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POROUS POLYSTYRENE GRINDING REASERCH

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Abstract

*The aim of the research was to examine the behaviour of porous polystyrene during grinding realised in a knife grinder. The assessment of the porous structure influence on the effectiveness of polystyrene disintegration was conducted in relation to previously obtained results of knife cutting realised at the same research site. These unquestionable advantages have caused that even over 1*10^6 kg of thermoplastic material includes in its structure the gas phase. The observed trend results from the tendency aiming to obtain plastic parts of light structures that may be used as construction materials. Due to the complex polymer-gaseous structure of porous materials, their mechanical recycling requires adapting special, different from typical for solid materials, cutting and grinding conditions. The behaviour of polymer materials under applied load is tightly connected with their structure. Earlier process analysis indicates that together with the cutting velocity increase, the impact cracking ratio in the material division increases. As a result of the conducted research, polystyrene recyclate was obtained, which might be reused in re-processing for new product production. Polystyrene porous structure is conductive to effective grinding, which is characterised by low energy consumption for grinding and high effectiveness in relation to the grinding degree.*

Keywords: recycling of polystyrene*, porous polystyrene, cutting of polystyrene, grinding of porous polystyrene*

1. Introduction

The use of physical or chemical pore-filling to increase the heat insulation or suppression properties of plastic materials like PELD, PP, PVC, to increase the rigidity, to replace the long-known foamed polystyrene in packaging industry by physically pore-filled polyolefin materials has also been noticed [1]. Moreover, the addition of chemical blowing agents to solid thermoplastic materials decreases the product shrinkage, improves the rheological properties as well as allows to create product geometries that so far have been considered as elements of the non-technological design (e.g. the use of different wall thicknesses) [1, 2]. It has also been found that thanks to chemical blowing agents there exists the possibility to shorten the injection cycle [1, 4]. For products of a complex shape and differentiated wall thickness the addition of even a small amount of a blowing agent decreases the shrinkage anisotropy, which eventually results in the decrease of the own tension level and deformations [1, 4]. These unquestionable advantages have caused that even over $1*10^6$ kg of thermoplastic material includes in its structure the gas phase. The observed trend results from the tendency aiming to obtain plastic parts of light structures that may be used as construction materials.

Due to the complex polymer-gaseous structure of porous materials, their mechanical recycling requires adapting special, different from typical for solid materials, cutting and grinding conditions

[3-7]. The behaviour of polymer materials under applied load is tightly connected with their structure. Polymer viscoelasticity causes that, apart from the grinder constructional features, also process temperature and the velocity of external forces interaction with the input material, causing its disintegration, influence the final grinding process effectiveness. Earlier process analysis indicates that together with the cutting velocity increase, the impact cracking ratio in the material division increases. This especially refers to solid thermoplastic materials [4, 7]. Basing on this, one may regard that an advantageous solution is the use of high peripheral speed of the knives. However, one should remember that high process dynamics causes the increase of powdery fraction participation and recycled material electrification. The phenomena is disadvantageous from the point of view of recycling the material. Due to low values of melting temperatures of PS, PE, and especially – of PVC, the material cutting velocity must be a compromise between the disintegration effectiveness and the recyclate quality.

The aim of the research was to examine the behaviour of porous polystyrene during grinding realised in a knife grinder. The assessment of the porous structure influence on the effectiveness of polystyrene disintegration was conducted in relation to previously obtained results of knife cutting realised at the same research site [4-7].

