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Study on the breaking strength of tensile specimens manufactured additively by thermoplastic extrusion of PLA, rPLA, PETG and rPETG

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Abstract. The paper presents the results of the study on the tensile strength of tensile specimens manufactured by additive manufacturing (FDM) of PLA, rPLA, PETG and rPETG. To substantiate the research, the current state of the transition to a circular economy in the additive manufacturing technology by thermoplastic extrusion of different types of materials was analyzed. The results of our experimental research led to the conclusions that the values of the tensile strengths of rPLA specimens are lower by (0.15 - 0.88) % compared to the values of the tensile strengths of specimens manufactured from PLA, while the values of the tensile strengths of rPETG specimens are lower by (1.05 - 2.05) % compared to the values of the tensile strengths of specimens manufactured from PETG. In this context, from the point of view of breaking strength, in the issue of PLA and PETG waste management, the results of our research, as well as those of other researchers, confirm the use of recycled materials as raw materials in the field of additive manufacturing technology through extrusion as a viable solution.

Keywords: tensile strength, comparative study, circular economy.

1. Introduction

Currently, the management of plastic waste is a global problem with a major impact on ecosystems. The current global plastic production is 441.25 million tons, 14% of the total production being recorded in Europe, [1-9]. At the European level, the issue of protecting the environment against plastic pollution is raised and at the same time the level of innovation is desired to be increased, [10]. To achieve this goal, the European Union has developed an action plan specifying that all plastic packaging will become recyclable by 2030, [10]. There is interest in discovering viable solutions for waste management, one of which is the use of the production

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and consumption model based on the circular economy. The production and consumption model based on the circular economy consists of recycling and reusing materials to manufacture new products, thus extending the life of the materials. Additive manufacturing technologies can be considered green technologies due to the working principle, the parts are made by successively depositing layers of material in accordance with the profiles of the 3D model, [11-15]. A major advantage of additive manufacturing technologies is the manufacture of complex elements without special tools or basing and fixing elements, the part being made from a single basing and fixing, [16-20]. The adoption of the production and consumption model based on a circular economy in the field of additive manufacturing technologies by extrusion of plastic masses can have significant beneficial effects, this is also highlighted in the specialized bibliography studied, [21-29]. In [24], the study on the management of polyethylene terephthalate (PET) waste and the opportunities for reducing the negative impact on the environment by using the 3R to 10R scenarios in the context of the circular economy is presented. In [25], the results of the study on the development of materials for 3D printing from PET waste are presented. The results of the study show that the hardness of recycled PET (rPET) specimens is 6% lower than the hardness of specimens made from virgin PET. The conclusions of the study show that the results of the tensile and shear strengths were 14.7% and 6.8% higher, respectively, for specimens made from rPET. In [26], the study on the recycling potential of acrylonitrile styrene acrylate (ASA) and coarse sand from mining activities is presented. For the study, composite materials were made from recycled ASA (rASA) and 10/20/40% coarse sand from mining activities. The results of the study show that the addition of 10% coarse sand from mining activities decreases the tensile strength by up to 50%. In [27], the study on the mechanical behavior of tensile specimens manufactured by FDM from recycled polylactic acid (rPLA) and recycled polyethylene terephthalate glycol (rPETG) is presented. Using the vertical and horizontal molten filament deposition methods, tensile specimens were fabricated on the Creality Ender 3 Pro 3D printer using the following materials and extrusion temperatures PLA - (210/220/230)°C, PETG - (225/235/245)°C, rPLA - (210/220/230)°C and rPETG - (225/235/245)°C. Subsequently, all specimens were tested for tensile and Vickers hardness. The conclusions of the study show that the mechanical properties of specimens fabricated from rPLA and rPETG are similar to the mechanical properties of specimens fabricated from virgin materials, PLA and PETG respectively. The extrusion temperature and the method of deposition of the molten filament significantly influence the tensile behavior of specimens manufactured by FDM from PLA, rPLA, PETG and rPETG. For specimens made from rPLA, the highest values of the tensile strength were obtained in the XY plane, at an extrusion temperature of 210°C, the range of values being (66.20 - 68.30) MPa. In the case of specimens made from rPETG, the maximum tensile strengths were also recorded in the XY plane, at an extrusion temperature of 235°C, the range of values being (57.20 - 59.00) MPa. In [28], the results of the study on the influence of the process parameters (layer height deposited in one pass

