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COMPOSITES THEORY AND PRACTICE

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EVALUATION OF MECHANICAL PROPERTIES OF POLYMER SANDWICH SYSTEMS USED FOR NOISE REDUCTION PURPOSES

The paper presents preliminary tests of an innovative laminar noise-dampening layered structure for industrial purposes, based on PUR foam containing a foam-recyclate. The test cycle included static tensile tests of foam specimens, acoustic dampening tests, technological gluing tests (foam layer with functional layers: magnetic foil and aluminium foil), foam and glue selection, static shear tests of the bonds between the foam layer and the functional layers. The results of the technological and the acoustic tests showed that application of the foam-based layered packet-structures is a very good method for noise-dampening of work-stands in industry. The demountable bond between the packet and the metalic wall is effective and simple to use. It enables application of the packet differentlyly on various work-stands. The static mechanical properties of the foams and of the glue-bonds were satisfactory and show the trouble-free, self-supporting behavior of the dampening packets.

Keywords: **mechanical properties, polymer foam, sandwich system, noise reduction**

OCENA WŁAŚCIWOŚCI MECHANICZNYCH POLIMEROWYCH UKŁADÓW WARSTWOWYCH PRZEZNACZONYCH DO TŁUMIENIA HAŁASU

Praca przedstawia wstępne badania innowacyjnej pakietowej (warstwowej) struktury wygłuszającej do zastosowań przemysłowych, opartej na piance PUR z zawartością piankowego recyklatu. Cykl badań obejmował próby statycznego rozciągania grupy pianek, próby akustyczne tłumienia, próby technologiczne klejenia pianek z warstwami funkcyjnymi (folia magnetyczna, folia aluminiowa), dobór pianek oraz kleju, próby ścinania statycznego złączy między pianką a warstwami funkcyjnymi. Wyniki prób technologicznych i akustycznych wykazały, że zastosowanie struktur pakietowych na bazie pianek z zawartością recyklatu piankowego jest bardzo dobrą metodą wygłuszania stanowisk technologicznych. Nietrwałe łączenie pakietu z metalową ścianką przy pomocy taśmy magnetycznej jest skuteczne i proste. Umożliwia stosowanie pakietu alternatywnie na różnych stanowiskach pracy. Statyczne właściwości mechaniczne pianek oraz złączy klejowych są zadowalające i wskazują na bezproblemową „samonośność" pakietów wygłuszających.

Słowa kluczowe: **właściwości mechaniczne, pianka polimerowa, układ warstwowy, tłumienie hałasu**

INTRODUCTION

The paper presents preliminary tests of an innovative laminar noise-dampening structure whose purpose is to reduce the noise level in a manufacturing plant. According to Polish law regulations concerning industrial safety (Ministry of Economy and Labour Regulation of 5 August 2005), the noise in industrial rooms should not exceed 80 dB. If it does exceed it, it is necessary to reduce working time or to ensure additional breaks for workers [1]. A solution to reduce noise within a factory hall, which would be both cheap and technologically simple, was therefore desirable. Such an approach led to the exclusion of among others, polymer-fibre composites [2, 3] and thermoplasts [4]. However, a new solution has been worked out, which additionally allowed the utilization of after-production PUR foam wastes. The solution includes the use of a properly thick layer of PUR foam (containing a significant content of PUR wastes) as a primary self-supporting layer, covered with additional functional layers - magnetic foil enabling one to create a demountable bond between the dampening packet and the movable metallic wall, and aluminium foil reinforced with glass fibre strands being an outer protective cover for the foam. The diagram of the layered noise-dampening structure and its bond with the metallic panel is shown in Figure 1.

The demountable bond between the noise-dampening packet and the metalic wall is necessary in the technical context of the analysed issue. It gives the possibility to apply the packet differently in various stands. The use of magnetic foil for this purpose is a very innovative solution.

