Polymer composites used to manufacture Naturacustic® acoustic screens
(Sponsored Article)

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Abstract: The useful properties of PVC-based composites intended for the production of a new type of pro-ecological acoustic screens for use in road construction as soundproof covers for urban housing estates, bridges and railway tracks were examined. The composites were obtained by melt mixing using a counter-rotating twin-screw extruder. PVC-based composites are characterized by high Charpy notch impact strength (> 12 kJ/m^2), high Rockwell hardness (> 78 N/mm^2), high oxygen index (50%), good resistance to UV radiation. An important advantage of these composites is the high content of agri-food waste (30 wt%), which makes the materials environmentally friendly.

Key words: PVC, composites, acoustic screens, natural fillers.

Kompozyty polimerowe stosowane w produkcji ekranów akustycznych Naturacustic®
(Artykuł Promocyjny)

Streszczenie: Zbadano właściwości użytkowe kompozytów na osnowie PVC przeznaczonych do wytwarzania nowego typu proekologicznych ekranów akustycznych do zastosowań w drogownictwie jako osłony dźwiękoszczelne osiedli miejskich, mostów i torów kolejowych. Kompozyty otrzymano metodą mieszania w stanie stopionym przy użyciu przeciwbieżnej wytłaczarki dwuślimakowej. Kompozyty na osnowie PVC charakteryzują się wysoką udarnością z karbem Charpy'ego (> 12 kJ/m^2), dużą twardością wg Rockwella (> 78 N/mm^2), wysokim indeksem tlenowym (50%), dobrą odpornością na działanie promieniowania UV. Istotną zaletą tych kompozytów jest duża zawartość odpadów rolno-spożywczych (30% mas.), co czyni materiały przyjaznymi dla środowiska.

Słowa kluczowe: PVC, kompozyty, ekrany akustyczne, napełniacze naturalne.

Acoustic screen, also known as a soundproof screen or partition placed between a noise source and a place where people stay, work or live, or a valuable natural area, to muffle or reduce the volume of sound. These are usually walls or slabs of sound-absorbing material placed at an appropriate angle on the edge of highways and other roads, running through housing estates or nature reserves, or around a strong sound source. The main division of screens is based on acoustic properties, construction, and terrain conditions. Screens are divided according to their acoustic properties (Fig. 1): reflective (reflect the sound wave towards the source), reflective – scattering (they also have scattering properties in the form of

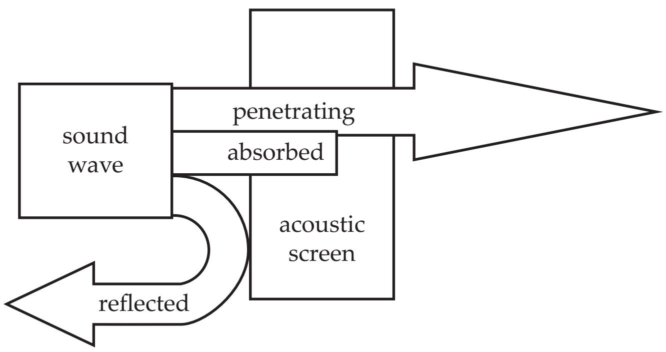

Fig. 1. Scheme of acoustic screens operation

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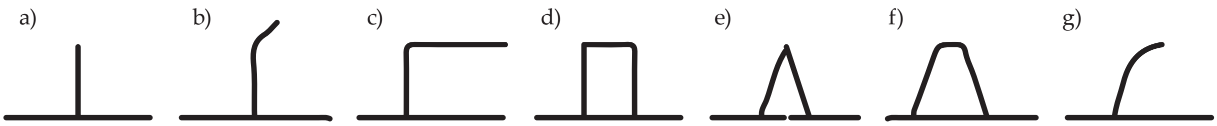

Fig. 2. Division of screens according to the shape of the cross-section: a) vertical, b) suspended, c) horizontal, d) cuboid, e) wedge, f) trapezoidal, g) arched

recesses and protrusions), absorbent (have a shape that increases absorbency, filled with absorbent materials, with the possibility of embedding plants, e.g. vines).

