Selected properties of recycled polypropylene obtained from porous injection molded parts (*Rapid Communication*)

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Abstract: In this work the influence of blowing agents residues on the density and melt flow rate (*MFR*) of the polypropylene (PP) moldings was investigated. A standard methodology to determine the density of polymeric porous material was used. The amount of blowing agent residues was indicated by the melt flow rate (*MFR*) change of PP moldings. The aim of the research was to explore and understand the phenomena occurring during the formation of the porous structure due to the decomposition of chemical blowing agents in the injection molding process. Special attention was paid to the influence of holding pressure and plasticizing temperature as well as the molding temperature onto the intensity of PP pore creation. Specially designed test stand for porous materials cutting and grinding was used for PP moldings.

Keywords: chemical blowing agent, polypropylene, grinding, recyclate, foam injection molding.

Wybrane właściwości recyklatu polipropylenowego pochodzącego z porowatych wyprasek formowanych metodą wtryskiwania

Streszczenie: W pracy badano wpływ na gęstość i wskaźnik szybkości płynięcia (*MFR*) pozostałości chemicznych substancji porotwórczych znajdujących się w rozdrobnionych, porowatych wypraskach z polipropylenu (PP). Wyznaczano te dwie właściwości, ponieważ gęstość porowatych materiałów polimerowych jest ich ważną cechą użytkową, a wartość *MFR* stanowi miarę pozostałości poroforu w materiale. Celem realizowanych badań była próba poznania zjawisk zachodzących podczas tworzenia struktury porowatej, spowodowanych rozkładem poroforów chemicznych w procesie wtryskiwania. Szczególną uwagę zwrócono na wpływ ciśnienia docisku, a także temperatury uplastyczniania i temperatury gniazda formującego formy wtryskowej na intensywność tworzenia się porów w PP. Do rozdrabniania wyprasek użyto oryginalnego stanowiska badawczego do cięcia i rozdrabniania materiałów porowatych.

Słowa kluczowe: porofory chemiczne, polipropylen, rozdrabnianie, recyklat, wtryskiwanie porujące.

Thermoplastic foaming is a method of modification, which decreases the product weight. Blowing agents are applied to decrease the molding shrinkage and to increase product rigidity. Use of a blowing agent can additionally improve the final product damping and its insulating properties which enables new applications of such polymer material [1—3]. Modification of polymeric product properties with chemical blowing agents has been described in number of publications [2—13]. The increase of porous thermoplastics production is accompanied by the increase of technological and after-use waste [14, 15]. Material potential gathered in porous mass products can be re-used if the recycling process is properly applied. Insufficient knowledge of mechanical engineering of porous materials grinding process is a main reason to distinguish the recycling of porous polymeric materials as a separate issue. The influence of blowing agents and its residues on the porous waste material processing is another important research field [5, 14, 15]. The presented work is a component of a wider research project concerning industrial application. The aim of the research is to evaluate the correlation between the structure of foamed, injected molded polypropylene (PP) samples and reprocessing indicators. Melting flow rate and molded parts density were most important areas investigated.

EXPERIMENTAL PART

Materials

The polypropylene (PP) used in experiments was Moplen HP548R produced by Basell Orlen.

The blowing agent for polypropylene was a concentrate in the form of granulate of Hydrocerol CF 40E by Clariant company. The decomposition of the blowing agents of endothermic nature takes place in temperature

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ranging from 150 to 240 °C, with a distinct maximum in the temperature of 175 and 205 °C [3, 11].

Sample preparation and testing

The first stage was production of porous samples of polypropylene with the use of a multi-cavity experimental mold (Fig. 1 a) and JSW 110H injection machine. Foaming injection molding was realized for two temperature profiles of the injection machine plasticizing unit:

Fig. 1. Photographs of: a) experimental injection mold, b) cutting and grinding stand for polypropylene porous moldings, c) ground foamed samples

— profile 1 (I — by nozzle — 210 °C, II — 210 °C, III — 200 °C, IV — 195 °C, V — 190 °C, VI — by hopper — 80 °C;

— profile 2 (I — by nozzle — 230 °C, II — 230 °C, III — 220 °C, IV — 215 °C, V — 210 °C, VI — by hopper — 80 °C).

Four molding temperatures ($T_1 = 20$ °C, $T_2 = 40$ °C, $T_3 = 50$ °C, $T_4 = 60$ °C), and two values of holding pressure ($p_{d1} = 20$ MPa, $p_{d2} = 0$ MPa) were used. The invariable process parameters were: injection time of 1 s, total cycle time of 45 s and injection pressure of 450 MPa. The blowing agents were added in the amount of: 0.5, 1.0, 1.5 and 2.0 wt %.

