomposition at low melting temperatures
PLA (Polilaktyd)	After igniting, it goes out	Low flammability – goes out	Similar to the smell of burned paraffin	It does not emit smoke
ABS (Acryl-nitrile-butadiene-styrene)	After igniting, it goes out	Flame bright, low flammability, dripping drops	Sweet aroma	It does not emit smoke
Spectrum Rubber (elastomer Rubber)	After burning, it burns further	Yellow flame, black charring of the material	Smell strangling	Smoke

4.1. Develompment of an algorithm for the identification of polimer materials

In order to identify polymers based on fire tests, proprietary software was created on the basis of table No. 3. The user of the program, having information about the behavior of the polymer during its combustion, selects material features from four drop-down lists. Material characteristics of the material burned were divided into four main groups:

- material behavior after the heating process,,
- the appearance and color of the flame,
- smell of fumes,
- plastic deformation during heating.

The number has been assigned to each polymers feature from a given group. The zero position of each group refers to the polymer with the number zero. Each item of the first of the four groups concerns the first polymer, etc. By selecting material features, the user determines the selected item from the four lists. Selected values are passed to the one-dimensional matrix. Each cell in the matrix was assigned a space for the value from the corresponding list. Data from the matrix are calculated using the statistical fashion function. The answer of the function is the numerical value most often found in the matrix. This value is sent to the Case structure selector. Particular cases of this structure were assigned polymer materials according to the numbering found in the four lists. The Case selector invokes the display of the identified polymer in this way. The scheme of the program's algorithm is shown in Figure 1.

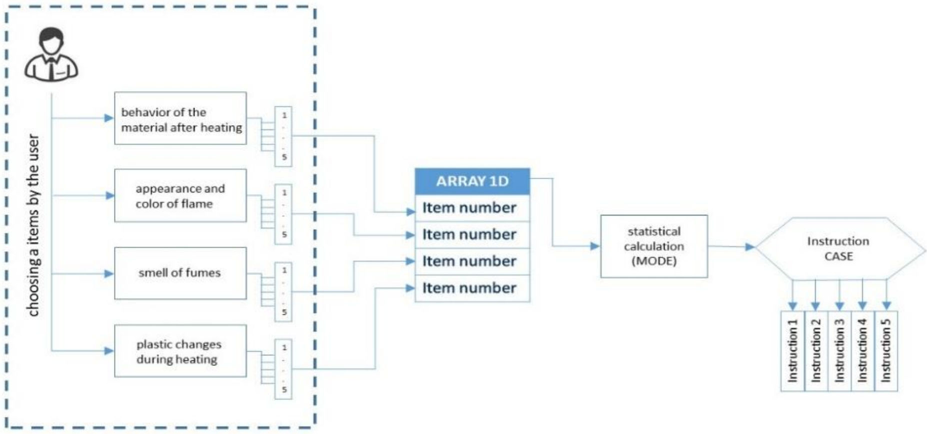

Fig. 1. Algorithm of the program for identification of polymer materials

The developed algorithm was used to build a program for identifying filaments used in 3D printing technology.

4.2. Developing the program using the algorithm

The LabView programming environment was used to build the program. It is an integrated environment intended for both software development as well as for controlling control and measurement systems as well as data processing and analysis. The language of programming in the LabView environment is G. On the basis of the developed algorithm, a program for identifying polymer materials has been made (Targowski, Sylwestrzak & Bajraszewski, 2009).

The view of the program's block diagram is shown in Fig. 2. The front panel view is shown in Figure 3.

