Acta Mechanica Slovaca
ISSN 1335-2393
www.actamechanica.sk

Microcellular Co-Extrusion Process and Selected Properties of Thin-Walled Products

Aneta Tor-Świątek[1,*], Ludmila Dulebova[2]

[1] Lublin University of Technology, Faculty of Mechanical Engineering, Department of Technology and Polymer Processing, 36 Nadbystrzycka St., 20-618 Lublin, Poland

[2] Technical University of Košice, Faculty of Mechanical Engineering, Department of Mechanical Engineering Technologies and Materials, 74 Mäsiarska St., 040 01 Košice, Slovakia

Abstract: The microcellular extrusion process takes place with the use of conventional technological line for extruding shapes and coatings under the changed processing conditions, such as temperature for particular zones of the plasticizing system and extruder head zones. The process differs from the conventional method with regard to the method of shaping the extruder product. In the conventional extrusion process, the plastic has a homogenous structure across the whole section, whereas during microcellular extrusion process the plastic, containing the input plastic and a special blowing agent, obtains a two-phase structure changing its structure into microcellular. One phase is solid and the other is microcellular. Microcellular phase is obtained by inserting the blowing agent into the input plastic during its manufacture. It takes place in the penultimate zone of the plasticizing system of the extruder under suitable process conditions which enable expansion of the blowing agent. Currently applied blowing agents have the form of gases and liquids (then they are inserted into the plasticizing system of the extruder by means of a special installation) but also powders and granulates inserted into the plasticizing system of the extruder together with the input plastic after previously mixing thereof. The article presents characteristics of the microcellular extrusion process and it describes selected research results of the process and microcellular extruder product properties.

Keywords: *microcellular extrusion process, blowing agent, micro pores, poly(vinyl chlorine).*

1. Introduction

Cellular extrusion of plastics is used in the manufacture of cable and wire coatings as well as different types of shapes, such as bars or tubes. In the process, special auxiliary agents are used which bring about changes in the structure of products. These agents, generally referred to as blowing agents, take different forms such as gas, liquid, powder or microspheres, and they display different, endothermic or exothermic, decomposition characteristics. Expansion of the blowing agent in the plastic occurs under proper processing conditions. Most important of them is temperature of both individual sections of the plasticizing unit and of the extruder head. It must high enough to cause decomposition of a selected blowing agent. In addition, decomposition must occur in a relevant section of the plasticizing unit of the extruder.

The microcellular extrusion process consists in adding the blowing agent, also referred to as the porophor, into the moulding compound, which under proper conditions of the extrusion process decomposes, at the same time emitting gas. The microcellular structure is obtained in the final section of the plasticizing unit

*** Corresponding author:** Aneta Tor-Świątek, ***E-mail address:*** *a.tor@pollub.pl*

of the extruder. The agent may be added to the plastic in the process of its manufacture or it may be delivered directly into the plasticizing unit of the extruder in the form of gas, powder, granules or microspheres. As a result of this processing procedure, the obtained product is given a diphase structure, turning from solid into cellular. New structure of the plastic may be microcellular along the entire cross-section or have a solid topcoat and a cellular core [1, 2].

Change in the structure of the plastic occurs also by proper selection of cellular extrusion conditions, i.e. temperature in individual sections of the plasticizing unit and the extruder head, as well as owing to design features of machines and tools used in this process. Properly selected moulding compound, microcellular blowing agent, conditions of the extrusion process and tool design enable manufacture of products displaying new, modified properties.

In microcellular extrusion of plastics with application of blowing agents, the extrusion product is obtained with new, modified physical and technological properties i.e. reduced mass of the product and reduced wear, improved dampening properties (heat, noise) and reduced processing contraction. As far as blowing agents are concerned, the type and quantity of inserted porophors play significant role, inasmuch as they exert influence on the final density of cellular plastic and determine the choice of cellular method.

Significant part in the process of cellular extrusion is played by temperature of individual sections of the plasticizing unit and the extruder head. It should be close to the decomposition temperature of the blowing agent, however its value must be adjusted in the manner ensuring that the porophor does not decompose too early or too late. In this process, it is important to ensure that the temperature of the extruder head is lower than the temperature of the final section of the plasticizing unit of the extruder. This results in the increased viscosity of the processed plastic, which prevents expansion of the gas in the plastic flowing in the extruder head [3, 4].