The density measurement of porous structure samples was conducted with the hydrostatic method, using Axis AD50 scales and immerse liquid.

The obtained moldings were ground into small pieces and sieved using sieves of ϕ 7 mm hole diameter (Fig. 1b and 1c) [14].

Melting flow rate (*MFR*) was measured with Zwick Roel Aflow plastometer at 2,16 kg load and 230 °C temperature.

RESULTS AND DISCUSSION

The effect of molding temperature and content of blowing agent on the density of molded PP (temperature on the nozzle 210 °C, no holding phase) is shown in Fig. 2. Density decreased inversely to increasing amount of the applied blowing agent and reached the value of about 850 kg · m^{-3}. The intensity of molding mass reduction increased slightly with the increase in temperature PP in the plastifying unit as well as with the injection molding temperature. As a result, porous moldings of mass reduced by about 6 % were obtained. Supplying the material with a greater amount of heat in the plasticizing unit and during the molding solidifying phase causes that the blowing agent decomposes also during the cooling phase in the mold cavity. Higher molding temperature is conducive to decompose the blowing agent, especially in the case of its high content (Fig. 2).

Holding pressure in the foam injection molding process has a negative influence on the porous structure forming as it hinders the pore development during cooling of the molded phase, regardless of the process temperature. A comparison of density in the analyzed samples, presented in Fig. 3, indicates the need to control the process in such a way that pores are formed in the mold cavity. While analyzing the results presented in Fig. 3, it can

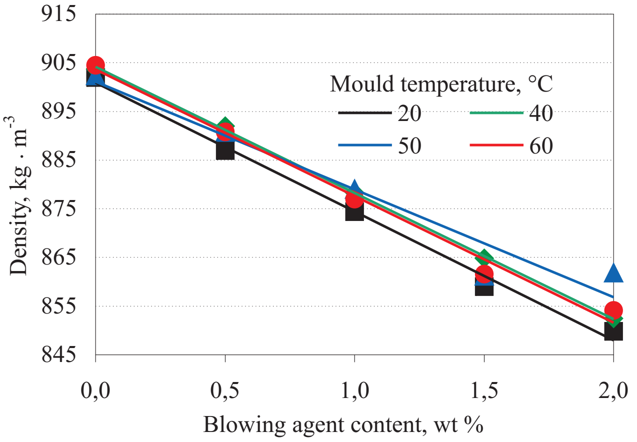

Fig. 2. The effect of mould temperature and blowing agent content on density of molded PP

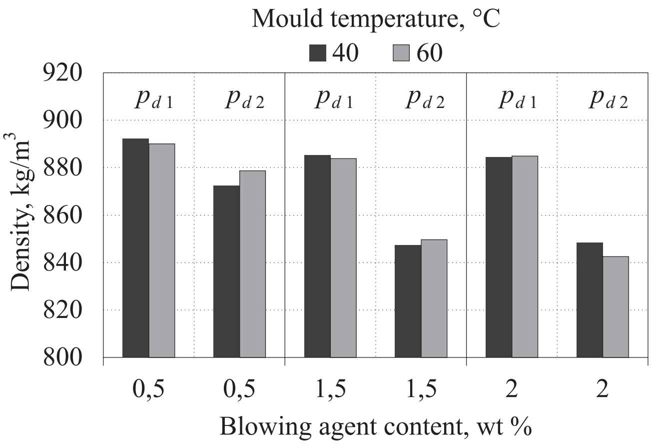

Fig. 3. The effect of blowing agent content and holding pressure (p_{d1} = 20 MPa and p_{d2} = 0 MPa) on density of PP foam

be seen that higher holding pressure makes the foaming process more difficult and as a result samples mass reduction is lower. Conducted visual evaluation of the outer molding surface confirmed in addition, that the foaming process has taken over the function of the holding phase (sunken marks on the molding surface 4 mm deep were not observed).

The influence of plasticizing temperature and molding temperature on the pore creation kinetics was confirmed by results of *MFR* measurements (Fig. 4). It was stated that the amount of unreacted blowing agents in the primary process increases when injection was conducted at lower plasticizing and injection molding temperature. Re-heating of the PP recyclate causes the appearance of secondary pores and increases *MFR* of the material. Nonetheless, one should remember that the grinding processes causes material degradation. Therefore the total *MFR* increase may be due to not only the activation of unreacted blowing agents but also due to macromolecule length reduction caused by shear stress generated during material cutting. The changes were observed for all injection molding temperatures in which the process was conducted.

