Lightweight Construction of Aluminum-cork Sandwich Composites in the Transportation Industry

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Multilayer Plycork Aluminum (Al) composites were produced *via* vacuum bonding using a vacuum membrane press. The cladding material of the Plycork Al composites was an aluminum sheet, while the core material consisted of a natural cork agglomerate with varying thicknesses. Fire resistance tests and comparative static four-point bending tests were conducted on the Plycork Al composite samples. In addition, the characteristics of the deformation caused by the bending stress were compared between the Plycork Al composite and birch plywood. It was evident that this light composite can be applied as a structural material for transport purposes in railway vehicles due to its specific desirable properties. Additionally, the use of Plycork Al composites posed no toxic risk regarding the gases released during a fire and ensured vital operational safety because sharp edges did not form when the material was destroyed. In conclusion, this light multilayer composite can be frequently used to replace conventional materials employed in the transportation industry.

Keywords: Natural cork; Aluminum; Plywood; Sandwich composites; Static four-point bending test; Fire resistance test; Transport

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INTRODUCTION

Sandwich composite structures consisting of a rigid surface layer and various light core materials have been used in many industries for years. The concept of multilayer composites dates back to 1849, but the beginning of the potential of this construction was first utilized during World War II (Njuguna 2016). Currently, these structures are being increasingly used on a large scale in the transportation industry. This is mainly due to their attractive functional properties, as well as the increase in ecological awareness of their users.

The sandwich concept enables high levels of stiffness and strength to be achieved with a reduced weight, thus making layered structures ideal in situations where lightweight construction is required. The reduction of the weight of the transportation structure enables the improvement of outcomes, such as the speed, range, engine power, and fuel consumption. In turn, this results in a significant reduction in costs and, currently of utmost importance, the reduction of CO_2 emissions for vibration damping and noise suppression.

The most commonly used core materials are honeycomb structures, synthetic foams, balsa wood, and nonwoven polyesters (Potluri *et al.* 2003; Krolikowski 2012; Sousa-Martins *et al.* 2013; Yi-Ming *et al.* 2014; Njuguna 2016; Ma and Feichtinger 2017). In recent years, a natural, renewable, and to a large extent, a biodegradable material has established itself. This material is known as cork agglomerate. There is a growing interest in this material due to its exceptional properties (Castroa *et al.* 2010; Sargianis *et al.* 2012; Urbaniak *et al.* 2017a,b,c).

Natural cork agglomerate is granulated and glued using withered bark of cork oak. The cork harvest is wholly environmentally friendly and is also pro-ecological due to the rapid increase in the uptake of carbon dioxide by the tree after debarking. Cork as bark of evergreen oak grows only in a specific region of the Western Mediterranean (Portugal, Spain, southern France and Italy, North Africa) and China. Cork may be described as a homogeneous tissue of thin-walled cells in the amount of 42 million per cubic centimetre, being regularly arranged without intercellular space (Pereira 2007). A specific structure of cork analogous to that of a hexagonal honeycomb is composed of about 45% suberin, 27% lignin, 12% celluloses, 6% waxes, and 6% tannins (Mano 2002; Carrott *et al.* 2006). Cork presents a relatively low density between 0.12 and 0.24 g/cm^3 because of its cellular structure, with cells having 85 to 90% of air inside, by volume (Silva *at al.* 2005; Pereira 2007; Urbaniak *et al.* 2017a). The weight of core material in layered composites is reduced in great measure due to low density of cork.

The unique properties of the cork result directly from its cellular structure and chemical composition. Cork material is characterized by high thermal and acoustic insulation, resistance to long-term load cycles, and insensitivity to changes in temperature and humidity. High suberin content is functioning as a natural barrier for liquids and gases, and being chemically inert. Moreover, it is characterized by the ability to slow the fire’s spreading or to reduce the penetration of fire (Pereira 2007; Urbaniak *et al.* 2017b).