– L_h and filling percentage – I_d) of FDM on the tensile behavior of specimens made from PETG are presented. The results of the study show that the two parameters considered influence the tensile behavior of FDM-fabricated PETG specimens, the filling percentage (Id) being the parameter that decisively influences the tensile strength. In [29], the study on the influence of FDM parameters (layer height deposited in one pass – L_h and filling percentage – I_d) on the tensile behavior of ASA specimens is presented. The conclusions show that the parameter that significantly influences the tensile strength of ASA specimens manufactured by FDM is the filling percentage - I_d.

In the present paper, the study on the tensile strength of tensile specimens manufactured additively by thermoplastic extrusion of PLA, rPLA, PETG and rPETG in the context of the circular economy is presented.

2. Research methods

The research uses the results of studies published by us in various specialized journals, which refer to the influence of process parameters (layer height deposited in one pass – L_h and filling percentage – I_d) of the additive manufacturing technology by thermoplastic extrusion (FDM) on the mechanical behavior of tensile specimens made of PETG, as well as the results of studies published by other authors who investigated the mechanical behavior of tensile specimens made of recycled materials. The tensile specimens (fig. 1) were designed and subsequently tested according to the ISO 527-1:2012 standard, [25, 27-29].

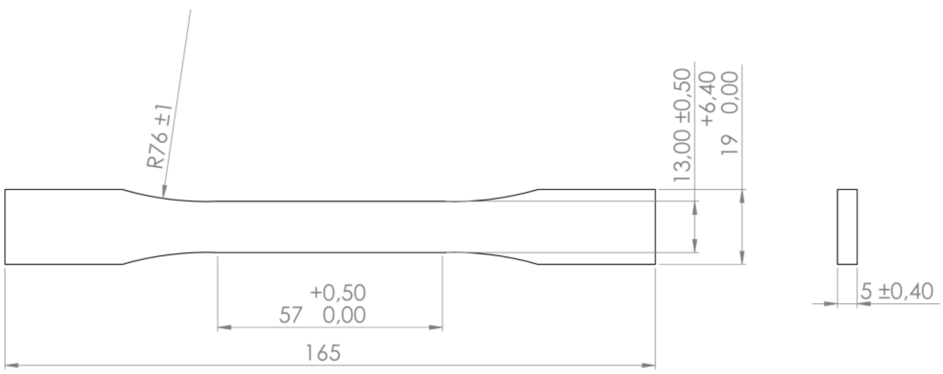

Fig. 1. Specifications of tensile sample.

Figure 2 shows the stages of additive manufacturing of tensile specimens, by thermoplastic extrusion.

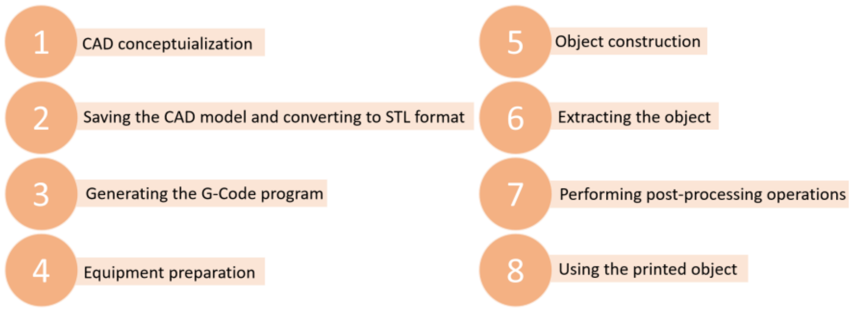

Fig. 2. Stages of additive manufacturing of tensile specimens, by thermoplastic extrusion.

3. Results and discussion

Figure 3 summarizes the results of studies in [25, 28]. Research [25] presents the study on the influence of the amount of rPET on the tensile behavior of specimens manufactured by FDM, and [28] presents the study on the influence of FDM parameters on the tensile behavior of specimens manufactured from PETG.