Noise barriers can also be divided according to the material from which the screen is made: metal, concrete, concrete with other components, glass, ceramic, wood, plastic, etc. Another criterion for dividing sound-absorbing screens is the shape of the cross-section (Fig. 2).

This division can also be made based on the shape of the vertical projection, including: rectilinear, curvilinear (acoustic considerations, aesthetics, terrain conditions, removal of monotony); and also due to the method of assembly: segmental (composed of successive large segments of catalog size), modular (composed of successive elements of a small module).

Considering the terrain conditions and surroundings of the communication road, screens are divided into free-standing, shielding the road in an excavation, shielding the road on bridges and viaducts, using existing buildings, built based on the natural relief of the terrain, natural embankments, and artificial embankment supplementation.

Most people do not realize the negative effects of staying in excessive noise for extended period. Such a low level of public awareness is since exposure to noise does not cause immediate negative effects but manifests itself over time in hearing loss and diseases of the nervous system.

According to conducted literature analysis, a wide variety of noise-absorbing materials are used for acoustic screens production. Most commonly used partially waste materials include: concrete slabs [1], wood chip and cement boards [1], perforated plates made of waste thermoplastics filled with waste glass fiber [2], modular metal filled with ground rigid polyurethane foams [3, 4], modular wooden ones filled with ground rigid polyurethane foams [5], concrete slabs with wood waste [6, 7], concrete filled with a layer of porous elastomers [8], modular, steel, filled with halves of car tires [9], conically arranged tires of various sizes, separated by a layer of earth and overgrown with vegetation [10], modular steel filled with vertically suspended tires [11], modular with a gel-concrete layer with attached panels made of rubber granules bonded with Krasol NN resin [12], modular ones made of a concrete layer or recycled plastics with pressed-in panels made of rubber granulate and/or PA non-woven fabric glued with primary polyurethane [13–19], modular non-woven fabrics with thermoplastics as a binder [20–22], in the form of panels made of chemically cured epoxy, acrylic or polyurethane resins filled with sand, granite dust and flint [23].

Due to the expected development of highways in Poland and the construction of detours, bridges, many companies import and install acoustic screens. Therefore, Molter has developed a prototype of an ecological and segmented screen protecting against noise generated around communication routes, and the results of this work are the subject of this publication.

EXPERIMENTAL PART

Materials

PVC blend for acoustic screen was obtained form PVC D-599 mixture (Anvil S.A., Włocławek, Poland), which composition is presented in Table 1. Other materials include rPVC – PVC regranulate; hops as a residue after the supercritical extraction process using CO_2,