Recently, multilayer composites made from renewable raw materials have debuted in the railway industry and have fulfilled the stringent technical requirements. Fire and corrosion resistance, thermal and acoustic insulation, favorable stress dissipation properties, and the long-term fatigue resistance of multilayer composites are very important properties in the transportation industry (Marsh 2002; Potluri *et al.* 2003; Pereira 2007; Urbaniak *et al.* 2014; Yi-Ming *et al.* 2014; Njuguna 2016). The equipment of rail vehicles must incorporate materials that inhibit the spreading of a fire to achieve an acceptable level of safety.

Requirements and fire protection measures for railway vehicles are listed in the European standard EN 45545-1 (2013). The introduction of this standard was aimed at increasing the safety of passengers and crew in the event of a fire aboard a rail vehicle, while enabling the passengers and crew to evacuate the vehicle to a safe place. The protection of passengers and crew includes, among other things, the prevention of fires by using materials that limit the spreading of a fire and minimize the effects of heat, smoke, and toxic gases.

The most popular materials used thus far in the railway industry are plywood constructions, but recently a new concept that combines ecological and economic benefits has been developed including layered composites made of aluminum and a natural cork called Plycork Al (Amorim 2012; Lucintel 2012; Urbaniak *et al.* 2014).

This paper presents the results of static four-point bending tests performed on sandwich-type composites made of aluminum and natural cork layers with differing thicknesses that were made using vacuum bonding technology. The obtained results of the tested composites were extensively compared to conventional materials, *i.e.*, birch plywood, commonly used in the transport industry. Additionally, fire resistance tests were also performed on the sandwich composites.

EXPERIMENTAL

Materials

The Plycork Al composites (Fig. 1) studied were aluminum-hardened H22 sheets with thickness of 1 mm (Aluminum Konin-Impexmetal SA, Konin, Poland). Their surface layer and core material consisted of the natural cork agglomerate Corecork NL20 (Amorim Cork Composites, Porto, Portugal) with various thicknesses (6.5 mm, 12.5 mm, 27.5 mm, and 40 mm), including the adhesive agent, SikaForce 7710 L100 polyurethane adhesive based on polyols and isocyanate derivates (Sika Deutschland GmbH, Stuttgart, Germany). The curing of SikaForce 7710 L100 takes place by a chemical reaction (polyaddition) of the two mentioned components. The properties of the NL20 natural cork and cured SikaForce 7710 L100 polyurethane adhesive are shown in Tables 1 and 2, respectively. Pre-treatment process of aluminum sheets was conducted in reference to the EN 12 487 (2007). Before an adhesive bonding process the sheets were prepared by chromate conversion coating process to passivate their surfaces. External surfaces of sandwich composite after chromate process are ready for finishing for example by painting or adhesive bonding with decorative layers, such as HPL laminates.

