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Mechanical and environmental properties of recyclates from bio-based plastics

Abstract: *Recycling of plastics has become one of the most important issues with respect to the conservation of energy and material resources. With the rise of Circular Economy, the aim of reducing the wastes and re-utilizing them have been stressed not only in the fossil-based plastics but also in the bio-based plastics. Bio-based plastics, which are derived partly or completely from the renewable resources, have their own share of challenges when they come to recycling and other end-of-life strategies. Taking into account factors like recycling rate and cost, influencing the recycling of bio-based plastics, this study analyses the material and environmental properties of using the recyclates of bio-based plastics as a secondary raw material by taking a reference product as a case study.*
Keywords: *Bio-based plastics, PLA, Recycling, Circular Economy*

WŁAŚCIWOŚCI MECHANICZNE I ŚRODOWISKOWE RECYKLATÓW Z TWORZYW SZTUCZNYCH NA BAZIE SUROWCÓW ODNAWIALNYCH
Streszczenie: *Recykling tworzyw sztucznych stał się jedną z najważniejszych kwestii w zakresie ochrony zasobów energetycznych i materiałowych. Wraz z rozwojem gospodarki o obiegu zamkniętym, cel ograniczenia ilości odpadów i ich ponownego wykorzystania zyskał szczególnego znaczenia nie tylko w przemyśle tworzyw sztucznych opartych na paliwach kopalnych, ale również w tworzywach pochodzących z surowców odnawialnych. Tworzywa sztuczne, które pochodzą częściowo lub całkowicie z odnawialnych źródeł, stawiają specyficzne wyzwania, jeśli chodzi o recykling i inne strategie wycofywania z eksploatacji poużytkowych odpadów. Biorąc pod uwagę takie czynniki, jak współczynnik recyklingu i koszty, wpływające na recykling tworzyw sztucznych opartych na surowcach naturalnych, niniejsze praca analizuje właściwości materiałowe i środowiskowe stosowania recyklatów tworzyw sztucznych na bazie surowców odnawialnych jako surowca wtórnego, przyjmując produkt referencyjny jako studium przypadku.*
Słowa kluczowe: *Polimery pochodzenia naturalnego, PLA, recykling, obieg materii*

INTRODUCTION

In the era of circular economy, resource conservation and re-utilization have been in the spotlight like never before. The transition from linear to circular economy is not a specific sector and it has been applied in all possible sectors of the global economy, thereby accelerating the sustainable development. Even against a backdrop of well-established technologies and markets to recycle plastics, the global recycling rate of plastics is lower than that of paper or steel [1]. The New Plastics Economy, created for the global consumption and re-utilization of all types of plastics, strives for improving and increasing the after-use of plastics, aligning with the principles of circular economy to make sure that the plastics never become waste and reduce the environmental and economic impacts associated with it [1].

Bio-based plastics, which has become of particular interest for the general public, research and industrial sector, due to the ecological concerns posed by the conventional fossil-based

plastics, contributes presently about 6% of the global plastics market [2]. Bio-based plastics would very well fit into the circular economy, as they are in favor of a circular model based on "reuse, recycle or biodegrade" by regenerating carbon dioxide and using renewable raw materials [3]. Bio-based plastics are suitable for a broad range of end-of-life options, including reuse, mechanical recycling, organic recycling and energy recovery. Mechanical recycling is considered as a favorable recycling method for the majority of bio-based plastics, especially Polylactic Acid (PLA) [4]. In this study, the material and environmental properties of recyclates from the mechanical recycling of bio-based plastics are analyzed.

MATERIALS AND METHODS

In mechanical recycling, two different kinds of recycled content exist: pre-consumer and post-consumer. Pre-consumer refers to the wastes resulting from the manufacturing processes (e.g. during injection molding) of the products like scrap, rejects and tailings, whereas the post-consumer refers to the finished products that have been used by consumers and then disposed into the waste bins, for recycling. The recyclability and re-use of the pre-consumer wastes are important for the processing industries to avoid production wastes thereby saving costs. In the case of an injection molding process, the production wastes, also known as sprue are ideally recycled back to the process. However, the quality of the sprue should always be checked as they experience material degradation due to mechanical shredding and renewed thermal stress during processing, which can then lead to the reduction in the long term stability of the components produced from these materials.

In this laboratory study, properties of pre-consumer recyclates from the bio-based plastics are discussed. The sprue and other production wastes are shredded and are re-fed to the original material, in different concentrations as shown in Fig 1.