In the extrusion of shapes and coatings, the shape and dimensions of the extrudate's cross-section is initially determined by the extruder head, in consideration of the Barus effect and the phenomenon of shrinkage. However, in order to obtain a cellular extrudate with a homogeneously smooth topcoat, it is necessary to fix its shape and dimensions by calibration. The task of calibrating machines used in the process is to cool the extrudant to such temperature which will ensure stability of its shape and dimensions. Selection of the calibrating machine determines the calibration method, proper design and microcellular extrusion method. While using the inside cellular method, external dimensions of the extrudant between the outlet of the extruder die and inlet to the calibrating machine are identical. In this case, intensity of cooling determines the thickness of the solid extrudant topcoat, as during this process no microcells are created on its surface. Whereas in case of the free extrusion method, the time of microcell growth is extended owing to a larger distance between the extruder head and the calibrating machine [5].

2. Microcellular Blowing Agents

Microcellular blowing agent (porophor) is selected depending on the type of plastic, in the manner ensuring that its decomposition temperature is higher than the plastic melting point, but lower than the plastic extrusion temperature. Cellular plastic in liquid form is not yet a stable system because as a result of interfacial tension at the plastic – gas contact point, and as a result of diffusion, the number of cells in the plastic is reduced, whereas their dimensions enlarge, which is an undesirable effect. The obtained microcells continue to enlarge until gas pressure and interfacial tension are balanced. Favourable structure of a small-cell plastic can be maintained in the product by its immediate cooling and solidification [6, 7].

Microcellular blowing agents used in the extrusion process can be divided into physical and chemical, however this classification is traditional and not exactly accurate.

Physical blowing agents (physical porophors) cover substances which do not change their chemical structure during the extrusion process; they only change their state of aggregation. Therefore they include liquids or gases dissolved in plastic materials under pressure, which after the increase in temperature and decrease in pressure evaporate or are educed in the form of micro-bubbles. This group of porophors includes easily volatile, low boiling point organic liquids: aliphatic hydrocarbons and their chloro and fluoro derivatives. Important feature of porophors is their relatively low vapour pressure in room temperature and high evaporation rate in the processing temperature.

Chemical blowing agents (chemical porophors) act similarly as physical porophors, yet gaseous products obtained as a result of their decomposition and causing the microcellular extrusion effect, remain inside the plastic material. Chemical blowing agents can be divided into organic and inorganic. Inorganic porophors especially include some carbonates and bicarbonates, for instance sodium bicarbonate [8].

Blowing agents used during microcellular extrusion of plastics may display exothermic or endothermic decomposition characteristics. Porophors used to date usually present exothermic decomposition characteristics. This may be the cause of local overheating and generation of irregular cellular structure of the product. The initiated porophor decomposition process progresses automatically even after energy cut-off. Therefore, products extruded with the use of such agents must be intensely cooled for a long time, in order to prevent strains and keep proper cellular structure. The main representatives of this group include hydrazides, e.g. sulfohydrazide and azo compounds, for instance azodicarbamide. This compound is widely used in microcellular extrusion of polyethylene, polyvinyl chlorine, polystyrene and polyamide.

In the case of blowing agents with endothermic decomposition characteristics, generation of gas during processing is rapidly stopped when the energy flow is cut off. Application of such blowing agents considerably shortens the cooling time. Examples belonging to this group especially include bicarbonates e.g. sodium bicarbonate, ammonium bicarbonate and 2-Hydroxypropanetricarboxylic acid [9, 10].

3. Experimental Procedure

Modification of cable coatings and examination of the extrusion process especially referred to the manufacture of coatings made of microcellular plastics, which resulted in reduced costs of plastic acquisition, energy costs of the process and transportation costs. Microcellular extrusion of thermoplastic materials conducted in the Department of Technology and Polymer Processing is a process in which modification of product properties is done through the change in extrusion conditions and design features of elements of the plasticizing unit and the extruder head, as well as by the use of auxiliary agents affecting the basic compound. For properties of the extruder product depend not only on the type of the plastic material, type and contents of the porophor, the size, number and geometric characteristics of cells generated during the microcellular extrusion process, but also on the conditions of the extrusion process.