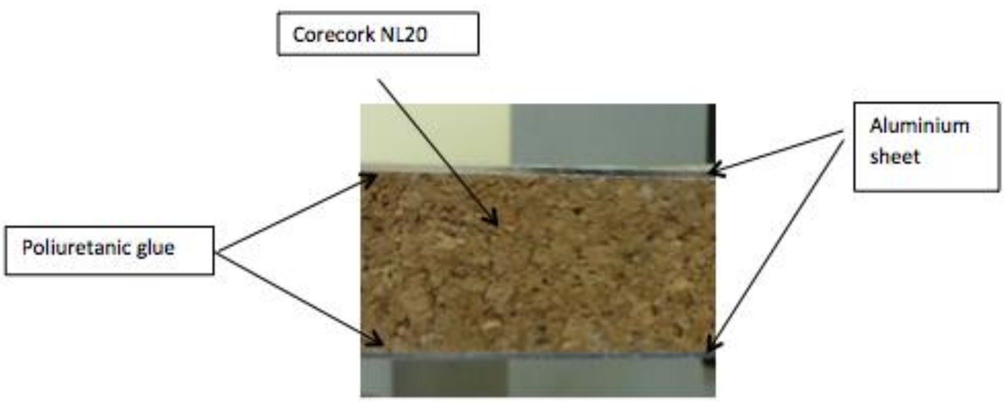


Fig. 1. 30-mm-thick Plycork Al composite

Table 1. Physical and Mechanical Properties of CoreCork NL20

Property	Value	Test Procedure
Density (kg/m^3)	200	ASTM C271 (2016)
Compressive strength (MPa)	0.5	ASTM C365 (2016)
Compression modulus (MPa)	6.0	ASTM C365 (2016)
Tensile strength (MPa)	0.7	ASTM C297 (2016)
Shear strength (MPa)	0.9	ASTM C273 (2016)
Shear modulus (MPa)	5.9	ASTM C273 (2016)
Thermal conductivity (W/mK)	0.034	ASTM E1530 (2016)
Loss factor (at 1kHz) (-)	0.043	ASTM E756 (2017)

Table 2. Physical and Mechanical Properties of cured SikaForce 7710 L100

Property	Value	Test Procedure
Density (g/cm^3)	1.5	CQP 006-5 (2012)
Viscosity (mPa•s)	10000	Brookfield - RVT 6/20 (2012)
Tensile strength (MPa)	13	ISO 527 (2012)
Elongation at tensile break (%)	8	ISO 527 (2012)
Tensile lap-shear strength (MPa)	9	ISO 4587 (2003)
Shore D hardness (D)	80	CQP 537-2 (2012)

The concept of selecting components to create this composite was based on a combination of environmentally friendly materials that are suitable for recycling, lightweight, durable for long-term use, and, most importantly, characterized by specific functional properties.

The reference material was 9-mm-thick birch plywood (ELMAS sp. j., Warsaw, Poland) covered with a standard anti-slip coating (density 220 g/m^2, RIGA TEX mesh print), which had been glued with a resinous phenolic adhesive. This plywood is used in the transportation industry for the flooring of semi-trailers, trailers, and buses.

Composite manufacture

The sandwich composites (Plycork Al) were made using vacuum bonding. Before the bonding process, the aluminum sheets were degreased at first and then subjected to chemical etching, decapitation, and chromatizing processes in order to obtain desirable adhesive properties. After every the pre-treatment operation, they were rinsed twice and dried in hot air (about 100 ^{o}C).

A sufficient amount of the polyurethane adhesive used on both sides of the cork agglomerate sheet comes up from 120 g/m^2 to 170 g/m^2. This process was carried out using a glue spreader with four rolls. The prepared core was combined with two layers of aluminum sheets, and then it was pressed with a membrane vacuum press with a force equal to 0.9 kg/cm^2 (Fig. 2). Application time, open time, and press time for SikaForce 7710 L100 in normal conditions (21 ^{o}C and relative humidity 50 %) were 60 min, 120 min, and 230 min, respectively.

Fig. 2. Membrane vacuum press

The vacuum membrane press method guarantees that an even pressure will be applied, which endows the Plycork Al composite with uniform properties across its entire surface. Plycork Al composites were produced and cut in the Rawicz's Factory Waggon Equipment RAWAG Sp. z o.o. (Rawicz, Poland). The cutting of samples was carried out with the Water Jet Streamcut plotter (Kimla, Czestochowa, Poland).

Methods

Static four-point bending tests

Plycork Al composites were tested at the West Pomeranian University of Technology in Szczecin (Poland) by means of static four-point bending tests, which consisted of loading the sample with two forces equal in value perpendicular to the bonded surface. The static four-point bending test was performed based on ISO 14125 (2001), where the width of the test samples was modified to 100 mm and the roll diameter of the supports was 25 mm due to the nature of the layered material when a force was applied. The bending test performed on the 15-mm-thick Plycork Al composite is shown in Fig. 3.