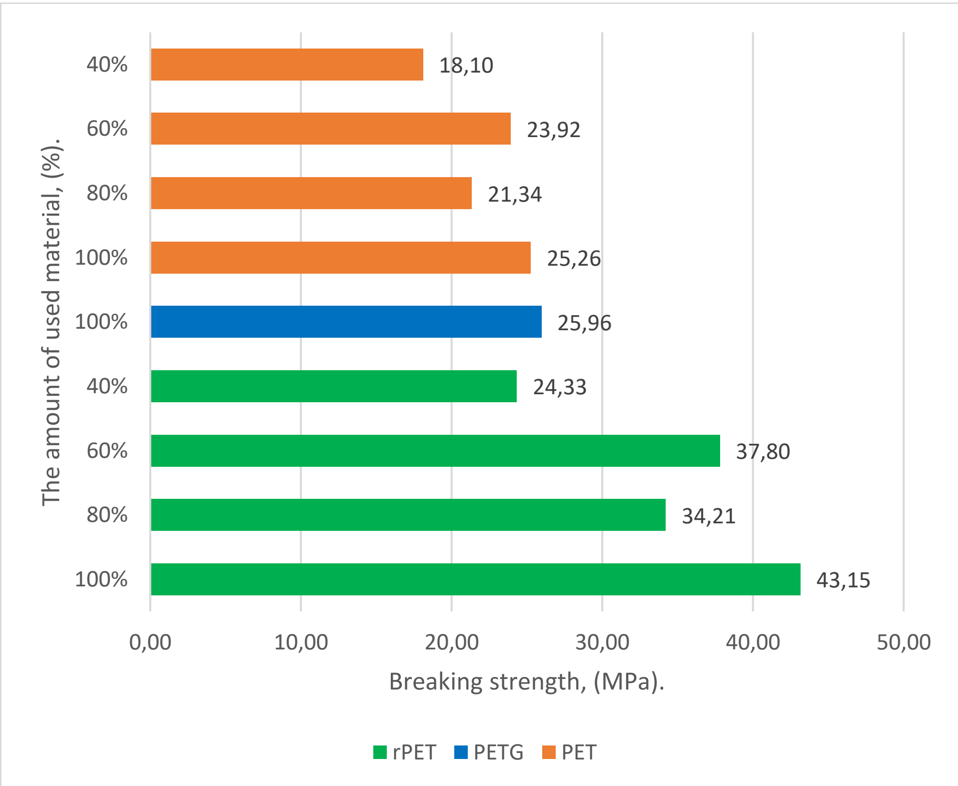

Fig. 3. Influence of the amount of recycled material on the breaking strength of tensile specimens manufactured by FDM from PET, PETG, rPET.

By increasing the amount of PET from 40% to 60%, the tensile strength of the tensile specimens increased by 24.33%, while increasing the amount of PET from 60% to 80% led to a 12.09% decrease in tensile strength. By increasing the amount of PET from 80% to 100%, the tensile strength of the tensile specimens increased by 15.52%.

Comparing the results obtained in the study [25], for tensile specimens made of 100% PET, with the results obtained in the study [28], for tensile specimens made of 100% PETG, those in the study [28] are 2.7% higher.

Increasing the amount of rPET from 40% to 60% led to an increase in the tensile strength of the tensile specimens by 35.63%, while increasing the amount of rPET from 60% to 80% resulted in a decrease in the tensile strength by 10.49%. By increasing the amount of rPET from 80% to 100%, the tensile strength of the tensile specimens increased by 20.72%.

Comparing the results obtained in the study [25] for rPET with the results obtained in the work [28] for PETG, we observe that the tensile strength of the tensile specimens manufactured by FDM from 100% rPET is higher by 39.84% compared to the tensile strength of the tensile specimens manufactured from 100% PETG.

Figure 4 summarizes the results from studies [27, 28] for tensile specimens manufactured by FDM, in the XY plane, from PLA, rPLA, PETG, rPETG, for extrusion temperatures - 210/220/225/230/235/245/250 °C.

For tensile specimens from study [28], made of PETG, the maximum breaking strength was 24.29 MPa and was obtained for the case of using the thermoplastic extrusion temperature T_e = 250°C. For tensile specimens from study [27], the maximum breaking strength of PETG specimens was 58.40 MPa, for the extrusion temperature T_e = 235°C. The highest values of the breaking strength of rPETG specimens were 57.20 MPa, at T_e = 235°C, while for specimens made of PLA the maximum breaking strength was 67.80 MPa (at T_e = 210°C), and the maximum breaking strength of rPLA specimens was 67.20 MPa (at T_e= 230 °C).

