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COMPOSITES THEORY AND PRACTICE

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THE INFLUENCE OF SURFACE ASYMMETRY OF THERMOPLASTIC COMPOSITES ON THEIR SOUND ABSORPTION

Among sound insulating materials used in the automotive industry, multilayer systems consisting of foams, nonwovens, mats, knitted fabrics or porous panels in different combinations are very popular. These materials can be replaced by fibre reinforced composites. These composites can be good sound absorbing materials even at low thickness. One way to increase sound absorption is to form a composite with an optimal structure and surface topography. In this work, the investigations concern the sound absorption by thermoplastic composites with surface asymmetry. The influence of surface asymmetry of thermoplastic composites on their sound absorption coefficient was studied. The first kind of asymmetry concerns the structure of the composite surface, i.e. plastic and fibrous structure. The second kind of asymmetry concerns the topography of the composite surface, i.e. the one side of the composite surface is smooth and on the opposite side it is characterized by some relief. The sound absorption coefficient was measured for different sample orientations to the sound wave to assess the significance of the surface asymmetry and to indicate a more favourable composite side from the sound absorption point of view. Generally, both the surface structure asymmetry and surface topography asymmetry influence the sound wave behaviour and consequently increase the composite sound absorption.

Keywords: **thermoplastic composite, sound absorption, surface asymmetry, fibre**

WPŁYW ASYMETRII POWIERZCHNIOWEJ NA DŹWIĘKOCHŁONNOŚĆ KOMPOZYTÓW TERMOPLASTYCZNYCH

Spośród materiałów tłumiących dźwięk stosowanych w przemyśle samochodowym bardzo popularne są układy warstwowe składające się z pianek, włóknin, mat, dzianin lub porowatych paneli w różnych kombinacjach. Materiały takie mogą być zastąpione przez kompozyty wzmacniane włóknami, które mogą wykazywać dużą absorpcję dźwięku nawet przy małej ich grubości. Jednym ze sposobów zwiększenia absorpcji dźwięku jest zapewnienie optymalnej struktury i topografii kompozytu. W pracy przedstawiono badania dotyczące absorpcji dźwięku przez kompozyty charakteryzujące się asymetrią powierzchniową. Badano wpływ asymetrii powierzchniowej kompozytu na współczynnik absorpcji dźwięku. Pierwszy rodzaj asymetrii dotyczył struktury powierzchni kompozytu, tj. struktury włóknistej oznaczonej jako „fibrous", i struktury bardziej sprasowanej, oznaczonej jako „plastic". Drugi rodzaj asymetrii dotyczył topografii powierzchni kompozytu, tj. jedna strona kompozytu była gładka, druga posiadała specjalnie nadany relief. Współczynnik absorpcji dźwięku był wyznaczany dla różnego ukierunkowania próbki kompozytu w stosunku do padającej fali dźwiękowej, tak by można było ocenić znaczenie asymetrii powierzchniowej i wskazać bardziej korzystną stronę kompozytu z punktu widzenia możliwości tłumienia dźwięku. Generalnie, zarówno asymetria struktury, jak i topografii powierzchni kompozytu wpływa na zachowanie się tłumionej fali dźwiękowej, a w konsekwencji na wzrost absorpcji dźwięku przez kompozyt.

Słowa kluczowe: **kompozyt termoplastyczny, absorpcja dźwięku, asymetria powierzchniowa, włókno**

INTRODUCTION

Sound insulating materials applied in the automotive industry are usually used in the form of multilayer systems consisting of foams, nonwovens, mats, knitted fabrics or porous panels in different combinations [1-3]. For more, different connected materials, which are obtained using different technologies and from different raw materials, the manufacturing process is longer with more stages and is more costly than in the case of a single layer material, for example a composite. Besides, a material thickness which is beneficial for the sound absorption of such systems [4] quite often equals several centimetres, or more. In the case of acoustic composites, the manufacturing process can be reduced and a high sound absorption coefficient can be reached even for a composite thickness of several millimetres [4, 5]. Moreover, the mechanical properties of composites are more advantageous than for other acoustic materials. Good sound insulation by the composite results from its structure, i.e. thickness, density, morphology of reinforcing fibres [5-7], and its surface topography [8].