Fig. 3. Static four-point bending tests performed on 15-mm-thick Plycork Al

The tests were carried out on the INSTRON 8501 Plus (Instron, High Wycombe, Great Britain) using the Series IX Automated Materials Testing System 8.34 with a bending speed of 5 mm/min at 23 ºC and 45 % relative humidity. The spacing of the supports (L) as dependent on the sample thickness (h) was calculated in accordance with ISO 14125 (2001), where L = 22.5 h (mm). The dimensions of the tested samples are shown in Table 3.

Table 3. The Dimensions of the Plycork Al Samples

Sample Thickness, h (mm)	Sample Length, l = 30 h (mm)	Sample Width, b (mm)
9	270	100
15	450	100
30	900	100

The bending stress was calculated from Eq. 1 and according to ISO 14125 (2001),

$$\sigma\ (\mathrm{N/mm^2}) = F \cdot L / b \cdot h^2 \quad (1)$$

where F is the maximum load (N), L is the spacing between the supports (mm), b is the width of the sample (mm), and h is the thickness of the sample (mm).

The deformation of the sample was calculated using Eq. 2 and according to ISO 14125 (2001),

$$\varepsilon\ (\%) = \left(4.7 \cdot s \cdot h / L^2\right) \cdot 100 \quad (2)$$

where s is the bend deflection of the sample (mm).

The modulus of elasticity of the composite was calculated using Eq. 3 and according to ISO 14125 (2001),

$$E\ (\mathrm{N/mm^2}) = \frac{0.21 \cdot L^3 \cdot \left(F'' - F'\right)}{b \cdot h^3 \cdot \left(s'' - s'\right)} \quad (3)$$

where F'' is the load with deflection arrow s'' (N), F' is the load with deflection arrow s' (N), s' is the deflection arrow with deformation $\varepsilon' = 0.0005$ (mm), and s'' is the deflection arrow with deformation $\varepsilon'' = 0.0025$ (mm).

The deflection arrows were calculated using Eqs. 4 and 5 and in accordance with ISO 14125 (2001),

$$s'\ (\mathrm{mm}) = \frac{\varepsilon' \cdot L^2}{4.7 \cdot h} \quad (4)$$

$$s''\ (\mathrm{mm}) = \frac{\varepsilon'' \cdot L^2}{4.7 \cdot h} \quad (5)$$

where ε' is the deformation of the sample on the bending surface equal to 0.0005, and ε'' is the deformation of the sample on the bending surface equal to 0.0025.

Fire resistance tests

Railway vehicles have an assigned operation category and a design category based on the type of service they operate, their infrastructural characteristics, and their design. The combination of the operation category and the design category equals the hazard level (HL) for the vehicle. The HL parameter determines which of the material testing requirements listed in EN 45545-2 (2015) are applicable. The standard specifies the test methods, conditions, and fire performance requirements. The requirements are specified under points R1 to R26.

Fire resistance tests performed on the Plycork Al composite referenced railway applications according to EN 45545-2 (2015). Plycork Al composites are commonly used in vertical interior surfaces, such as side walls, partitions, doors, hoods, *etc.* All requirements listed for the R1 group must be met.

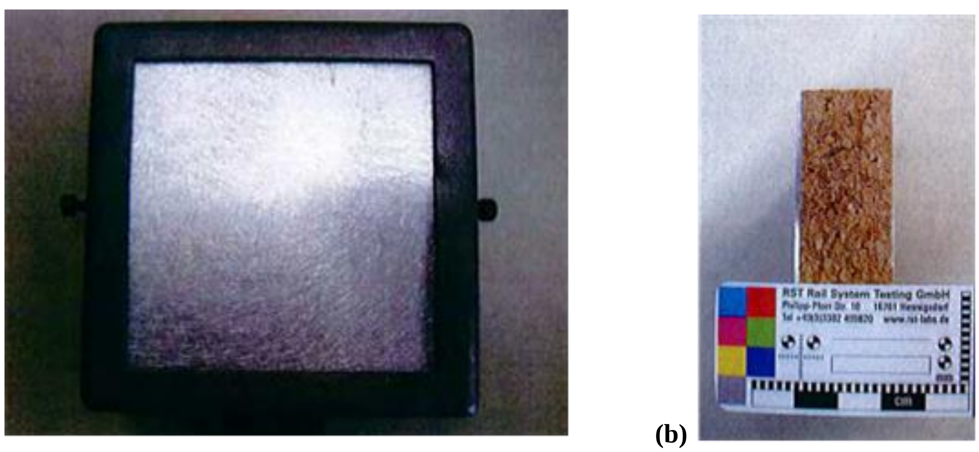
This paper also presents the results of the gas analysis carried out in the smoke chamber using the Fourier transform infrared (FTIR) spectroscopy technique. The analysis of the gas released during the exposure of a specified surface area of the test sample in the smoke chamber was one of five requirements listed in the standard.