The manufacturing process of cable coatings obtained from the plastic containing blowing agents was conducted with the use of microcellular extrusion and microcellular coextrusion process lines (Fig. 1.) used in the manufacture of topcoats for electric cables.

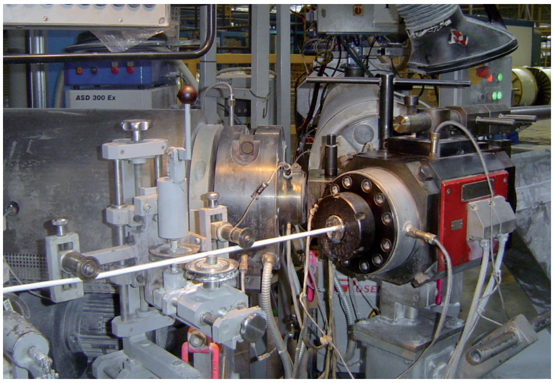

Fig. 1: *Fragment of microcellular co-extrusion line of PVC cable layer.*

During studies on microcellular extrusion and co-extrusion processes, PVC PXO-84-147-9010 EKO polyvinyl chloride was used. This plastic has density of 1480 kg/m3 and hardness of 84 Sh° A (according to data provided by the producer). The abovementioned plastic was modified with a physical blowing agent with endothermic decomposition characteristics, taking the form of a blowing system. This agent was delivered as 0%, 0.3% and 0.4% of the mass during the microcellular extrusion process and as 0%, 0.4% and 0.5% during microcellular co-extrusion. This system takes the form of granules with 1.2-1.8 mm in diameter and it contains 50% of the blowing agent mass.

During the study, the conducted microcellular

Tab. 1: *Conditions of single-layer microcellular extrusion process and double-layer microcellular co-extrusion process of PVC cable.*

Content of porophor (%)	Machine	Temperature in plasticizing system (°C)					Temperature in extruder head (°C)					Rotational speed of screw (r/m)	Pressure (MPa)
		I	II	III	IV	V	I	II	III	IV	V		
Microcellular extrusion process of PVC cable single-layer													
0.3	Extruder 1	30	150	160	190	190	180	175	165	160	165	60	21.0
0.4		30	150	160	195	195	180	175	165	160	165		
Microcellular co-extrusion process of PVC cable double-layer													
0.4	Extruder 1	30	150	160	160	160	162	163	160	155	150	44	21.4
	Extruder 2	30	170	190	190	185	175	165	160	155	150	44	25.5
0.5	Extruder 1	30	150	160	160	160	162	163	160	155	150	44	21.4
	Extruder 2	30	170	190	190	185	175	165	160	155	150	43	26.0

Tab. 2: *Research results of physical properties.*

Type of cable layer	*Content of porophor (%)*	*Density (kg.m⁻³)*	*Degree of porosity (%)*	*Water absorptivity (%)*	*Tensile strenght (MPa)*	*Unit elongation (%)*
Single-layer	0	1459	0	2.2	14.2	695.50
	0.3	1144	22	2.0	11.4	552.26
	0.4	1103	25	1.6	11.3	488.29
Double-layer	0	1459	0	2.2	14.2	695.50
	0.4	1050	28	1.9	11.9	636.88
	0.5	928	36	1.4	11.8	569.96

extrusion and co-extrusion processes referred to single- and double-layer coatings of power cables (YDY) 2 x 1.5 with ohmic resistance. Conditions of the conducted processes are shown in Table 1.

In all cases, the line speed of the manufactured cable was 300 meters per minute. In both processes, a special gravimetric feeder was used.

In the coextrusion process, a double-layer cable coating was manufactured, of which the internal one was microcellular, and the external was solid. The plastic containing a blowing agent was delivered from the plasticizing unit of extruder 1, whereas the solid plastic - from the plasticizing unit of extruder 2.

4. Results and Discussion

Cable coatings obtained as a result of conducted processes (Fig. 2-4.) were examined in terms of selected physical properties, i.e. density, degree of porosity and tensile strength. The examinations were conducted in accordance with international standards [11, 12].