For this setup, granulates of the blend (IfBB-Blend HD115-IS38x), made of bio-based polymer PLA and additives like nucleating agents and plasticizers (these blends are used for the manufacture of products such as computer mouse, pen and toothbrush) are added to an injection molding machine and tensile bars as test specimen are produced. These tensile bars are then shredded in a toothed mill serving as ground material. The grounded materials are again added to the starting material (blend) in different concentrations (25wt%, 55wt% and 75wt %) and are once again injection molded to produce the tensile bars, which material properties (melt flow rate, tensile strength/modulus, impact strength, molar mass) are analyzed. The recyclates are added to the starting material under ideal conditions without other polymers or impurities. In the case of post-consumer recycling, the

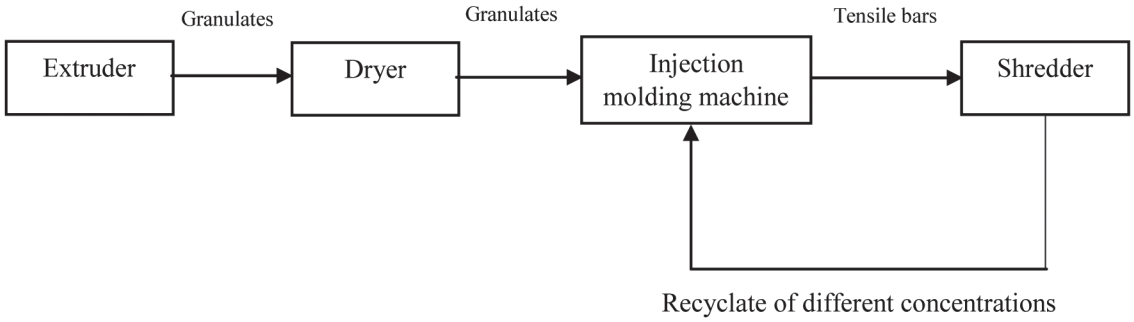

Figure 1. Experimental setup of pre-consumer recycling of bio-based plastics
Rysunek 1. Eksperymentalna konfiguracja recyklingu tworzyw sztucznych opartych na surowcach pochodzenia biologicznego

external factors like sun, heat, moisture and contamination (physical and chemical) would have to be taken into account. Apart from the material properties, the environmental impacts of adding recyclates with the starting material at different concentrations are analyzed with a help of a Life Cycle Assessment (LCA) software GaBi [5].

MATERIAL PROPERTIES OF RECYCLATES

The material properties of the recyclates are analyzed, with the blend as the reference material. This blend is mixed with the shredded recyclates of tensile bar of the same blend at different concentrations (25wt%, 55wt% and 75wt %). The different properties of the resulting injection molded tensile bars are shown in Figure 2, alongside blend as the reference material (in black). Along with the common parameters like tensile strength and impact strength, molar mass (kg/mol) is also considered as an important parameter. This parameter is intended to provide more information on the material degradation of recyclates, thereby giving a clear picture on its reduced durability.

It is evident that with an increasing the recycled content (up to 75%) added to the starting material, the Melt Flow Rate (MFR) increases i.e. the material becomes more fluid. This can be further explained with a slight molar mass degradation in comparison to the reference material. Significant reduction in the cycle time is not apparently seen due to the flowable material (1-4 sec). Furthermore, the molar mass reduction for a recyclate concentration of 25-55% is around 8% and for 75% recyclate is around 15%, thereby having no significant influence on the mechanical properties like tensile strength and tensile modulus.