The conventional toxicity index (CIT) is used to assess the toxic gases from railway products. The CIT parameter is calculated based on the test results, for specific materials or products. The CIT_G is calculated for general products. During the test, eight gas components were analyzed. The reference concentrations for CO_2, CO, HF, HBr, HCl, HCN, HF, NO_x, and SO_2 are listed in Table 4. These references are based on IDLH (Immediately Dangerous to Life and Health) values recognized as a limit for personal exposure to the gas components by NIOSH (National Institute for Occupational Safety and Health) and are consistent with the EN 45545-2 (2015).

Table 4. Reference Concentrations of the Gas Components

Gas Component	Reference Concentration (mg/m^3)
CO_2	72000
CO	1380
HBr	99
HCl	75
HCN	55
HF	25
NO_x	38
SO_2	262

The 42-mm-thick Plycork Al test sample is shown before testing in Fig. 4. The sample was mounted in a steel frame in accordance with the specifications listed in the test standards.



(a) (b)

Fig. 4. Plycork Al 42-mm-thick sample before the test: (a) front face and (b) sideways

Three square test (75 mm × 75 mm) samples 25-mm-thick were prepared in relation to the surface exposed to the real conditions of use. Before testing, the samples were conditioned in a standard atmosphere (temperature of 23 ºC ± 2 ºC and relative humidity of 50 % ± 5 %) until a constant weight was reached (Δm < 0.1 % in 24 h). The apparatus and test conditions are described in the European Standard ISO 5659-2 (2017). The exposure conditions depend on the type of product. For product samples with large surfaces, such as walls or ceilings, the samples should be exposed to a radiant heat flux of 50 kW/m^2 without a pilot flame. The described conditions are representative of fires that may impact the railway product during either the developing stages or the developed stage of a fire inside railway vehicles.

During the test, gas samples were collected twice; first after t_1 = 240 s, then again after t_2 = 480 s. For each component of the gas listed in Table 6, the value of its concentration, which is necessary to determine the CIT, was defined as follows,

$$CIT_G = 0.0805 \cdot \sum_{i=1}^{i=8} \frac{c_i}{C_i} \tag{6}$$

where CIT_G is the conventional toxicity index for general products, c_i is the concentration measured in mg/m^3 ith gas, and C_i is the reference concentration measured in mg/m^3 ith gas.

$$CIT_G = \max\left(\langle CIT_4 \rangle, \langle CIT_8 \rangle\right) \tag{7}$$

The CIT_4 and CIT_8 values are suitable for the fourth and eighth minute, respectively.

RESULTS AND DISCUSSION

Static Four-point Bending Tests

Exemplary curves showing the stress-strain ratio measured in a static four-point bending test for Plycork Al composites with 9 mm, 15 mm, and 30 mm thicknesses are presented in Fig. 5. The dependencies of the bending stress, deformation, and bending modulus as a function of the composite thickness are shown in Figs. 6 through 8.