In the literature the investigations usually concern composite materials similar on both sides with smooth surfaces, [9, 10]. It is well known that good acoustic material should be porous and additionally with a diversified surface topography. Any roughness on the material surface gives some changes in behaviour of an incident sound wave. Imparting a relief with a protrusion diameter over 10 mm to the composite surface, it is possible to increase the sound absorption of that composite [8]. In this work, the investigations concern sound absorption by thermoplastic composites with surface asymmetry. The influence of surface asymmetry of thermoplastic composites on their sound absorption coefficient was studied. The first asymmetry concerns the structure of the composite surface, i.e. plastic and fibrous structure. The second asymmetry concerns the topography of the composite surface, i.e. one side of the composite surface is smooth and on the opposite side it is characterized by some relief. The sound absorption coefficient was measured for different sample orientations to the sound wave to assess the significance of the surface asymmetry and to indicate the more favourable composite side from the sound absorption point of view.

EXPERIMENT

Materials

Polylactide (PLA) fibres 6.7 dtex/64 mm, under the name of *Ingeo Fibre* type *SLN2660D*, with a finishing composition containing polylactide resin and no hazardous compounds, supplied by the Far Eastern Textile Ltd. (Taiwan) were used as the composite matrix material. These fibres made of aliphatic polyester and characterized by a melting point in the range of 165÷170°C are completely biodegradable and pose no significant hazard to the environment.

As the composite reinforcing standard, man-made viscose (Vi) fibres 4.4 dtex/70 mm, characterized by a destruction point of 174÷190°C were used.

Composite manufacturing

Thermoplastic composites were obtained from nonwoven multilayer structures in a press machine with a water-cooling system (Hydromega, Poland). A needle punched nonwoven consisting of 80 wt.% PLA fibres and 20 wt.% viscose fibres was manufactured from fleece with a cross system fibre arrangement. Needle punching of the fleece layer was carried out on a needle punching machine, Asselin (France), with the following technological parameters: kind of needles - 15 x 18 x 40 x $3^1/_2$ RB; number of needle punches - 40/cm^2; depth of needle punching - 12 mm.

The system consisting of 8 nonwoven layers was pressed. Composites with asymmetry were manufactured with diversified technological parameters. In order to obtain a composite with a diversified surface topography, the fibrous system was laid on a Teflon plate with orifices during the pressing process. The technological conditions of the pressing process were the following:

1. Heating up to 170÷172°C, upper plate not maximally pressed down
2. Consolidation during 5 min at 0.25÷0.56 MPa
3. Cooling to 25°C at 0.25÷0.56 MPa

In this way, the effect of surface asymmetry was obtained.

Testing methods

The mass per square meter of nonwoven was established according to standard PN-EN 29073-1 (ISO 9073-1), and the thickness of the composites - according to standard ISO 9073-2. The sound absorption of the composites was studied in a small-sized impedance tube type 4206 (Brüel&Kjaer, Denmark) using two ¼-inch Condenser Microphones Type 4187 (Fig. 1). The physical sound absorption coefficient (a quotient of acoustic energy absorbed by the given material to the energy of an acoustic incident wave) was determined for each sample by the method according to the standard procedure: ISO 10534-2:1998 in the high frequency range of 500÷6400 Hz. The diameter of the investigated composite samples was equal to 29 mm. The sound absorption coefficient was measured for both sides of each composite.

Fig. 1. Test set-up with Kundt tube

Rys. 1. Stanowisko do badania dźwiękochłonności, tzw. rura Kundta

RESULTS

A needle punched nonwoven with 80 wt.% PLA fibres and 20 wt.% viscose fibres was obtained. The mass per square meter of this nonwoven was equal to 130.90 g/m^2. In order to obtain a composite with a thickness of several millimetres, the system of 8 nonwoven layers was pressed.

Composites with surface structure asymmetry

Three kinds of composites were obtained at different time and pressure of consolidation. The technological parameters of the pressing process and the characteristics of composites 1-3 are presented in Table 1. On two sides of composite 1, the surface structure is plastic and similar on both sides, composite 2 had a more fibrous upper side than bottom side, and composite 3 had completely different sides: fibrous and plastic.

