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Structure and properties of cellular thin-walled cable coatings

RAPID COMMUNICATION

Summary — The paper describes the manufacturing process of cable and conduit double-layered coatings by cellular co-extrusion method. This coatings were obtained using poly(vinyl chloride) (PVC) and 0—0.5 wt. % of Adcol-blow UP-0Xb+X1020 as a blowing agent. The density and porosity of the produced samples were investigated. On the basis of their results the usefulness of obtained coatings to insulate electrical cables was evaluated.
Keywords: cellular co-extrusion process, blowing agent, cable coating.

STRUKTURA I WŁAŚCIWOŚCI CIENKOŚCIENNYCH POROWANYCH POWŁOK KABLI
Streszczenie — W artykule scharakteryzowano proces wytwarzania metodą współwytłaczania porującego powłok dwuwarstwowych kabli elektrycznych. Powłoki te otrzymano z poli(chlorku winylu) (PVC) i 0—0.5 % mas. Adcol-blow UP-0Xb+X1020 pełniącego rolę środka porującego. Przeprowadzono badania gęstości i porowatości wytworzonych próbek w zależności od ilości użytego środka porującego. Na podstawie ich wyników oceniono przydatność otrzymanych powłok do izolacji kabli elektrycznych.
Słowa kluczowe: współwytłaczanie porujące, środek porujący, powłoka przewodu elektrycznego.

The technology of cellular extrusion of thermoplastics is aimed at obtaining cellular products devoid of hollows on the outer surface and showing minimal processing shrinkage. Properly selected processing conditions allow to manufacture products with new, modified physical and technological properties [1—3]. The new products are characterized, among others, by reduced weight, improved damping and insulation properties and the possibility of utilization after use, retaining at the same time physical and technological properties similar or identical to those of cellular products. To obtain cellular structure, the properties of an extrudate are modified by using an appropriate type of polymer or by incorporating blowing agents (porophors) into the polymer. The obtained extrudate may have an entirely solid or an entirely cellular structure; it may be cellular across its thickness or have a cellular core with a solid outer skin [4—8].

The properties of a cellular extrudate depend on many factors [7, 8]:

— the type of polymer;

— the type and content of the blowing agent;

— the size, number and geometric characteristics of cells formed during cellular foaming;

— the method used and conditions of the extrusion process;

— the distribution of polymer temperature in the extruder's plasticizing system and in the extrusion head;

— extrusion rate (at low extrusion rates, foaming occurs close to the die, which may contribute to the formation of uneven cellular structure).

A blowing agent can be gaseous, solid or liquid. Gases and liquids are introduced into the input polymer under appropriate conditions — under pressure, using special devices which deliver them to the feed section of the plasticizing system during extrusion. Solids, on the other hand, as well as some liquids, are incorporated into the polymer already during its production [8—10].

Modification of polymers with selected blowing agents is determined by the conditions characterizing this process and its course as well as by the properties and structure of the obtained foamed product. Introduction of a blowing agent into a polymer plastic during extrusion offers significant material and energy savings.

The foaming process results in a change of selected physical and functional parameters as well as some specified geometric features of the obtained extrudate. Yet, there are no explicitly established research methods and existing methods are not suitably adapted for testing the effectiveness of the cellular extrusion process.

The aim of this works was to investigate the influence of the blowing agent during the extrusion of poly(vinyl chloride) on the process and on the physical properties and properties of the surface of extrusion product. Another objective was assessment of the examined polymer in terms of required conditions and properties of cable topcoats.

EXPERIMENTAL

Materials

The cellular coating extrusion tests were performed using poly(vinyl chloride) (PVC), stocked by the „NKT Cables" Company in Warszowice. PVC with trade name PZH 92 manufactured by Finproject Divisione Compounds had the density of 1459 kg/m^3 (according to the data obtained from the producer).

PVC was modified with the use of one type of granulated blowing agent selected to match the type of the processed polymer and the method applied. It was dispensed as 0.3 to 0.5 wt. %. It was Adcol-blow UP-0Xb+X1020 produced by Clariant Masterbatch Division.

Adcol-blow UP-0Xb+X1020 is an exothermically decomposing system that has the form of cylindrical pellets 2 to 3 mm in diameter. The blowing agent contained in this material system is a mixture of an appropriate ratio of chemical compounds, among others azodicarbonamide. According to the manufacturer recommendations, good foaming efficiency can be achieved at processing temperature ranging between 145 and 180 °C.