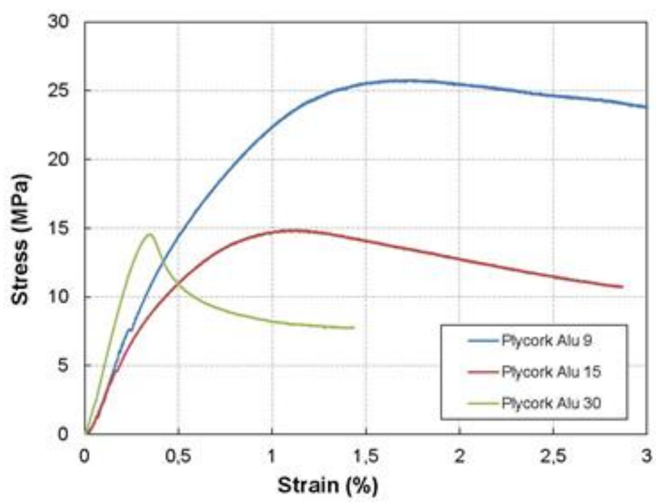


Fig. 5. Bending stress as a function of strain of Plycork Al composites with thicknesses of 9 mm, 15 mm, and 30 mm

The static four-point bending tests showed that the bending strength of the the composites and the deformation of the Plycork Al decreased as the thickness of the core material increased. A higher semi-elastic core content from the natural cork agglomerate resulted in the composite exhibiting greater stress dissipation and less plastic deformation. Thus, the highest strength and the highest deformation among the tested structures were obtained for 9-mm-thick Plycork Al, *i.e.*, 1.7% and 25.1 MPa, respectively. In contrast, the smallest values were measured for 30-mm-thick Plycork Al, which were 0.4% and 14.5 MPa, respectively (Figs. 6 and 7, Table 5).

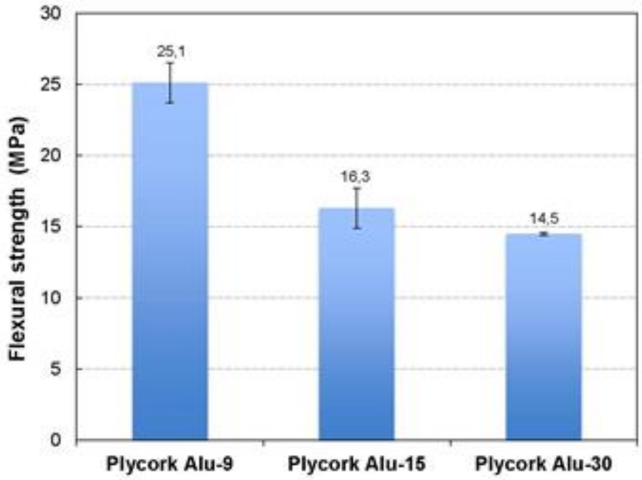


Fig. 6. Flexural strength of Plycork Al composites with thicknesses of 9 mm, 15 mm, and 30 mm

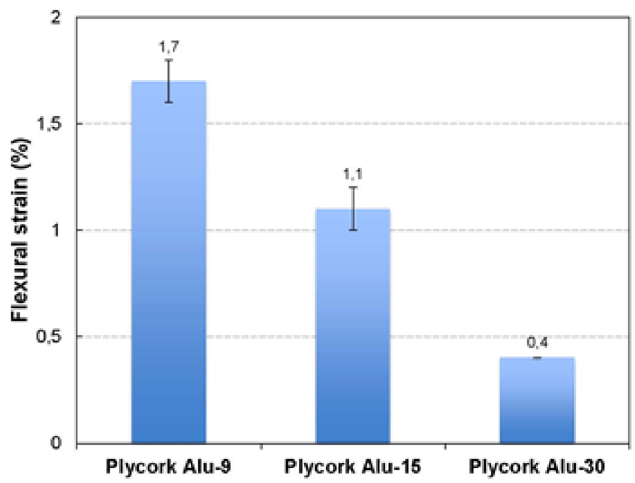


Fig. 7. Flexural strain of Plycork Al composites with thicknesses of 9 mm, 15 mm, and 30 mm