Composites with surface topography asymmetry

In each composite, the one side was characterized by a smooth surface, the second side was characterized by a relief-shaped surface (Fig. 2).

Fig. 2. Composite with relief

Rys. 2. Kompozyt z reliefem

Depending on the orifice diameter of the Teflon plate used (ϕ = 5, 10, 13 and 17 mm), the protrusion size was different. The composite thickness with flattened protrusions was diversified on its surface area: on the protrusion spots it was greater, while between the protrusions it was smaller. The characteristics of composites 4÷7 are presented in Table 1.

TABLE 1. **Characteristics of composite materials**
TABELA 1. **Charakterystyka kompozytów**

Composite number	Orifice diameter [mm]	Technological parameters of consolidation			One side	Second side
		Temperature [°C]	Time [min]	Pressure [MPa]		
1	-	170÷172	5	0.56	plastic	plastic
2	-	170÷172	5	0.25	plastic/ fibrous	plastic
3	-	170÷172	3	0.25	fibrous	plastic
4	5	172÷172	5	0.56	smooth	relief
5	10	172÷172	5	0.56	smooth	relief
6	13	172÷172	5	0.56	smooth	relief
7	17	172÷172	5	0.56	smooth	relief

The acoustic measurements were carried out for both sides of the composite. For composite 1 with both smooth plastic surfaces, the composite side facing the incident sound wave is unimportant, the absorption curves overlap (Fig. 3).

From Figures 4 and 5 presenting the sound absorption of composites 2, 3 with surface structure asymmetry, it can be seen that the relationship between the sound absorption coefficient and sound frequency is the same at low frequencies independent of the side of the investigated composite that is oriented to the sound source. At mid and high frequencies this relationship changes, i.e. the absorption is higher for the plastic surface. In the case of the plastic surface oriented to the sound wave in the space between a piston and the plastic surface, multiple sound reflection and major energy damping occurs.

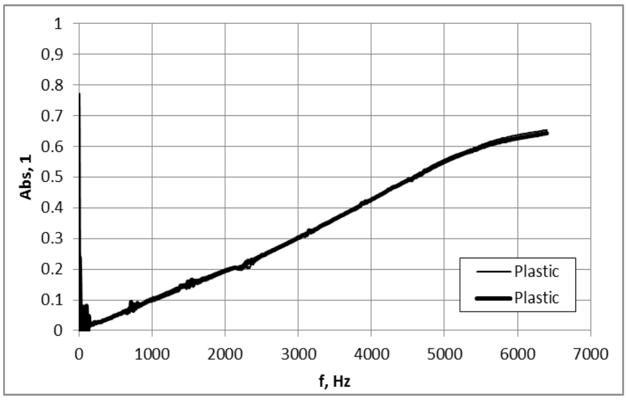

Fig. 3. Sound absorption coefficient of composite 1 (plastic-plastic)

Rys. 3. Współczynnik absorpcji dźwięku dla kompozytu 1 (plastic-plastic)

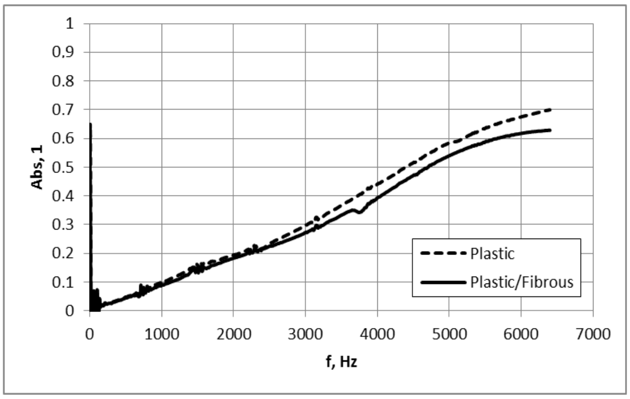

Fig. 4. Sound absorption coefficient of composite 2 (plastic/fibrous-plastic)

Rys. 4. Współczynnik absorpcji dźwięku dla kompozytu 2 (plastic/fibrous-plastic)