Sample preparation

Polymers were modified by introducing blowing agents into PVC by mixing. The mass of polymer and blowing agents was measured with a WTE-2000 laboratory balance reading to 0.1 g. The components were mixed by manual stirring. The content of the blowing agent (0—0.5 wt. %) was adopted as a variable factor.

The process of producing electric cable coating using PVC with a blowing agent was conducted at NKT Cables Company in Warszowice. W3 co-extrusion line available in the above mentioned company was applied. This co-extrusion line, presented in Figure 1, is used in the production of coatings for wires and cables of various types and applications. It was equipped with three horizontally-positioned Rosendahl extruders.

The main extruder had a plasticizing system with a screw having an external diameter of 120 mm, while the auxiliary extruders had plasticizing systems with 60 mm diameter screws. The co-extrusion line contained an angular extrusion head used for coating co-extrusion, a

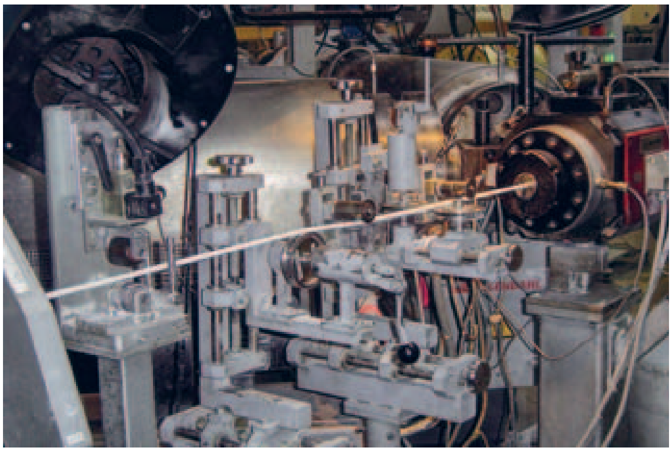


Fig. 1. Section of the technological line for cellular co-extrusion

cooling unit (a cooling bath), take-off units, and other required elements of the technological line. The preset take-off speed of the cable conductor was 500 m/min and was the minimal speed at which the described co-extrusion line can operate.

T a b l e 1. Technological parameters applied in cellular co-extrusion technological line in technological tests

Blowing agent content wt. %	Machine	Temperature of the plasticizing system, °C	Temperature in the extrusion head, °C	Extruder screw speed rpm	Pressure in the extrusion head MPa
Single-layer extrusion coating					
0.3 0.4 0.5	extruder 1	150—190	180—165	60	21.0
Double-layer extrusion coating					
0.4	extruder 1	150—160	162—150	44	21.4
	extruder 2	170—185	175—150	44	25.5
0.5	extruder 1	150—160	162—150	44	21.4
	extruder 2	170—185	175—150	43	26.0

In Table 1 the technological parameters of the co-extrusion process used in this work are listed.

Methods of testing

The density of the PVC coating samples was determined using a pycnometric method. The measurements were made in conformity with the standard PN-EN ISO 1183-1:2006. Measurements were made on samples coming from coatings with a mass in the range of 1 to 5 g. It has to be noted, though, that because the coatings were made up of two solid layers and one foamed layer, which were impossible to unequivocally separate from one another during the density measurements, the determined density of the PVC coating samples is not the density of the foamed layer of the cable coating. The measurements were made in conformity with the recommendations of the standard PN-EN 50396:2009.

It was assumed for further considerations that the thickness of the solid layer of a cable with double-layer coating represents about 50 % of the thickness of the entire coating, and the remaining 50 % is a product of microcellular extrusion. Thus, 50 % of the coating has a constant density of the solid plastic, namely ρ_n = 1459 kg/m^3, while the remaining 50 % of the coating has the density of the cellular layer (ρ_s).

Microscopic studies of the structure of the cross-sections of the coatings produced were performed using an Confocal Microscope, type Olympus FluoView FV1000 equipped with software for image analysis.

RESULTS AND DISCUSSION

During technological tests of the process of cellular coating extrusion, electric cables with a symbol YDY 2 x 1.5 mm^2 450/750 V were produced. They are cables with single- and double-layer PVC coating with various contents of the blowing agent. Figure 2 shows an exemplary cable with diameter of outer surface 7.80 mm and with a thickness from 1.10 to 2.50 mm.

Dispensing the blowing agent into PVC by manual stirring before extrusion during technological tests proved to be effective. No visual changes and no changed properties of the examined product resulting from the manner of dispensing and mixing PVC with the blowing agent have been observed.