2. Research methodology

Extruded parts obtained in the laboratory single-screw extruder with mounted research head of 13,5x8 mm mouthpiece cross-section were used for the research. The head was equipped in a three-zone heating system, thanks to which it was possible to achieve proper foaming of the chemical blowing agent in the solid polystyrene. The material was produced of KRASTEN 552 9002 polystyrene by the company Synthos S.A. (Czech Republic) with simultaneous Expancel 980 MBX 120 blowing agent by the company Akzo Nobel (Sweden) dosing. The blowing agent concentrate was added to PS in the amount of 4% of mass. The extrusion process was realised at the following parameters: a) extruder plasticising unit temperature: zone I - 145 ^{0}C, zone II - 215 ^{0}C, zone III - 215 ^{0}C, b) extruding head temperature: zone I - 140 ^{0}C, zone II - 140 ^{0}C, c) screw rotary velocity n_s = 85 rot./min^{-1}. Profiles of the average cross-section of 14.5x8 mm were obtained, with final cross-section dimensions, especially for porous extruded material, controlled by the peripheral velocity of the suction cylinders. The porous material density with the content of the blowing agent of 4% in mass was estimated at the level of 446,3±12,6 kg·m^{-3}, while for solid PS the obtained density equaled 986,5±21,4 kg·m^{-3}. Initially cut material was disintegrated at the research site for examining the cutting and grinding processes, whose description and research capacities are included in research thesis [4, 7]. Knives of special design ensuring adequate susceptibility to deformation at the influence of the cutting force were equipped in strain gauges by company VISAY (Germany), which were stuck in the full bridge configuration. The courses of the alterations of force and torsion moment were registered by means of a converted ESAM Traveller 1 (Germany) with software, at the assumed examining time of 10^{-2} s. Cutting knives of geometrical features presented in research [4], were applied, whose cutting edges were reclined in relation to the rotor axis by the angle $2\lambda = 6^0$. The angle of the cutting knives equalled 60^0. The tests were conducted at the peripheral velocity of the moving knives of 3 m·s^{-1} and with the use of sieve of the hole diameter of ∅ 9 mm. The calculation of the unitary energy consumption (in relation to the ground mass) was carried out basing on the torque alteration diagram during the realisation of grinding process, according to the methodology suggested in research work [8]. The grain distribution of the obtained recyclate was estimated through sieve analysis in dry conditions with the use of sieves of the hole diameter of ∅ 8; 7; 6, 5; 3,5; and 2. The process was realised in an eccentric sieve machine and the analysis time equalled 8 minutes. While grinding, the temperatures of the fixed knife and in the area of the separating sieve were also measured.

3. Results of grinding

The analysis of grinding research indicates significant influence of material structure on its mechanical recycling susceptibility. Specific energy consumption for solid polystyrene grinding is essentially lower to the energy quantity needed for grinding extruded polystyrene with 4% porophore content (Fig. 1). At the same time, no effect of porophore content on the energy level needed for material cutting was found out. In all the cases of porous polystyrene a similar level of energy consumption was obtained, slightly higher than 40 $kJ \cdot kg^{-1}$. Such a low level of energy consumption, when compared to other polymer materials, on porous polystyrene disintegration shows high susceptibility of this material to grinding.