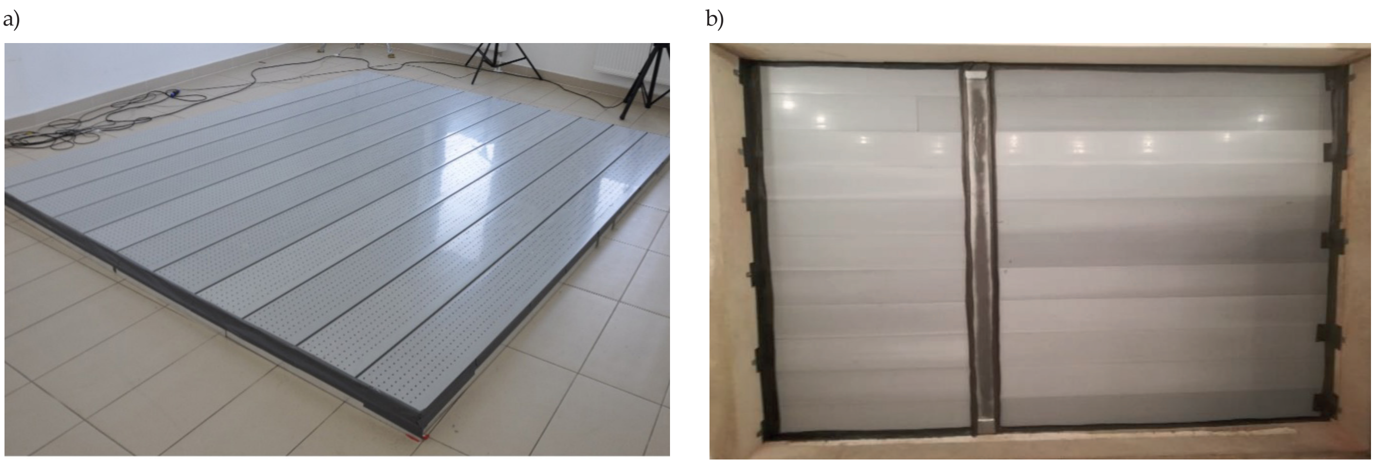

Fig. 3. PVC acoustic screens: a) before installation, b) after installation

T a b l e 1. Composition of the PVC D-599 dry blend

Component	Trade name	Producer	Content wt%	Function
Poly(vinyl chloride)	PVC Neralit 601	Spolana, Orlen Unipetrol Group, Płock, Poland	100.0	Main ingredient
Organotin	Patstab 2310	SAIF Zone, Sharjah, UAE	2.0	Stabilizer
Calcium stearate	Ceasit I	Baerlocher GmbH, Unterschleißheim, Germany	1.2	Stabilizer
Fatty acid ester	Loxiol G-32	Emery Oleochemicals Group, Cincinnati, Ohio, USA	1.5	Grease
Acrylic-based polymer	Poraloid K-125	Dow, Michigan, USA	1.0	Grease
Acrylic-based polymer	Poraloid K-175	Dow, Michigan, USA	1.0	Grease
Parafin	Naftolube FTP	Akdeniz Chemson, Frankfurt, Germany	0.5	Grease

T a b l e 2. Composition of the developed PVC-based composites

Sample	Content, wt%								
	PVC	rPVC	Hops	PER	APP	Grafit	SiO_2	UV	UV2
K0	100.0	0	0	0	0	0	0	0	0
K1	57.5	17.5	30.0	1.0	4.0	5.0	1.0	0.7	0.5
K2	57.5	17.5	30.0	1.0	4.0	10.0	1.0	0.7	0.5
K3	35.0	35.0	30.0	1.0	4.0	5.0	1.0	0.7	0.5
K4	35.0	35.0	30.0	1.0	4.0	10.0	1.0	0.7	0.5
K5	70.0	0.0	30.0	1.0	4.0	5.0	1.0	0.7	0.5
K6	70.0	0.0	30.0	1.0	4.0	10.0	1.0	0.7	0.5

colloidal silica (SiO_2) (Hi-Sil T700, PPG Industries, Inc., Pittsburgh, PA, USA); APP – ammonium polyphosphate (NORD-MIN JLS-APP, Nordmann, Hamburg, Germany), pentaerythritol (Charmor PM15, Perstorp Holding AB, Malmö, Sweden); expanded graphite with a particle size of 290 mesh (Sinograf, Toruń, Poland), Chemsorb 234 as compounds from the group of substituted benzotriazole (WTH, Gmbh, Stade, Germany), Chemnox AN-1076 as antioxidant (WTH, Gmbh, Stade, Germany).

Preparation of PVC-based composites

To reach the assumed parameters of PVC-based composites used in the sound-absorbing screen production (i.e., mechanical properties, content of agri-food waste and flame resistance), graphite and expanded perlite as well as agri-food waste (30 wt%) were added into the polymer matrix. In addition, instead of some pure PVC, recycled PVC (rPVC) was also used. Melt compounding of PVC-based composites was carried in a twin-screw extruder (Zamak Mercator, Skawina, Poland). The extrusion zone temperatures ranged from 140 to 175°C. The composition of the developed PVC-based composites is presented in Table 2. The compounded samples were injection-molded in a Haake MiniJet II injection molding machine II (Thermo Fisher Scientific, Waltham, USA) at 170°C using a pressure of 650 bar. Mold temperature was 50°C, injection time 5 s, plasticizing time 120 s and post-injection pressure 600 bar. The dimensions of the sample were in accordance with ISO 527 and amounted to 60×10×2 mm.