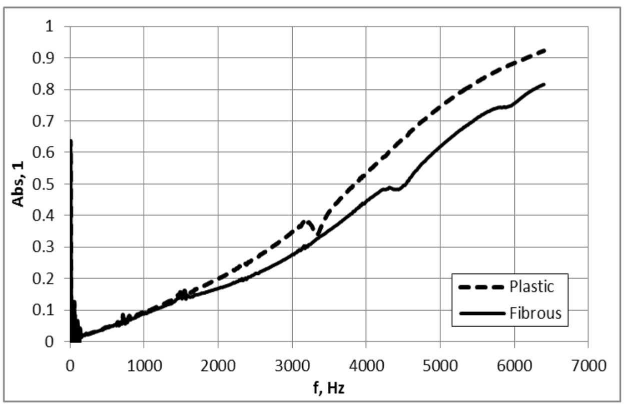

Fig. 5. Sound absorption coefficient of composite 3 (fibrous-plastic)

Rys. 5. Współczynnik absorpcji dźwięku dla kompozytu 3 (fibrous-plastic)

If one composite surface has some relief, the composite side oriented to the sound wave is important from the acoustic point of view. The behaviour of a sound wave is different depending on the surface topography. For the studied composites 4-7 (Figs. 6-9) the dependence is the same - for the smooth surface oriented to the sound source, the sound absorption is higher than for the relief surface.

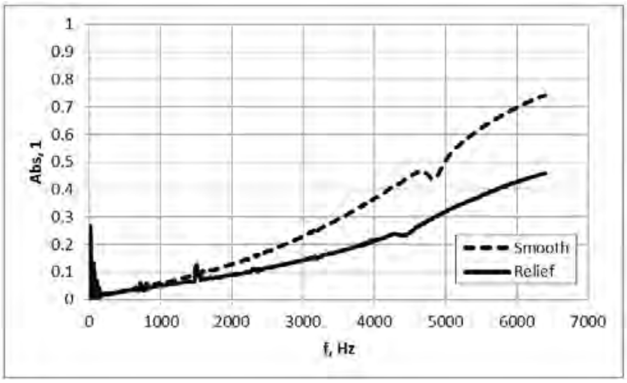

Fig. 6. Sound absorption coefficient of composite 4 (smooth-relief, ϕ 5 mm)

Rys. 6. Współczynnik absorpcji dźwięku dla kompozytu 4 (smooth-relief, ϕ 5 mm)

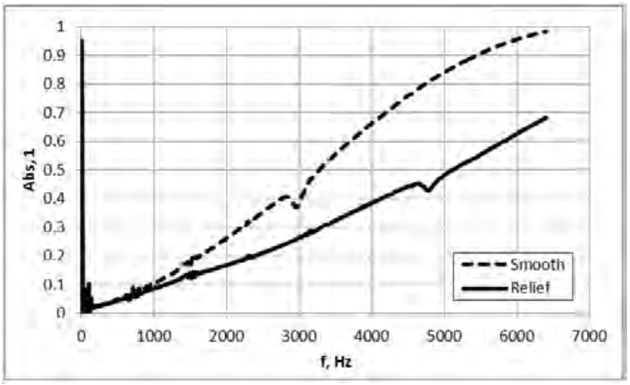

Fig. 7. Sound absorption coefficient of composite 5 (smooth-relief, ϕ 10 mm)

Rys. 7. Współczynnik absorpcji dźwięku dla kompozytu 5 (smooth-relief, ϕ 10 mm)

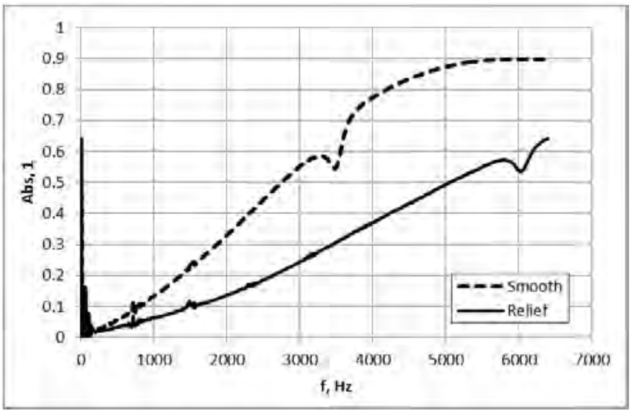

Fig. 8. Sound absorption coefficient of composite 6 (smooth-relief, ϕ 13 mm)