Table 2 shows results of the measurements of the cable coating density, the density of the cellular layer, and the degree of porosity of samples obtained with various contents of the blowing agent. The obtained product was a rod with porosity degree of 14—38 % and density ranging from 1240 to 915 kg/m^3. This results in reduced density of the obtained cellular product. The porosity degree, being a property determining the volume of the gaseous phase in the cellular product, at the same time determines the value by which the density of the product is reduced.

T a b l e 2. Results of studies on the apparent density and porosity degree of cable coatings

Type of sample	Content of the blowing agent wt. %	Density of the porous layer kg/m^3	Degree of porosity, %
single-layer coatings	0	1459	0
	0.3	1240	14
	0.4	1103	25
	0.5	915	38
double-layer coatings	0	1459	0
	0.3	1220	16
	0.4	1050	28
	0.5	928	36

The amount of the blowing agent was selected so that, under the assumed conditions of cellular coating co-extrusion, single-layer and double-layer coating cables were produced. In the case of the single-layer and double-layer coatings containing 0.3 wt. % of the blowing agent, the obtained degree of porosity of 14 and 16 %, respectively and the density of 1240 and 1220 kg/m^3, respectively, are insufficient.

The result is that the porosity of the plastic increases most effectively at the blowing agent contents between 0.4 and 0.5 wt. %. This is borne out by the fact that at the obtained porosity degree of 25—38 % and the density of 1050—915 kg/m^3, the continuity of the coating was maintained across its cross-section and the coating had a uniform micropore distribution and a uniform pore size.

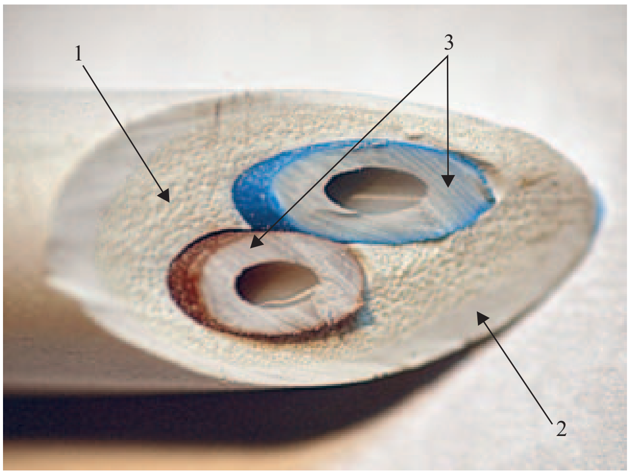


Fig. 2. View (20× magnified) of double-layered coating structure (copper cores have been removed) obtained using blowing agent in amount 0.5 wt. %: 1 — cellular internal layer, 2 — solid external layer, 3 — layers of cable cores

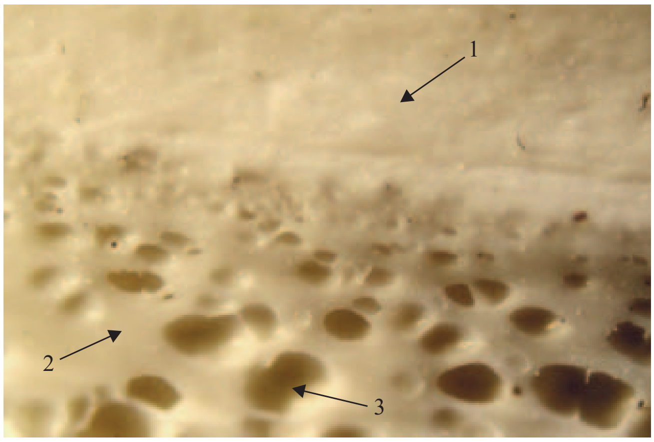


Fig. 3. View of double-layered coatings structure containing blowing agent in amount 0.4 wt. %: 1 — solid external layer, 2 — cellular external layer, 3 — pores