Methods

Tensile properties

Tensile testing was carried out according to ISO 527, by using Instron 5967 testing machine (Instron, Norwood, MA, USA). The crosshead speed was set at 5 mm/min (until 1% tensile strain was obtained), and then the speed was increased to 50 mm/min. All these tests were conducted at ambient temperature and an average value of five repeated tests was taken for each composite.

Notched Charpy impact strength

Charpy impact strength was determined using a Ceast/Instron (Instron, Norwood, MA, USA) impact hammer with a force of 1 J. Samples for testing in the shape of bars were prepared by cutting a notch and then placed horizontally on the machine supports in such a way that the hammer hit the center of the sample edge. Five measurements were performed for each series in accordance with the ISO 179/1Ea standard.

Rockwell hardness

Rockwell hardness was measured according to ISO 6508 using a Zwick/Roell (Ulm, Germany) hardness tester at ambient temperature. Ten determinations were performed for each series.

Flexural properties

The determination of strength properties during a static bending test was carried out on an INSTRON 5967 (Instron, Norwood, MA, USA) testing machine using a three-point measurement method with five measurements were performed for each series in accordance with the ISO 178 standard. The test was carried out at ambient temperature with a bending speed of 1 mm/min (until 0.25% of bending strain was obtained, after which the speed was increased to 10 mm/min).

Limiting oxygen index

Limiting oxygen index (LOI) was measured at room temperature according to EN ISO 4589-2 using an instrument from Fire Testing Technology Ltd. (East Grinstead, UK).

Resistance to UV radiation

To determine the resistance to UV radiation of the acoustic barrier prototype, accelerated aging tests were carried out. The test was carried out in the Xenotest Alpha+ (Atlas, Mount Prospect, Illinois, USA) accelerated aging chamber in accordance with the PN-EN ISO 4892-2 standard, for 3000 h using cycle 1 of method A. To determine the effect of aging on the appearance of the samples, color change tests were carried out using the Konica Minolta CM-5 spectrophotometer (Konica Minolta, Tokio, Japan). Measurements were made on two samples of each composition at 4 points on the samples surface. The results were compared with those obtained for samples before aging. The color was determined using the independent CIE Lab model, in which "L" describes the luminance (brightness, from black to white), "a" describes the color from green to purple, and "b" describes the color from blue to yellow.

Using the CIE Lab color space, the distances between the tested colors were determined, the so-called ΔE (Table 3). ΔE is the impression of the difference between color shades noticed by the observer. To determine the distance between the colors ΔE of the moldings and the standard, the Equations 1–4 were used:

$$\Delta L = L_1 - L_2 \tag{1}$$

$$\Delta a = a_1 - a_2 \tag{2}$$

$$\Delta b = b_1 - b_2 \tag{3}$$

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{4}$$

where: L, a, b – values defining the color of two samples (measured and standard), index 1 refers to the sample before aging, while 2 to the sample after aging.

T a b l e 3. Range of Δ*E values**

$0 < \Delta E < 1$	normal, invisible color deviations
$1.01 < \Delta E < 2$	very small deviations, recognizable only by an experienced observer
$2.01 < \Delta E < 3.5$	mean deviations, recognizable by an inexperienced observer
$3.51 < \Delta E < 5$	clear color deviations
$\Delta E < 5.01$	large color deviations

RESULTS

Mechanical properties

The mechanical properties of PVC-based composites are summarized in Table 4. It was found that the mechanical properties of composites depend on their composition. The introduction of fillers increases the Young's modulus. In the case of K5 and K6 composites, a significant increase in the flexural modulus was also achieved. Moreover, PVC-based composites show higher Rockwell hardness with lower impact strength, tensile and flexural strength. However, composites are characterized by high impact strength and good tensile and flexural properties.