Rys. 8. Współczynnik absorpcji dźwięku dla kompozytu 6 (smooth-relief, ϕ 13 mm)

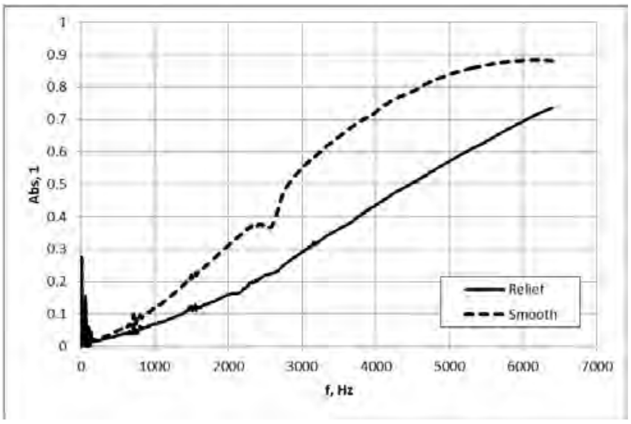

Fig. 9. Sound absorption coefficient of composite 7 (smooth-relief, ϕ 17 mm)

Rys. 9. Współczynnik absorpcji dźwięku dla kompozytu 7 (smooth-relief, ϕ 17 mm)

Generally, for the composite side with the smooth surface oriented to the sound source, a higher sound absorption is observed than for the side with the relief surface. When the relief surface is oriented to a piston, the space for energy damping is bigger than in the opposite situation. The differences in sound absorption are the most considerable for composite 6 with a relief of 13 mm (Fig. 8) For this composite, the increase in sound absorption, as a result of exposure of the smooth surface side to the sound wave, reaches over one hundred per cent within the wide frequency range (Fig. 10).

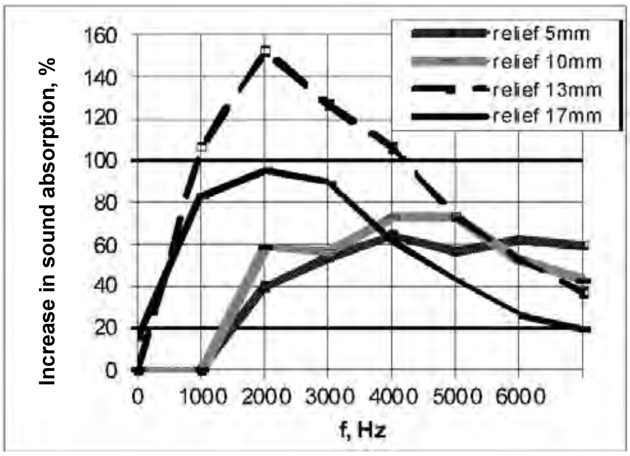

Fig. 10. Increase in sound absorption for composite side with smooth surface in relation to relief side

Rys. 10. Wzrost absorpcji dźwięku dla strony kompozytu z płaską powierzchnią w stosunku do strony z reliefem

CONCLUSIONS

If the surface structure and topography of a composite are the same or similar on both sides, the sound absorption is identical independent of the side oriented to the sound wave.

Generally, both the surface structure asymmetry andsurface topography asymmetry influence the sound wave behaviour and consequently increase composite sound absorption.

For composites with surface structure asymmetry, the higher the asymmetry, the higher the difference between the acoustic properties of the investigated composite sides is. The sound absorption coefficient of a more plastic surface is higher than that of a more fibrous surface.

In the case of composites with surface topography asymmetry, a smooth surface is favourable from the acoustic point of view. For all the composites with relief, in the whole frequency range studied, the sound absorption coefficient is higher when the sound wave action is directed towards a smooth surface. For the composite with a relief of 13 mm, the highest increase in sound absorption coefficient in nearly the whole frequency range is observed, as a result of changing the relief side to the smooth side exposed to the sound wave.

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