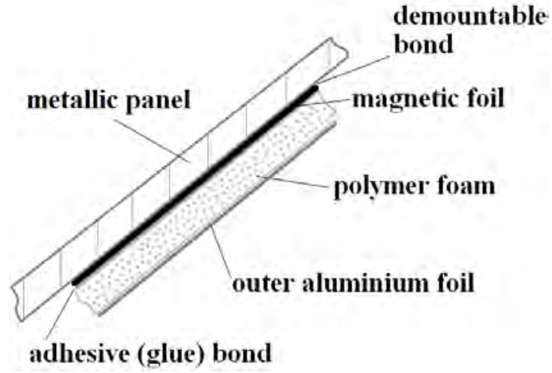

Fig. 1. Diagram of layered noise-dampening structure and its bond with metallic panel

Rys. 1. Schemat warstwowej struktury wygłuszającej i jej połączenia z metalową ścianką

An adhesive-bond technique seems to be the only reasonable solution within the proposed system concerning technical conditions and requirements for the bonded materials: easy application, lack of different protruding elements (e.g. bolt heads) and high versatility of the potential applied materials [5, 6]. The relatively large surface precludes the use of some novel bonding methods, e.g. thermoclinching [7], or mechanical bonding methods like stitching [8]. The mechanical properties of the adhesive bond, when the adhesive is properly selected, ensure good elasticity and lack of brittleness, which becomes a significant problem in the case of the frequent necessity of mounting / demounting the element and its bending (unavoidable for - a large surface sheet) [9, 10].

The paper describes the cycle of developing a dampening structure, consisting of: 1) selection of the foam layer by the functional (acoustic) and mechanical evaluation of an accessible set of foams, 2) selection of the adhesive for the adhesive fast bond concerning accessibility, cost and productibility, 3) mechanical evaluation of the bonds between the foam and the functional layers (magnetic foil, aluminium foil).

Additional tests, conducted outside of this study, revealed that the load-bearing ability of the demountable bond (magnetic foil - metal wall) is satisfactory both at tearing and shearing.

MATERIALS AND METHODS

The study covers preparation of the foam specimens and cycle of tests, allowing us to select the most optimal dampening structure. The cycle consisted of four parts: 1) static tensile tests on 14 foam types, 2) acoustic dampening tests (after initial selection) on 7 foam types, 3) technological tests on adhesive bonding of the foam layers with the functional layers with the use of 3 types of adhesives, 4) static shear tests of the bonds between the foam layer and the functional layers - after second selection of the foams and the adhesive.

The foams for the tests were prepared by foaming polyurethane with an addition of a high content of foam recyclates (fragmented recycled foams) having various mass density (60÷240 kg/m^3). The recyclates as well as the filling PUR "matrix" were soft foams with open porosity. The recyclate was in the ground form (particles, 3÷15 mm in diameter) and arises from after-production and after-use wastes. It was diverse in terms of material grade and properties, but it was soft PUR foam only. The produced foams contained up to 85% recyclate. The applied elastic, open-cell foams, were produced by JAG PPH (type A: technical designation R-FOAM, type B: technical designation T-FOAM). In view of the technological issues, there were no possibilities to bond the foam layer with the functional layers in one process during foaming of the matrix (co-foaming). An additional technological step (adhesive bonding) was necessary.

12 types of foam with addition of the recyclate (designation B) and two low-density comparative foams (designation A) were prepared for mechanical evaluation by static tensile tests - see Table 1.

TABLE 1. **Results of static tensile tests for tested PU foams**
TABELA 1. **Wyniki prób statycznego rozciągania pianek PU**

Foam designation X + density [kg/m^3]	**Conventional maximum stress [kPa]**	**Relative elongation at F_{max} [%]**
B-40	27 ±3	52 ±5
B-50	32 ±4	59 ±8
B-60	41 ±4	64 ±5
B-70	41 ±3	62 ±9
B-90	69 ±5	76 ±7
B-110	83 ±7	67 ±12
B-140	109 ±14	75 ±11
B-160	109 ±6	57 ±10
B-180	139 ±12	60 ±9
B-200	147 ±16	50 ±4
B-220	170 ±19	55 ±10
B-240	234 ±13	57 ±8
A-22	83 ±4	147 ±6
A-25	52 ±3	78 ±5

The tests were conducted on an INSTRON 4469 testing machine. The displacement rate was 20 mm/min, and the measuring head load range was 5 kN. The spacing between the holding clamps (measuring base) was 225 mm, the width of the specimen was 50 ±2 mm. The thickness of the specimens was 40 ±2 mm. Four specimens were tested from each type of foam. The tests were conducted in accordance with the PN-77/C-05012.05 standard. An exemplary image of the tensile test of the foam is presented in Figure 2a.