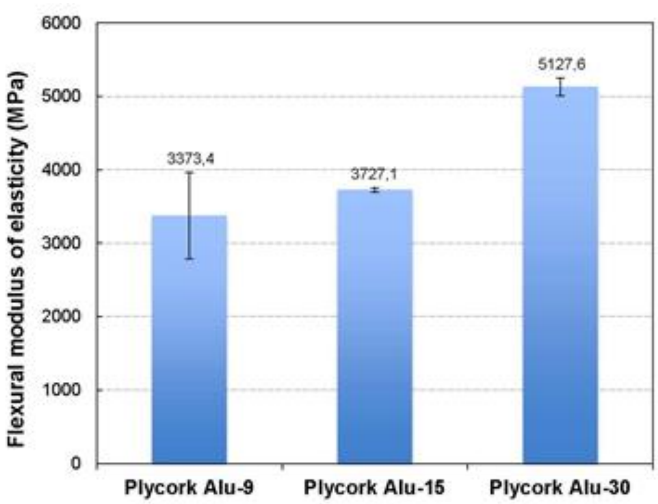


Fig. 8. Flexural modulus of elasticity of Plycork Al composites with thicknesses of 9 mm, 15 mm, and 30 mm

The inverse relationship was illustrated by the modulus of elasticity during bending. The highest value for the modulus of elasticity was achieved by the 30-mm-thick Plycork Al composite and measured 5128 MPa, and the lowest was showed by the 9-mm-thick Plycork Al composite and measured 3373 MPa (Fig. 8, Table 5).

When designing a composite structure, it is important not only to take the conditions of use into consideration, but also the mechanism for the destruction of composites (Sousa-Martins *et al.* 2013). The destruction of Plycork Al composites containing a natural cork agglomerate proceeded gradually during the static four-point bending tests (Fig. 5). Only the external surface layer was subjected to plastic deformation. A core material made of a natural cork agglomerate only thickened at the locations where forces were applied without showing any loss of properties or cracks in the structure. Unlike a conventional structure made of plywood, a damaged Plycork Al composite did not form sharp edges, which would have been an additional threat to passengers and personnel during a collision.

(a) (b)

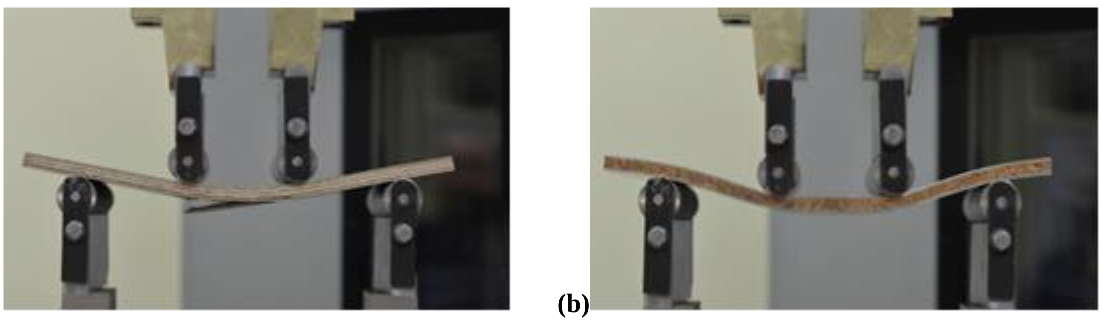


Fig. 9. Four-point bending test for (a) 9-mm-thick birch plywood panel (b) 9-mm-thick Plycork Al

(a)

(b)

Fig. 10. Samples of 9-mm-thick: (a) Plycork Al composite and (b) birch plywood after the four-point bending tests

(a)

(b)

(c)

Fig. 11. Samples of Plycork Al composites with thicknesses of (a) 9 mm, (b) 15 mm, and (c) 30 mm after the four-point bending tests

To compare the behavior of materials under a load, a 9-mm-thick sample of plywood was examined for reference purposes. During the test, the structure composed of plywood rapidly broke uncontrollably, whereas the structure made of Plycork Al dissipated the stress in the light core material made of cork agglomerate (Figs. 9, 10, and 11).