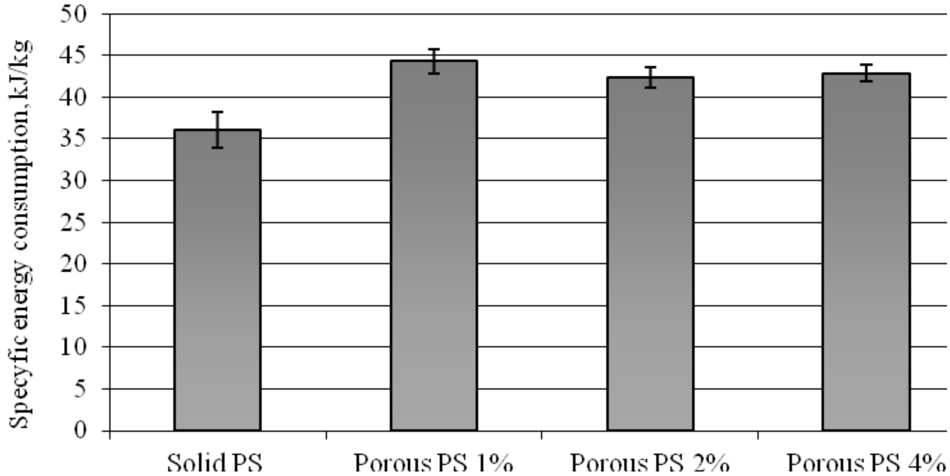

Fig. 1. Changes of the specific energy consumption during grinding polystyrene of variable pore quantity in a knife mill. The tests were conducted at the tangential velocity of the moving knives of 3 $m*s^{-1}$ and with the use of sieves of the hole diameter of ø 9 mm (the figure shows average values and standard deviations).

The changes in material grinding effectiveness can especially be noticed while analysing the mass changes during grinding (Fig. 2) as well as taking into account the changes of energy consumption, which were defined basing on the torque changes (Fig. 3).

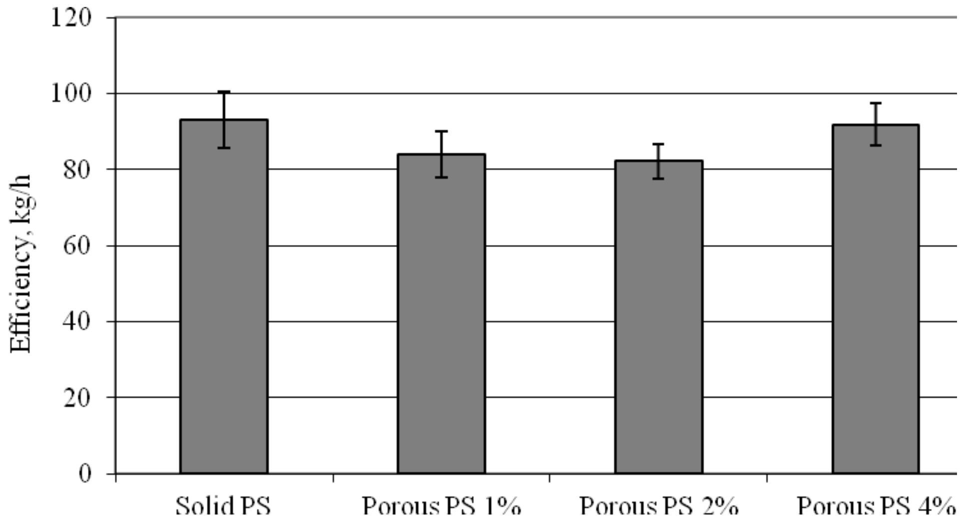

Fig. 2. Changes of the efficiency during grinding polystyrene of variable pore quantity in a knife mill. The tests were conducted at the tangential velocity of the moving knives of 3 $m*s^{-1}$ and with the use of sieves of the hole diameter of ø 9 mm (the figure shows average values and standard deviations).

The analysis of the two diagrams indicates the fact that in case of solid polystyrene grinding, due to its low toughness, the input segmentation takes place through cutting and impact cracking. The process proceeds very intensively due to the fact that in the gap between the moving and fixed knives material segmentation is initiated through its incising and the following uncontrolled brittle cracking caused by rotary movement of the rotor. Porous structure creation limits the phenomenon and emphasises the significance of cutting as the basic material segmentation manner. Pores created by introduction into the PS structure a blowing agent or a neutral gas moderate crack propagation while cutting and constitute a kind of its flexible phase. Chemically modified polystyrene segmentation is connected with the highest energy expenditure (Fig. 3), which indicates that in these cases the material disintegration takes place mainly through cutting.