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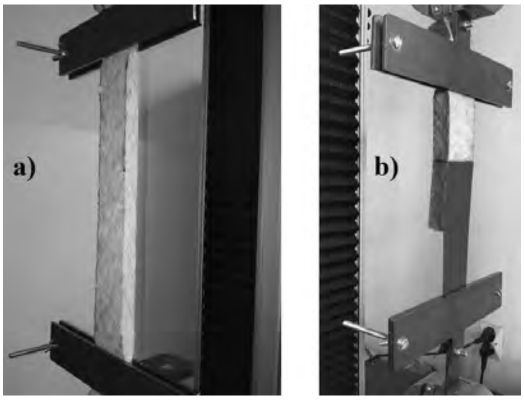

Fig. 2. Mechanical tests: a) foam tensile test, b) foam - magnetic foil bond shear test

Rys. 2. Próby mechaniczne: a) próba rozciągania pianki, b) próba ścinania połączenia pianka - folia magnetyczna

The acoustic tests were carried out on the testing stand presented in Figure 3.

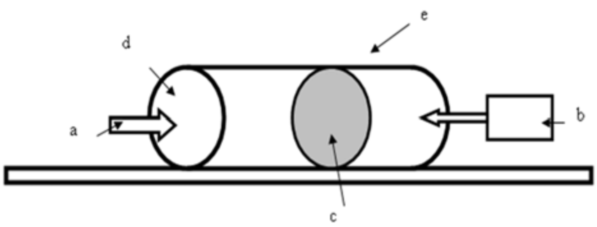

Fig. 3. Diagram of stand for acoustic measurements: a - electric vibration inductor, b - digital gauge, c - PU foam specimen, d - metal bowl, e - PVC pipe

Rys. 3. Schemat stanowiska do pomiarów akustycznych: a - elektryczny wzbudnik drgań, b - licznik cyfrowy, c - próbka pianki PU, d - metalowa czasza, e - rura PCW

Such acoustic tests are the element of noise evaluation analysis in work-stands [11]. For the acoustic tests, 7 foam types having density from 22 kg/m^3 (22 and 25 kg/m^3 - comparative foams) to 240 kg/m^3 were selected. Five specimens were prepared for the each foam type. The results of the tests are presented in Table 2.

TABLE 2. **Results of sound intensity (*L*) measurements for A and B specimen series**

TABELA 2. **Wyniki pomiarów natężenia dźwięku (*L*) dla próbek serii A i B (factor of variation - współczynnik zmienności)**

Specimen type	Thickness [cm]	L_{AV} [dB]	σ [dB]	Factor of variation
A -22	40	101.04	0.15	0.0015
A - 25	40	100.68	0.28	0.0028
B - 90	40	98.36	0.17	0.0017
B - 140	40	92.76	0.17	0.0018
B - 160	40	91.82	0.11	0.0012
B - 220	40	90.99	0.46	0.0051
B - 240	40	89.64	0.41	0.0046
lack of material - background	-	104.30	0.41	0.0048

Technological evaluation of the bonding process and the bonds between the foam layer and the functional layers (aluminium foil and magnetic foil) was conducted for 3 alternative adhesives: 1) assembly adhesive (synthetic rubber based) 48A by CASTORAMA, 2) 2-component polyurethane resin EKOPUR J (elastomer) by MINOVA EKOCHEM, 3) polyester resin POLIMAL 1059 AWTP by ORGANIKA SARZYNA.

The bonds were directly evaluated in terms of three factors: 1) occurrence of defects visible with the naked eye after repeated bending, 2) producibility of the bond - ease of adhesive application and bond formation, 3) quality of the bond concerning the occurrence of discontinuities visible with the naked eye. The elements were evaluated in following system: "+" - positive rate, "-" – negative rate: occurrence of the considered problem. The results of the technological evaluation are given in Table 3.