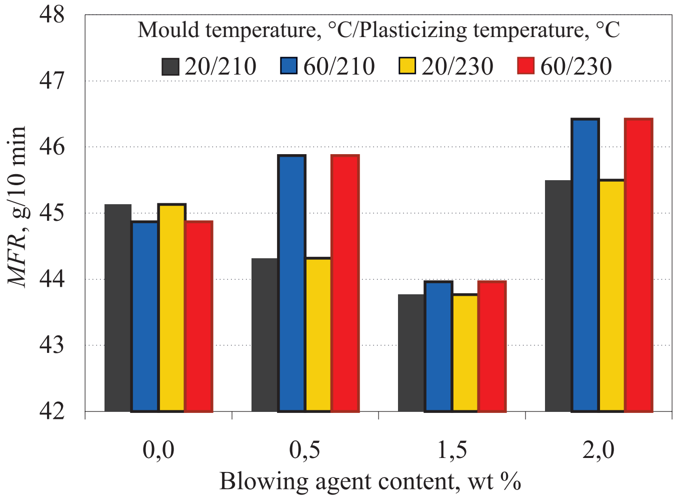

Fig. 4. The effect of blowing agent content and primary processing conditions (mould temperature and plasticizing temperature) on melt flow rate (*MFR*) of PP recyclate

The confirmation of the mechanism of porous phase creation in PP gives presented in Fig. 5 analysis of *MFR* changes in recyclates obtained from samples injected with holding pressure, especially for those obtained at lower temperature in the machine plastifying unit. A significant increase of *MFR* was observed, especially for higher blowing agent content (1.5—2 %), which indicates the secondary pore creation during *MFR* testing in temperature of 230 °C. Disadvantageous, from the point of view of gas phase development, injection conditions (low melt temperature and holding phase influence) cause that a portion of porophores does not undergo decomposition at all and secondary recyclate heating in the plastometer initiates the foaming process. The observed tendencies are characteristic for all used molding temperatures.

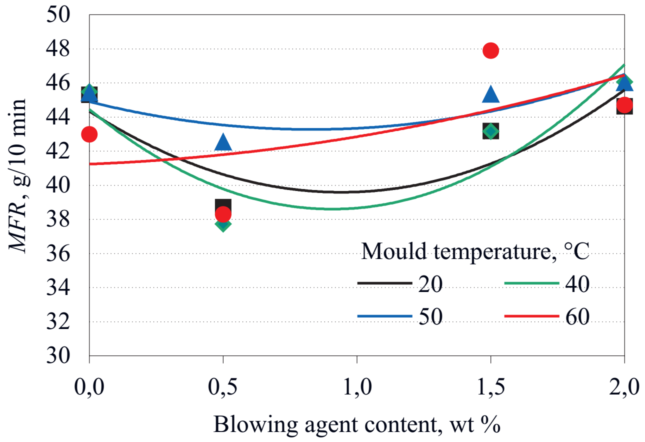

Fig. 5. The effect of blowing agent content and mould temperature on melt flow rate (*MFR*) of PP recyclate produced using plasticizing temperature of 210 °C

The *MFR* decreases with the melt temperature increase (profile 2 of temperature in the injection machine plasticizing unit). No significant *MFR* rise was noticed, while in the case of holding phase applying, the index assumed lower values. This may result from the deterioration of the melt flow in the plastometer nozzle due to the increase of internal friction and unreacted blowing agents. This means that pore creation starts already in plasticizing unit in the injection molding machine.

The *MFR* change analysis indicates also that a small contents of porophores (0.5 % of the mass) causes that local porous structure is created. Heterogeneous structure is obtained, with locally placed single pores of large volume, most frequently in the sample core [3]. This probably results in large changes in *MFR* value of samples with a low porophore content.

CONCLUSIONS

Along with the growth of porophore content in PP, sample density decreases and the change level depends on the injection process parameters. A significant role in the process is played by the holding pressure and plasticizing temperature, especially the temperature set in the injection unit nozzle as well as the molding temperature. Injection molding cycle with the holding phase hinders porous structure creation in polypropylene, which is reflected by the molding density.

The blowing agent content directly affects the *MFR* value of polypropylene parts. Molding at low temperatures of the injection machine plastifying unit and with holding pressure of 20 MPa causes that some amount of the blowing agent does not dissolve, decomposes in the polymer and remains in such state in the material until secondary processing. This improves recyclate flow and causes creation of secondary porous structure in samples.

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