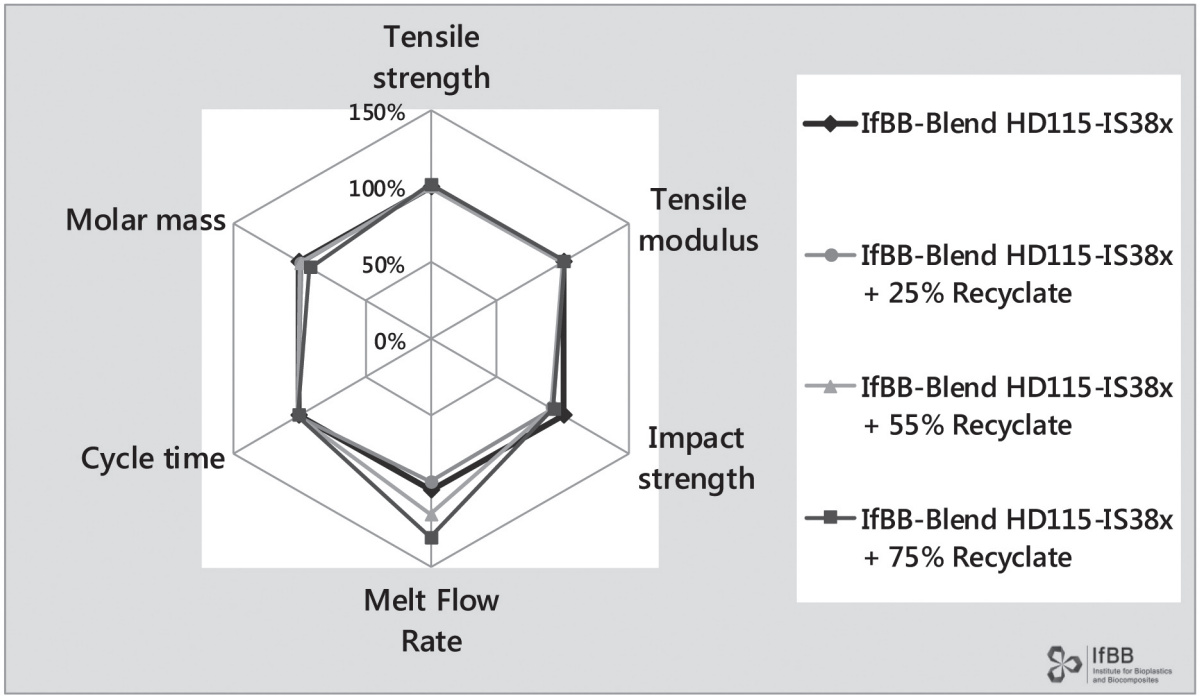

Figure 2. Material properties of the blend with different concentrations of recyclate

Rysunek 2. Właściwości materiałowe mieszanki o różnych stężeniach recyklatu

ENVIRONMENTAL PROPERTIES OF RECYCLATES

The potential environmental impacts involved in the manufacture of 1 kg of bio-based plastic blend (IfBB-Blend HD115-IS38x) were calculated with the help of LCA. LCA studies the environmental aspects and potential impacts throughout the product's lifecycle from raw material acquisition through production, use and disposal. Even though the potential impacts of the bio-based plastic blend throughout its lifecycle have been studied, we are setting the boundary system from raw material acquisition phase to the processing phase, where the sprue will be generated from the injection molding processes. LCA for this study is carried out in accordance to ISO 14040 and ISO 14044, which are the standards required for LCA. The model for the processing phase of the blends with 25% recyclate concentration as an example is shown as GaBi Model in Fig 3. The modelling was done based on 'cut-off' approach, where the ground material that comes out of the injection molding machine doesn't carry any impacts with it, but just the power consumption for shredding these wastes. Blend (virgin material) and ground materials (recycled content) goes into the dryer and injection-molding machine at different concentrations amounting to 1 kg. The materials arising from the injection-molding machine will not get any credit (in terms of reduction in environmental impacts) through this approach and the corresponding impacts are calculated. The power consumption for dryer, injection-molding machine and the shredder were calculated on site.

The environmental impacts are calculated based on the impact assessment method from International Reference Life Cycle Data System (ILCD)/Product Environmental Footprint (PEF) recommendations [6]. Even though all possible impact categories from this method were studied in this project, this paper discuss the Global Warming Potential (GWP) (including biogenic carbon dioxide) of the product system with different recyclate concentrations as shown in Fig 4.