TABLE 3. **Technological test results of adhesive bonds**

TABELA 3. **Wyniki testów „technologicznych" złączy klejowych**

Bond and adhesive component	Flexural resistance	Producibility	Bond discontinuities
PU foam - PU foam assembly adhesive	+	-	-
PU foam - PU foam Polimal1059 AWTP resin	-	+	+
PU foam - PU foam Ekopur J	+	+	+
PU foam - magnetic foil assembly adhesive	+	-	-
PU foam - magnetic foil Polimal1059 AWTP resin	-	+	-
PU foam - magnetic foil Ekopur J	+	+	+

The static shearing tests of the bonds between the foam layers and the functional layers were conducted on an INSTRON 4469 testing machine. The displacement rate was 10 mm/min and the measuring head load range was 5 kN. The specimens were held in special clamps - see Figure 2b. The spacing between holding clamps was 225 mm, length of the sheared area was 75 mm (measuring base) and the width of the specimen was 50 mm. Five specimens were tested for each bond. The tests were carried out in accordance with the PN-69/C-89300 standard.

RESULTS AND ANALYSIS

The tensile tests results of the foam specimens (Table 1) revealed that the addition of foam recyclate enables one to obtain a material having mechanical properties close to "fresh" low-density foams, especially when the density of the product exceeds

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100 kg/m^3. The strength and deformability obtained for the B-110 - B-240 foam specimens ensure trouble-free, self-supporting behavior of the packets at any orientation to the ground - they will not burst under their own weight, even at a 200 mm foam layer thickness. The morfology of the breakage area of the foam specimens (see Fig. 4) showed good bonding between the bonding foam (matrix) and the recyclate particles - it contains only a few separated matrix-particle interfaces and prevailing surface of halved recyclate particles.

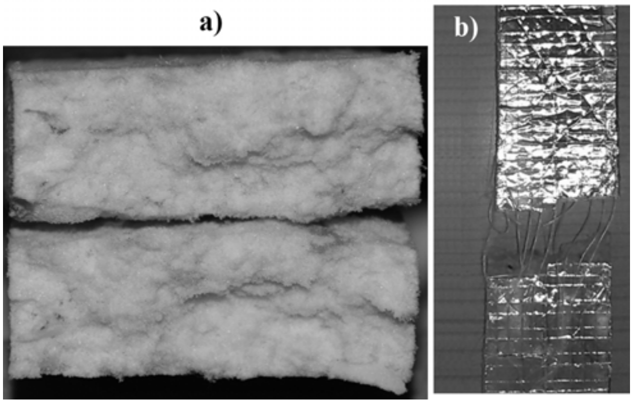

Fig. 4. Failure effects on specimens after tests: a) breakage area of foam specimen after tensile test, b) aluminium foil after breakage in shear (*foam - foil* bond) test - pulled-out strands of glass fibre are visible

Rys. 4. Efekty zniszczenia badanych próbek: a) obszar zerwania próbki pianki w próbie rozciągania, b) folia aluminiowa z widocznymi wyciągniętymi pasemkami włókna szklanego zerwana w próbie ścinania połączenia z pianką

The acoustic tests (results in Table 2) showed very good noise-dampening efficiency of the tested foam specimens. The dampening efficiency increases with the foam density. For the B-240 foam it averages almost 15 dB. It is a significant value which can improve the work conditions in the production hall [1, 11]. Preliminary tests in real conditions (technological room) revealed satisfactory efficiency of such a solution.

After selection based on the technological tests, (results in Table 3) the EKOPUR J polyurethane adhesive was chosen to bond the foam layer with the functional layers. Taking into account the results of the mechanical tests (Table 1) and especially the results of the acoustic tests (Table 2), as well as the producibility and availability of components, the most suitable for regular application was the B-240 foam.

The results of the shear tests (conducted for adhesive bonds between the foam layer and the functional layers) are presented in Table 4. The sets of force-elongation curves from these tests are shown in Figures 5 and 6.