The tensile strength of tensile specimens manufactured by FDM from rPLA is lower by (0.15 - 0.88)% compared to the tensile strength of PLA specimens, while the tensile strength of tensile specimens manufactured by FDM from rPETG is lower by (1.05 - 2.05)% compared to the tensile strength of PETG specimens.

Comparing the results obtained in the works [14, 15], it is found that the tensile strengths of tensile specimens manufactured by FDM from PETG are lower by:

- (63.53 - 63.85)% compared to the tensile strengths of those made by rPLA;
- (63.58 - 64.17)% compared to the tensile strengths of those made by PLA;
- (56.86 - 57.52)% compared to the breaking strengths of rPETG;
- (57.31 - 58.41)% compared to the breaking strengths of PETG.

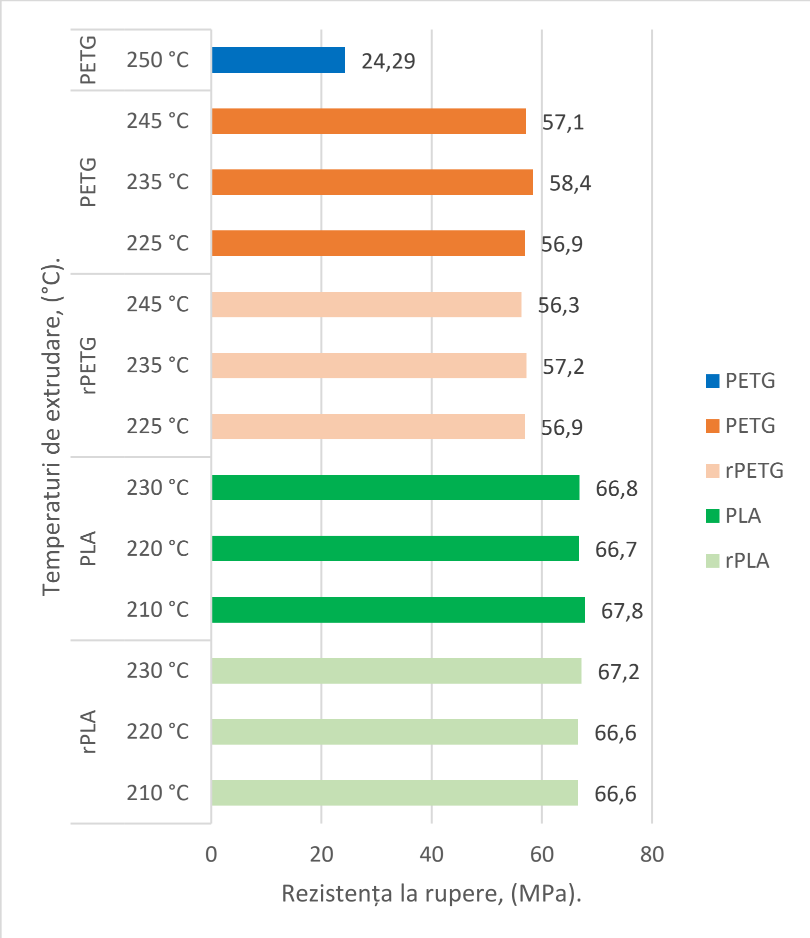

Fig. 4. Influence of thermoplastic extrusion temperatures on the breaking strength of tensile specimens manufactured by FDM from PETG, rPETG, PLA, rPLA.

4. Conclusions

The paper presents the study on the tensile strength of tensile specimens manufactured by additive manufacturing through thermoplastic extrusion of PLA, rPLA, PETG and rPETG, in the context of the circular economy. To substantiate the research, the current state of the transition to the circular economy in the additive manufacturing technology through thermoplastic extrusion of different types of materials was analyzed. From the point of view of tensile strength, in the issue of PLA and PETG waste management, the results of our research, as well as those of other researchers, confirm the use of recycled materials as raw materials in the field of additive manufacturing technology through extrusion as a viable solution. Given the results of the study, the authors propose to extrapolate it by researching the mechanical behavior in tension, compression, resilience and bending of specimens manufactured by FDM from rPETG and rASA.

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