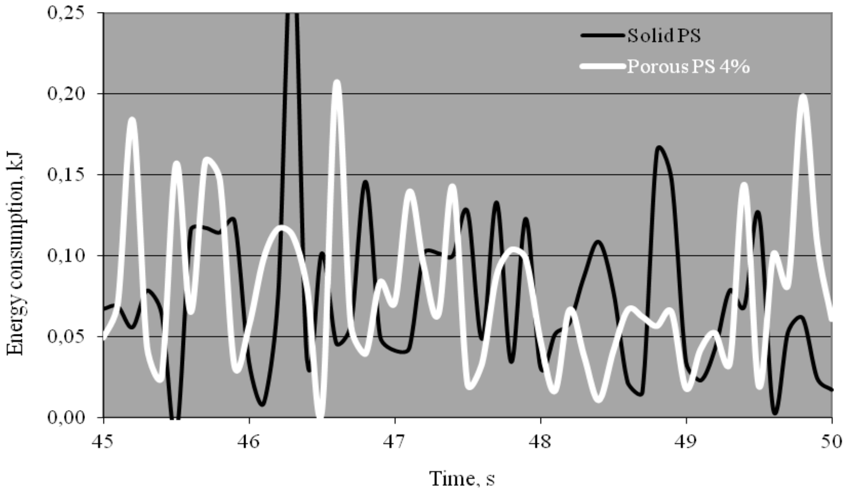

Fig. 3. The exemplary course of change of energy consumption (measurement at regular intervals - 0,1 s) required to disintegration polystyrene of different porosity degree

Obtaining a defined segmentation degree for solid PS is the most prolonged, and unitary energy expenditure for this material grinding is lower than for extruded PS with 4% of blowing agent in mass. This is the result of a high participation of gaseous phase in material, which constitutes the area of material unwholeness. The dominant participation of cutting in porous polystyrene disintegration is confirmed by the measurements of the temperature registered inside the mill chamber and in the area of the sieve. For all the cases considered in the research heat load is minor, and the temperature did not exceed 40^0C.

The analysis of the obtained recyclate disintegration shows the dominant participation of fraction of grain range of $3,5<x<5$mm, regardless the structure type (Fig. 4). This grain fraction participation constitutes about 35% of the whole mass of the obtained recyclate. Fractions of $5<x<6$ mm and $6<x<7$ mm also have a great weight for the grain distribution. Together they constitute another 35% of the mass of the analysed recyclate input regardless the polystyrene structure type. It can, therefore, be agreed that the sieve of Ø 9 mm generates the greatest content of grains within the range of 3,5 to 7 mm, which, form the point of view of further processing, is a positive phenomenon.

It is also worth mentioning that the initial analysis of microscope pictures reveals that in case of porous polystyrene a set of grains with flat cross planes and straight edges was obtained (with clear marks of knife cutting), which shows the dominant significance of cutting in material division. Solid polystyrene recyclate is characterised by similar shape. On the contrary, the difference in relation to porous material concerns the cutting surfaces which for recyclate are less flat with elements of hollows and bulges. This shows a significant participation of percussive cracking in brittle polystyrene disintegration, which gives an additional confirmation of low energy consumption for solid PS. Initiated by cooperative cutting knives material cutting is, due to its hardness and brittleness, further propagated unprompted. The above described mechanism of polystyrene division finds its confirmation in the obtained recyclate grain content.

Despite the use sieves of the hole diameter of 9 mm in the knife mill, about 50% of the mass is composed of grains of the average volume of 5 mm and less (Fig. 4).