Shearing of the foam-magnetic foil bond led to breakage of the foil. The bond itself did not reveal any signs of failure. The aluminium foil is a 2-layer structure with strands of glass fibre between them (to improve tear-toughness). It is applied as the cover of the dampening packet in order to ensure protection of the foam against external affects (dirt, moisture). Shearing of the foam-aluminium foil bond resulted in breakage of the foil, without damaging the bond itself. As the first effect, breakage of the glass fibre strands and pulling them out occurred - the pulled-out strands are visible in Figure 4b.

TABLE 4. **Conventional maximum shear stress (σ_{Umax}) and corresponding conventional relative displacement, for bonds between foam layer and: aluminium foil and magnetic foil**

TABELA 4. **Umowne naprężenie maksymalne przy ścinaniu (σ_{Umax}) oraz odpowiadające mu umowne przemieszczenie względne dla złączy pianki z folią aluminiową oraz z folią magnetyczną**

Bond	σ_{Umax} [kPa]	Conventional relative displacement at σ_{Umax} [%]
foam - aluminium foil	30 ± 8	9.7 ± 3.4
foam - magnetic foil	34 ± 9	9.8 ± 2.7

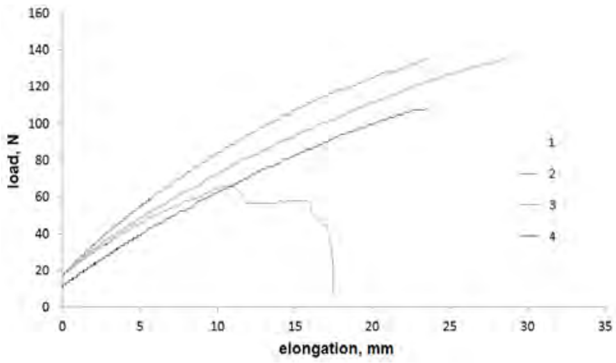

Fig. 5. Shear curve set: foam-aluminium foil bond

Rys. 5. Rodzina krzywych ścinania: połączenie pianka-folia aluminiowa

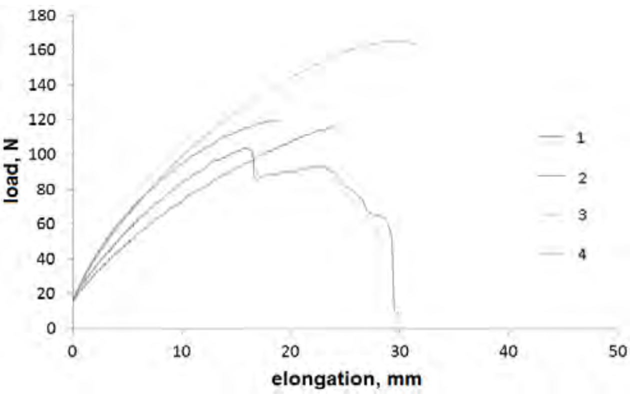

Fig. 6. Shear curve set: foam-magnetic foil bond.

Rys. 6. Rodzina krzywych ścinania: połączenie pianka-folia magnetyczna

The shear tests were applied for evaluation of the bonds beacause the packets (and the bearing metal panels) are positioned mostly in the vertical direction or at about a 45-degree angle. In such conditions shearing is the most likely type of load. In addition, shearing is the most "neuralgic" type of load for various glue bonds [5, 9].

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The obtained test results ensure a shear strength of both adhesive bonds (Table 4) at a minimum level of 3000 kg/m^2, which is absolutely enough to hold the dampening packet, at any position in static load conditions.

It would be advantageous to carry out a research program containing creep and fatigue tests for further verification of the applicability of the noise-dampening packets.

CONCLUSIONS

- The application of packets based on PUR foams with an addition of foam recyclate is a very good method for noise dampening of work-stands, which was confirmed by technological and acoustic tests.
- The method of demountable bonding of the packets with the metal panel with use of magnetic foil is efficient and simple. It enables application of dampening packets alternative differently on various work-stands.
- The static mechanical properties of the foams and of the adhesive bonds are satisfactory and illustrated the trouble-free, self-supporting behavior of the dampening packets.
- Further verification of the applicability of the packets could concern creep and fatigue tests.

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