The method of determining apparent density of plastic materials was applied during studies on density of sample cellular extrudates. WS-11 laboratory scales was used to measure density of the modified plastic. Refined particles of sample extrudant, whose mass ranged from 1 to 5 g, were the object of study.

The degree of porosity of the extrudant is determined by its porosity, i.e. percentage of the entire material covering cells. In order to determine it, the results of density measurements of the manufactured coatings were used.

Cable samples were examined in term of water absorptivity in accordance with appropriate conditions of the tests. Samples were put into distilled water 168 h ± 1 h and next were expose to ageing researches in temperature of 50±2 °C in 24±1 h. WA34 laboratory scales and KC-100/200

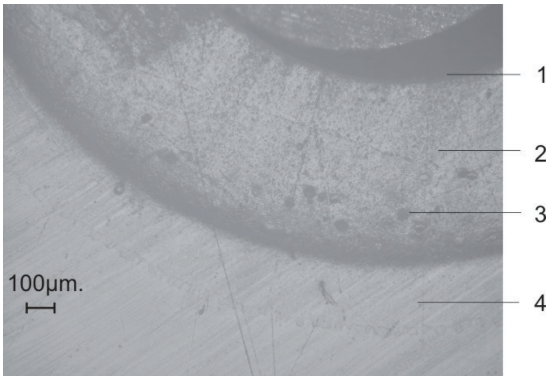

Fig. 2: *Structure view of PVC double-layer cable with 0,3% content of porophors: 1 – inter layer, 2 – core, 3 – pores, 4 – outer layer.*

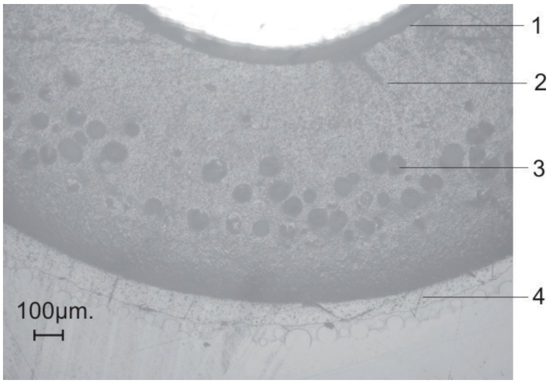

Fig. 3: *Structure view of PVC double-layer cable with 0,4% content of porophor: 1 – inter layer, 2 – core, 3 – pores, 4 – outer layer.*

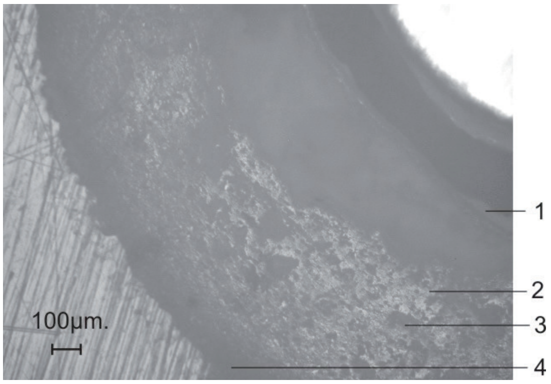

Fig. 4: *Structure view of PVC double-layer cable with 0,5% content of porophor: 1 – inter layer, 2 – core, 3 – pores, 4 – outer layer.*

thermal chamber were used to measure water absorptivity of modified cable.

To specify the selected mechanical properties of ducts, tensile strength and ultimate elongation were tested. The tests were conducted in accordance with relevant recommendations with the use of Zwick Z 100 testing machine.

Excerpt from the test results for selected mechanical properties of cable topcoats is presented in Table 2.

5. Conclusions

Microcellular extrusion and coextrusion sub-processes were conducted under the same processing conditions, in order to obtain an electric cable with a single- and double-layer microcellular topcoat. Examination of selected physical properties of the obtained coats has shown that adding a blowing agent to the moulding compound affects their values. However, noticeable reduction in tensile strength falls within the range of values recommended by relevant standards of their use. Density of the extrudant was reduced by 15% in the case of a single layer, and by 36% in the case of a double layer. This reduction results in decreased consumption of the processed plastic and at the same time, increased material saving. However, measurements taken during extrusion failed to show any change in puncture resistance of the manufactured power cable coatings.