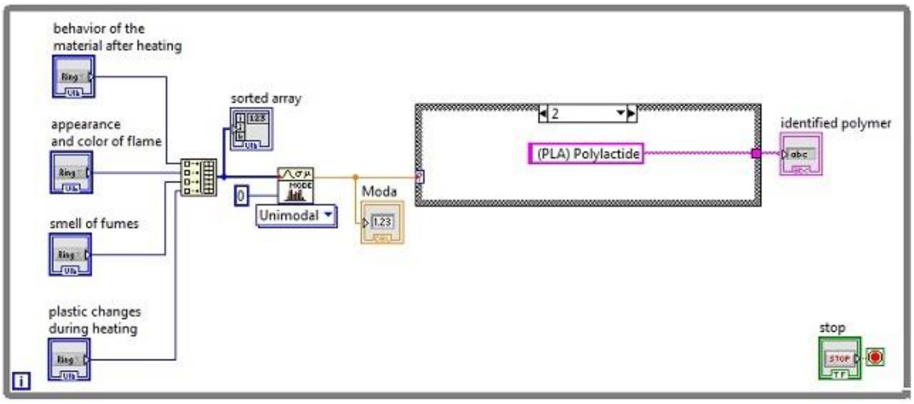

Fig. 2. Program view in block-diagram form

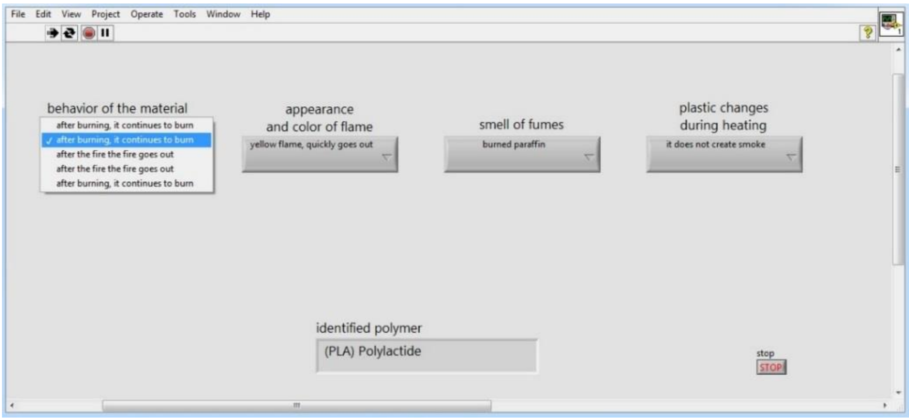

Fig. 3. Program view in the form of a user panel

Figure number 3 shows the main program window view on the example of selecting one of the polylactide polymers. After observing the features during the fire test of the polymer, the user selects the appropriate options from the program drop-down list. The computer program uses the input data and case construction to identify the polymer. The user obtains information about the name of the polymer being burned. The software enables the identification of five filaments on the polymer market. Taking into account the continuous development of the present and the emergence of new polymer materials, it is recommended to expand the program with further material items.

5. CONCLUSIONS

The tests of combustion of polymeric materials allowed organoleptic observation of characteristic features. The performed fire tests of polymers were described on the basis of a literature review and own research. On this basis, five most-used filaments in 3D printing technology were described. The National Instruments LabView environment was used to make the software used to identify polymers. In order to check the correctness of the LabView program, attempts were made to work in various combinations.

Using the results of the research, the following conclusions were determined:

- Polymers that contain additives to reduce or delay the flammability of plastics (flame retardants) inhibit the ignition process and reduce the rate of pyrolysis reactions. The rate of combustion of the polymer is determined subjectively and it is difficult to establish it in a computer program.
- Additional substances added to polymers, e.g. fillers, plasticizers, dyes, stabilizers, lubricants, can change the behavior of the polymer during combustion. Then using the program is difficult.
- During the combustion test of polymers, it was observed that some of them did not sustain smoking after removing them from the flame. And this behavior makes the filament identification process more difficult.
- Some filaments have the ability to self-burn after removing the samples from the flame. This type of information can be included in a computer program to identify flammable 3D prints.

The yellow flame is a characteristic feature of polymers that release aromatic hydrocarbons during burning. On the other hand, aliphatic hydrocarbons burn with a blue flame, giving off an unnoticeable, burning flame, or they do not emit a burning flame at all.