Flammability

The aim of the tests was to determine the minimum oxygen concentration at which continuous combustion of

T a b l e 4. Properties of the PVC-based composites

Property	K0	K1	K2	K3	K4	K5	K6
Notched Charpy impact strength, kJ/m²	44.5	16.8	24.0	16.1	15.5	12.8	36.5
Hardness, N/mm²	80.3	107.6	98.7	81.4	89.4	103.5	102.2
Tensile strength, MPa	59.5	33.5	34.7	39.1	28.5	36.1	38.7
Young's modulus MPa	2220	3417	3600	2721	2800	3130	4560
Flexural strength, MPa	87.7	56.4	58.8	42.3	45.7	62.1	62.0
Flexural modulus, MPa	3000	3010	2980	2450	2590	4020	4245
LOI, %	37.5	<50	>50	<50	>50	<50	>50

T able 5. Color change of PVC-based composites under the influence of UV radiation

Composite	ΔL	Δa	Δb	$|\Delta E|$
K0	15.45	-12.37	-22.96	30.3
K1	-2.80	0.12	0.41	2.83
K2	2.21	-0.78	0.45	2.39
K3	1.98	-0.24	1.14	2.30
K4	2.10	-0.24	1.14	2.40
K5	1.54	-0.1	1.3	2.02
K6	1.76	-0.11	-0.11	1.77

the sample was observed (Table 4). It was found that the key ingredient determining the high LOI value is graphite. Composites containing 10 wt% of this filler were characterized by the highest fire resistance (LOI > 50%).

Resistance to UV radiation

Samples were tested before and after the accelerated aging process under UV radiation to examine color changes of PVC-based composites. The results are summarized in Table 5. The ranges of ΔE values and the corresponding color differences are presented in Table 3. The results showed that the addition of fillers and UV stabilizers to PVC-based composites causes smaller color deviations after the accelerated aging process. The lowest ΔE value was obtained in the case of the K6 composite, while the remaining PVC-based composites were characterized by medium color deviation.

CONCLUSIONS

A prototype of an ecological, segmented acoustic screen based on PVC composites was developed. The obtained composites are characterized by good mechanical properties, especially high impact strength, high hardness, and high resistance to fire and UV radiation.

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REFERENCES

[1] Pat. *GB* 1 451 193 (1976).
[2] Pat. *GB* 1 171 030 (1969).
[3] Pat. *RU* 2 196 679 (2003).
[4] Pat. *EP* 0 527 115 (1993).
[5] Pat. *DE* 19 722 235 (1998).
[6] Pat. *EP* 0 417 049 (1991).
[7] Pat. *FR* 2 765 907 (1999).
[8] Pat. *DE* 4 135 149 (1992).
[9] Pat. *KR* 95 005 92Y (1995).
[10] Pat. *EP* 0 319 512 (1989).
[11] Pat. *DE* 19 634 678 (1998).
[12] Margryta J.: *Elastomery* **2001**, *5(1-2)*, 7.
[13] Mantel F. Ochocona R.: *Plasty a Kacuk* **2001**, *38(2)*, 39.
[14] Mantel F. Ochocona R.: Materials from „II Środkowo-Europejska Konferencja pt.: Recykling Materiałów Polimerowych Nauka-Przemysł" November 12–14, 2003, part IV.
[15] Pat. *SK* 360 2000 (2000).
[16] Pat. *SK* 47 2002 (2002).
[17] Pat. *SK* 116 2002 (2002).
[18] Pat. *SK* 65 2002 (2002).
[19] Pat. *SK* 348 2002 (2002).
[20] Pat. *DE* 19 548 128 (1997).
[21] Pat. *JP* 08 296 161 (1996).
[22] Pat. *US* 4 193 474 (1980).
[23] Pat. *GB* 2382816 (2003).
[24] Pat. *PL* 435509 `(2020).

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