Acknowledgments

This work was supported by KEGA 059TUKE-4/2016.

References and Notes

[1] ***Bieliński, M.,*** (2004). Techniki porowania tworzyw termoplastycznych, Wydawnictwo Uczelniane ATR w Bydgoszczy,

[2] ***Garbacz, T., Jachowicz, T., Tor-Świątek, A.,*** (2016). The effect of blowing agents on the effectiveness of poly(vinyl chloride) extrusion. Advances in Science and Technology Research Journal, 10, 32, 217-223.

[3] ***Tor-Świątek, A.,*** (2013). Evaluation of the effectiveness of the microcellular extrusion process of low density polyethylene. Eksploatacja I Niezawodnosc-Maintenance and Reliability, 15, 3, 225-229.

[4] ***Tor-Świątek, A.,*** (2015). Innovative hybrid polymer composites cellular polymer-metal powder obtained in extrusion process. Acta Innovations, 17, 12-21.

[5] ***Markovičovà, L., Hurtalova, L, Zatkaliková, V., Garbacz, T.,*** (2014). Evaluation of composite structures by light microscopy and image analysis. Manufacturing Technology : Journal For Science, Research And Production,14, 3, 351-355.

[6] ***Błędzki, A., Karuk, O., Kirschling, H., Kühn, J., Jaszkiewicz, A.,*** (2006). Microcellular polymers and composites. Polimery, 10, 51, 697.

[7] ***Garbacz, T., Dulebova, L.,*** (2013). Porophors used in the extrusion process. Chemistry & Chemical Technology, 7, 1, 113-118.

[8] ***R. Sikora,*** (2006). Przetwórstwo tworzyw Polimerowych, Wydawnictwo Politechniki Lubelskiej, Lublin.

[9] ***Sikora, J., Samujło, B.,*** (2013). Impact of feed opening width and position on PVC extrusion process effectiveness. International Polymer Processing, 28, 3, 291-299.

[10] ***Klepka, T., Garbacz, T., Bociąga, E.,*** (2014). Some properties of extruded porous microducts. Przemysl Chemiczny, 93, 6, 907-910.

[11] PN-EN ISO 845:2000. Cellular Plastics and Rubbers, "Determination of Apparent (Bulk) Density.

[12] PN-EN ISO 1798:2001. Flexible porous plastic - Determination of tensile strength and elongation at break.

Biographical notes

Aneta Tor-Świątek, PhD. MSc., *is assistant professor in Lublin University of Technology, Faculty of Mechanical Engineering, Department of Technology and Polymer Processing. After graduating (2004) from the Faculty of Mechanics PL, specialty Polymer Processing took a job at the Polymer Processes Department as an assistant on February 1, 2005. In March 2011, she defended her doctoral thesis: "Research on the course and effects of the process of extrusion of microcellular modified poly(vinyl chloride)"and obtained the degree of doctor of technical sciences in the discipline of Construction and Operation of Machines. She is a specialist in the field of polymer plastics processing, mainly extrusion and injection, composite materials, modification of polymer materials with auxiliary agents and research on the properties and structure of polymer materials. Moreover, thanks to completed post-graduate studies, he also specializes in work safety, industrial hygiene and intellectual property protection. She is the author and co-author of over 66 scientific and didactic works published in national and foreign magazines, scientific monographs and conference materials. She is also the author and co-author of 15 patents, 2 industrial designs, 8 patent applications and 1 trademark.*

Assoc. prof. Ľudmila Dulebová, Ing. PhD., *is associate professor at the Technical University of Košice, Faculty of Mechanical Engineering, Department of Mechanical Engineering Technologies and Materials. She graduated in 1983 at the VŠT Košice and obtained the PhD. degree (2008) in 23-07-9 Mechanical Engineering Technology and Materials at the Technical University of Košice. Her research areas are processing and simulation of injection molding, as well as testing and analysis of the properties of polymer materials and composites. She is a co-author of three monographs and six textbooks. She is the author or co-author of 204 published scientific publications in foreign and national magazines, scientific monographs and conference materials. Three her paper were registered in Current Contents paper, twenty-five papers were registered in Web of Science and Scopus. She is also co-author of three patents.*