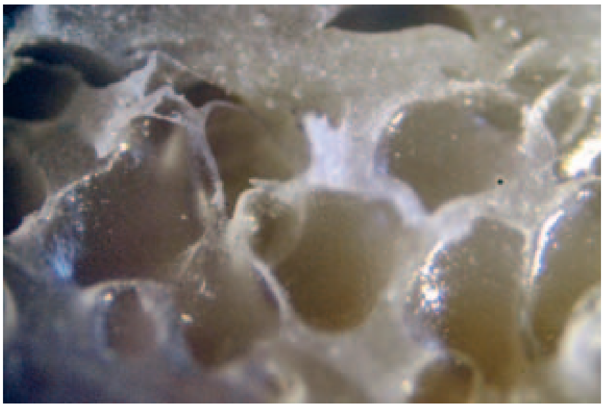
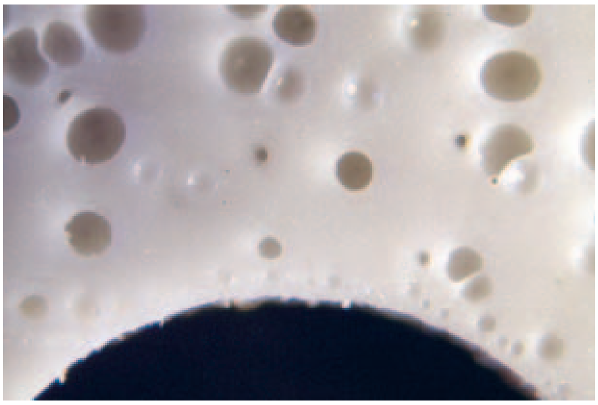


Fig. 4. View of double-layered coatings structure containing blowing agent in amount 0.5 wt. %

a)



b)

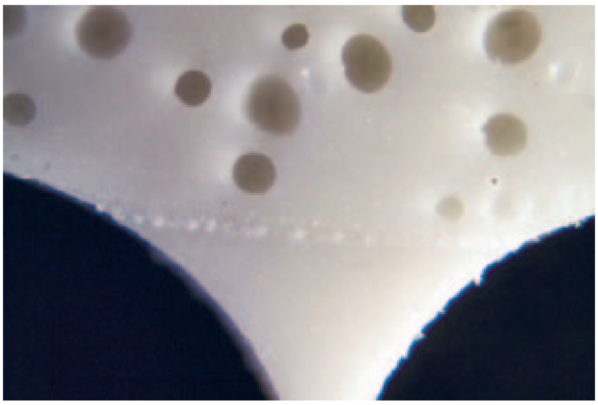


Fig. 5. Microscopic images (100× magnified) of two fragments (a and b) of the cross section obtained for single-layered coatings made of cellular PVC with 0.3 wt. % of the blowing agent

Figures 3 and 4 present images of the cross-sections of the coating obtained using 0.4 and 0.5 wt. % of the blowing agent, respectively.

Based on the analysis of these images, it was found that the coating containing 0.4 and 0.5 wt. % of the blowing agent had a clearly visible solid outer skin and the most uniform distribution of micropores, which were all of a similar size. In the case of coatings containing 0.3 wt. % of the blowing agent microscopic images, presented in Figure 5, demonstrate that the distribution was uneven and the pores visible were small. On the other hand, the image obtained using confocal microscope, shown in Figure 6, exhibit that the coating containing 0.5 wt. % of the blowing agent showed a high density of micropores, pores of different sizes and the continuity of the coating was maintained across its cross-section.

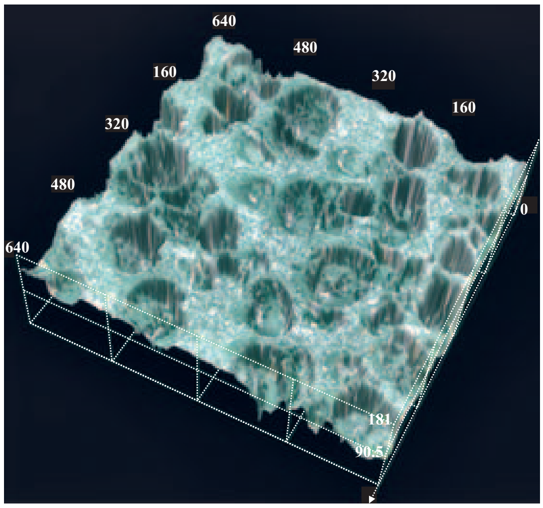


Fig. 6. Microscopic image (confocal microscope, type Olympus FluoView FV1000) of the cross section of the single-layered cable coating made of cellular PVC and 0.4 wt. % of the blowing agent

The scatter of micropores and pores in the coating may have been due to uneven metering of such a low amount of the blowing agent. In the case of coatings obtained with 0.4 wt. % or higher content of the cellular blowing agent, the degree of porosity and the density were very good, especially when account is taken of the thickness of the individual coating layers.

Use of 0.4 to 0.5 wt. % of a blowing agent in the process of cellular coating co-extrusion makes it possible to produce an electric cable conductor at an economically advantageous cost.

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