The collected information from the research process was used to identify polymers using the proprietary program. From the validation process of the program, it follows that the program identified all of them correctly for the five studied filaments. Therefore, you can infer about the correct execution of the algorithm and the operation of the program. The authors decided to use the five most common filaments on the market. However, the structure of the program gives the possibility of expanding its functionality to identify further polymeric materials.

REFERENCES

Błędzki, A. K., & Faruk, O. (2006). Influence of Processing Temperature on Microcellular Injection-Moulded Wood-Polypropylene Composites. *Macromolecular Materials and Engineering*, *291*(10), 1226–1232.

Błędzki, A. K., & Kardasz, D. (1998). Możliwości szybkiej identyfikacji tworzyw sztucznych w procesie recykling. *Polimery*, *43*(2), 79–87.

Broniewski, T., Kapko, J., & Płaczek, J. (2000). *Metody badań i ocena właściwości tworzyw sztucznych*. Warszawa: WNT.

Garbacz, T., & Dulebova, L. (2013). Porophors during the extrusion process. *Chemistry and Chemical Technology*, *7*(1), 113–118. doi:10.23939/chcht07.01.113

Garbarczyk, E., Józefowic, K., & Rybarczyk, A. (2014). Technologia druku 3d na zajęciach laboratoryjnych. *Poznan University of Technology Academic Journals. Electrical Engineering*, *80*, 245–251.

Okamoto, K. T. (2003). *Microcellular Processing.* Cincinnati: Hanser Gardner Inc.

Klepka, T. (2014). *Nowoczesne materiały polimerowe i ich przetwórstwo*. *Część 1*. Lublin: Wydawnictwo Politechniki Lubelskiej.

Korga, S., & Flis, M. (2018). Analiza najczęstszych niepowodzeń występujących podczas procesu druku addytywnego. In B. Buraczyńska & A. Kuczmaszewska (Eds.), *Młody inżynier XXI wieku* (pp. 35–45). Lublin: Wydawnictwo Politechniki Lubelskiej.

Matuana, L. M., Park, C. B., & Balatinecz, J. J. (1998). Structures and mechanical properties of microcellular foamed polyvinyl chloride. *Cellular Polymers*, *17*(1), 1–16.

Mroziński, A. (2010). Problemy recyklingu tworzyw polimerowych. *Inżynieria i Aparatura Chemiczna, 49*(5), 89–90.

Pearce, J. M., Morris Blair, C., Laciak, K. J., Andrews, R, Nosrat, A., & Zelenika-Zovko, I. (2010). 3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development. *Journal of Sustainable Development*, 3(4), 17–29. doi:10.5539/jsd.v3n4p17

Przygodzki, W., Włochowicz, A., & Janowska, G. (2007). *Palność polimerów i materiałów polimerowych*. Warszawa: WNT.

Rabek, J. F. (2013). *Polimery. Otrzymywanie, metody badawcze, zastosowanie*. Warszawa: Wydawnictwo Naukowe PWN.

Rosato, D. V., Rosato, M. G., & Schott, N. R. (2010). *Plastics Technology Handbook. Volume 2 – Manufacturing, Composites, Tooling, Auxiliaries.* Highland Park: Momentum Press.

Targowski, P., Sylwestrzak, M., & Bajraszewski, T. (2009). Środowisko LabVIEW – własności i przykłady zastosowań. *Postępy Fizyki*, *60*(6), 255–256.

Wittbrodt, B. T., Glover, A. G., Laureto, J., Anzalone, G. C., Oppliger, D., Irwin, J. L., & Pearce, J. M. (2013). Life-cycle economic analysis of distributed manufacturing with open-source 3-D printers. *Mechatronics*, *23*(6), 713–726. doi:10.1016/j.mechatronics.2013.06.002

Wróblewska-Krepsztul, J., Michalska – Pożoga, I., Szczepiński, M., & Szczepiński, M. (2017). Biodegradacja – atrakcyjna alternatywa dla obecnych technik utylizacji odpadów tworzyw polimerowych. *Przetwórstwo tworzyw*, *23*(6), 579–584.