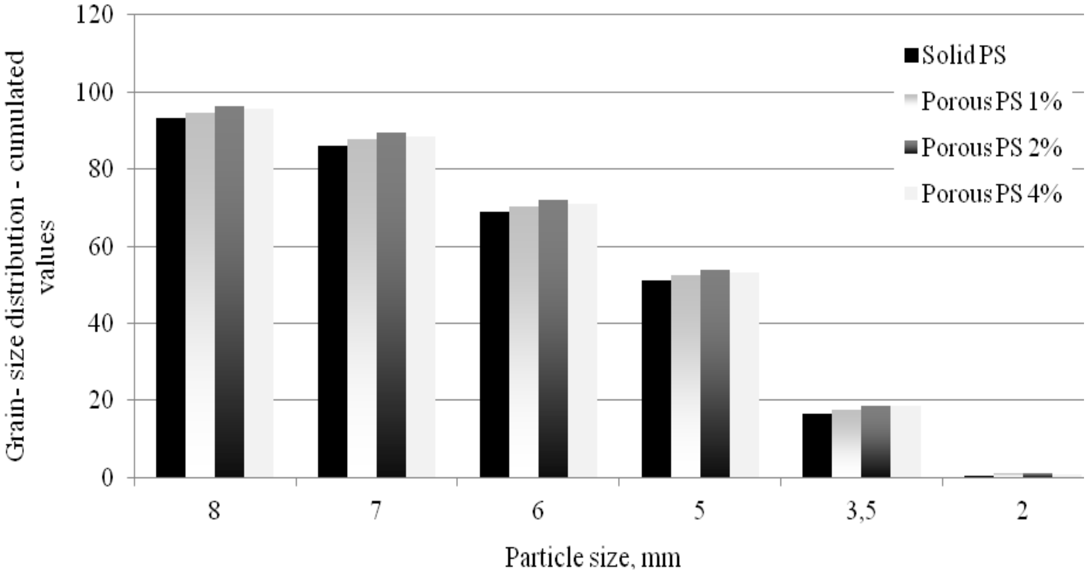

Fig. 4. Grain size distribution of the obtained PS recyclate

5. Conclusions

The presented research proves that the porous structure created in polystyrene significantly influences the material susceptibility to grinding. Together with the pore content growth in the PS structure, the material segmentation in a knife mill chamber takes place with the lower participation of impact cracking, mainly though cutting. Polystyrene modification through its pore-filling caused obtaining the material of a restricted susceptibility to impact cracking, whose segmentation to the grain degree allowing subsequent processing requires higher energy expenditures. Porous polystyrene grinding is form the point of view of efficiency and unitary energy consumption, far less effective. The employment of the same material disintegration conditions caused obtaining similar grinding degree. The dominant fractions, constituting more than 60% of the input mass, are a set of grains of much smaller dimensions than the ones used in the working chamber of the sieve (the hole diameter of Ø 9mm).

References

[1] Bieliński, M., *Techniki porowania tworzyw termoplastycznych*, Akademia Techniczno-Rolnicza, Bydgoszcz 2004.

[2] Sołtysiak, R., Bieliński, M., *Właściwości litych i porowatych płyt z PVC*, Inżynieria i Aparatura Chemiczna, SIMPress, 44 (36), pp. 74-75, Gliwice 2005.

[3] Flizikowski, J., *Rozdrabnianie tworzyw sztucznych*, Akademia Techniczno-Rolnicza, Bydgoszcz 1998.

[4] Sykutera, D., *Stanowisko badawcze i wstępne wyniki badań cięcia termoplastycznych tworzyw porowatych*, Przetwórstwo Tworzyw, IMPiB, 4 (136), pp. 214-217, Gliwice 2010.

[5] Sykutera D., *Cięcie wolnoobrotowe porowatego PVC,* Inżynieria i Aparatura Chemiczna, SIMPress, 45 (37), pp.76-77, Gliwice 2006.

[6] Sykutera, D., *Recykling mechaniczny porowatego polietylenu małej gęstości*, Przetwórstwo Tworzyw, IMPiB, 5 (143), pp. 382-384, Gliwice 2011.

[7] Sykutera, D., *Stanowisko do cięcia i rozdrabniania porowatych tworzyw termoplastycznych*, Zeszyty Naukowe Politechniki Poznańskiej, 12, pp. 331-336, Poznań 2010.
[8] Konieczka, R., Kałużny, W., Sykutera, D., *Drehschneiden im Prozess der Feinzerkleinerung von Gummi*, Kautschuk Gummi Kunststoffe, Hüthig Verlag, 9 (50), pp. 641-644, Heidelberg 1997.

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