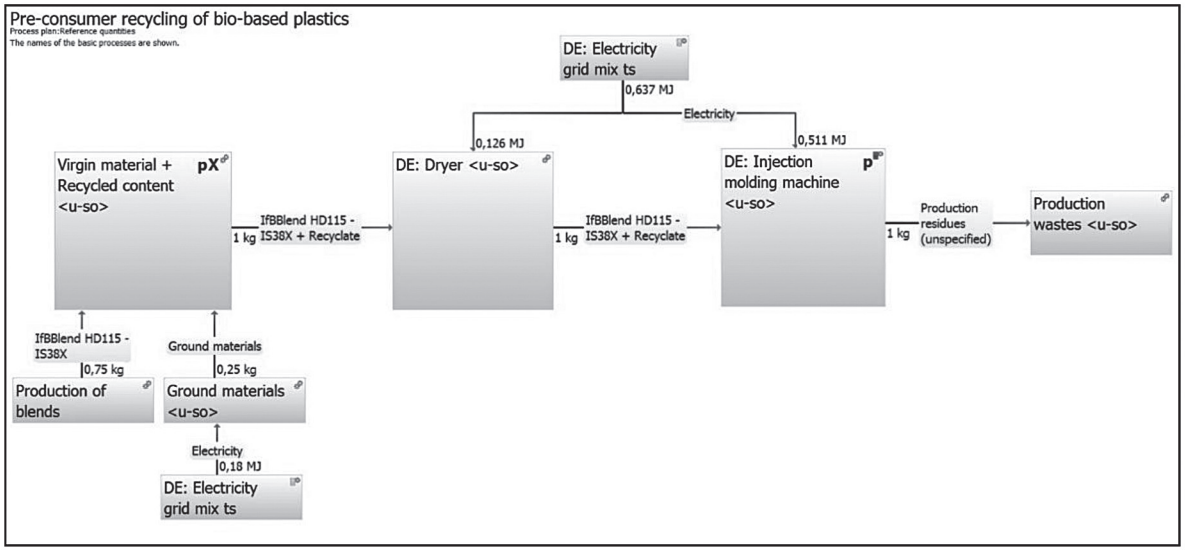

Figure 3. LCA model of the pre-consumer recycling of biobased plastics

Rysunek 3. Model LCA recyklingu przed skupem konsumentów z tworzyw biologicznych

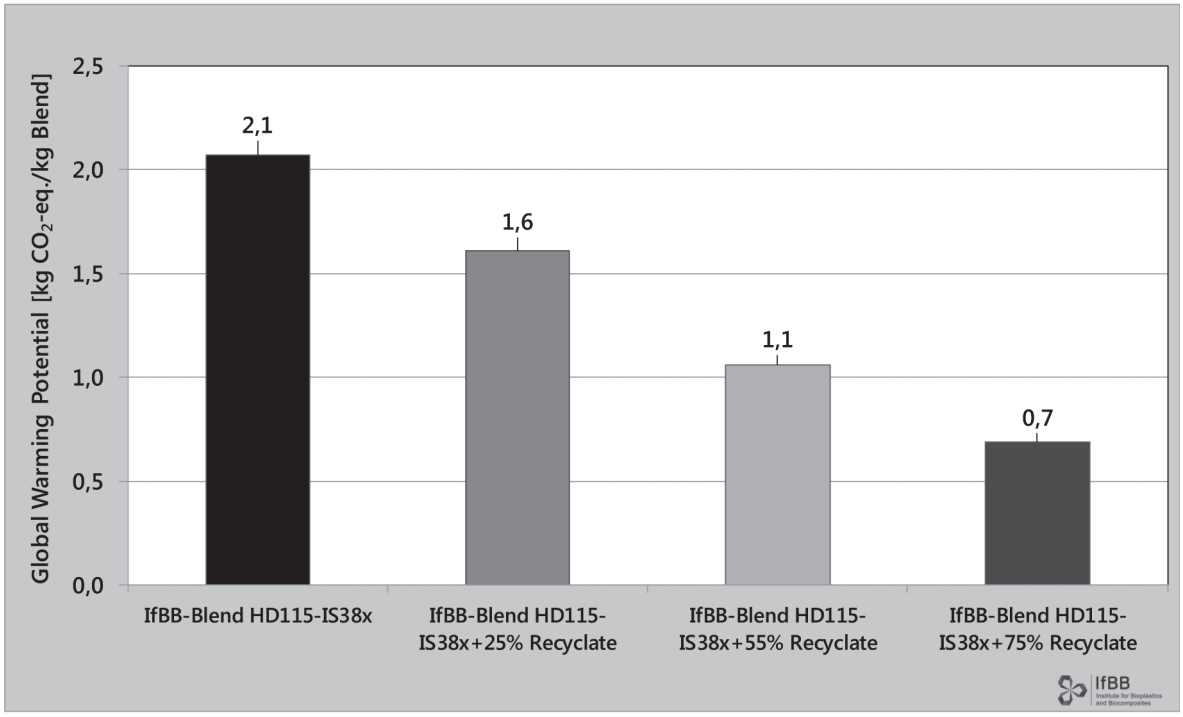

Figure 4. Global Warming Potential of the blend with recyclates of different concentrations
Rysunek 4. Globalny potencjał ocieplenia spowodowany przez mieszanki z recyklatami

In the figure, it can be seen that the GWP of the blends reduces with the increase in recyclate concentrations from values of around 2.1 to 0.7 kg CO_2-eq/kg blend. This has to do with the reduction in the impacts involved in the production of the virgin material, which concentration reduces with the subsequent increase in the recyclate concentration. The total impacts of the blend was calculated by taking into account the raw materials involved in the production of 1 kg of the bio-based plastic blend.

CONCLUSION AND DISCUSSION

The material and environmental properties of the pre-consumer recyclates were studied by adding the processed sprue from the injection molding processes to the bio-based plastic blends in different concentrations and injection molded again. The reintroduction of reject material that falls during the industrial processing is possible and does not have a significant effect on the material properties. The injection molding parameters like holding pressure and cooling time have to be slightly adjusted due to the changes in viscosity. However, influence of the long-term stability of recycled materials was not investigated in this study. In the case of environmental properties, the total environmental impacts of the product are reduced with an increase in the concentration of recyclates used, along with the virgin bio-based plastic blends. Even though this laboratory setup is not a complete reflection of the reality, this study could pave the way to improve the recyclability of bio-based plastics in the future.

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