The results of the static four-point bending tests for multilayer Plycork Al composites and birch plywood are presented in Table 5.

Table 5. The Static Four-point Bending Tests Obtained for 9-, 15-, and 30-mm-thick Plycork Al Composites and 9-mm-thick Birch Plywood Results Completed with Volume Density Measurements

Samples	Flexural Strength σ_z (MPa)	Flexural Modulus of Elasticity E_z (MPa)	Strain ε at σ_z (%)	Deflection at σ_z (mm)	Volume Density (kg/m^3)
Plywood-9	70.2 ± 5.9	1427.7 ± 132.9	1.0 ± 0.1	9.4 ± 1.3	769.6
Plycork Al-9	25.1 ± 1.4	3373.4 ± 589.4	1.7 ± 0.1	16.4 ± 0.7	736.6
Plycork Al-15	16.3 ± 1.4	3727.0 ± 27.9	1.1 ± 0.1	17.0 ± 1.3	590.4
Plycork Al-30	14.5 ± 0.1	5127.6 ± 123.6	0.4 ± 0.1	11.3 ± 0.3	380.4

Flexural strength and modulus of elasticity normalized by density for Plycork Al composites with thicknesses of 9-, 15-, and 30 mm and birch plywood of 9 mm are presented in Fig. 12. It shows differ properties of Plycork Al composites compared to birch plywood. The Plycork Al composites have higher specific modulus of elasticity but the plywood has higher specific flexural strength.

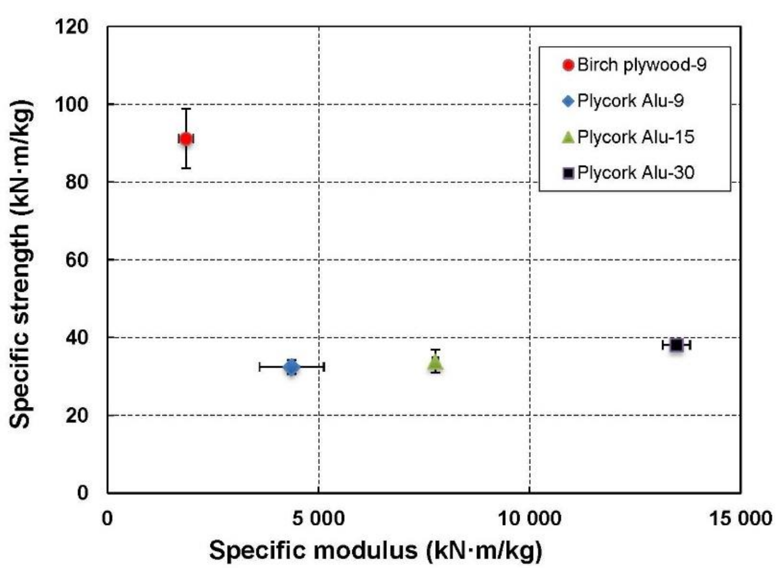


Fig. 12. Specific flexural strength and specific modulus of elasticity of Plycork Al composites with thicknesses of 9 mm, 15 mm, 30 mm compared to birch plywood of 9 mm

Table 6. Test Results of Fire Tests for the 42-mm-thick Plycork Al Composite

Gas Component		After 4 min		After 8 min	
		(ppm)	(mg/m^3)	(ppm)	(mg/m^3)
Carbon dioxide	CO_2	397	639	475	755
Carbon monoxide	CO	0	0	2	2
Hydrogen fluoride	HF	0	0	0	0
Hydrogen chloride	HCl	0	0	0	0
Hydrogen bromide	HBr	0	0	0	0
Hydrocyanic acid	HCN	0	0	0	0
Nitric oxide and dioxide	NO_x	0	0	0	0
Sulphur dioxide	SO_2	0	0	0	0

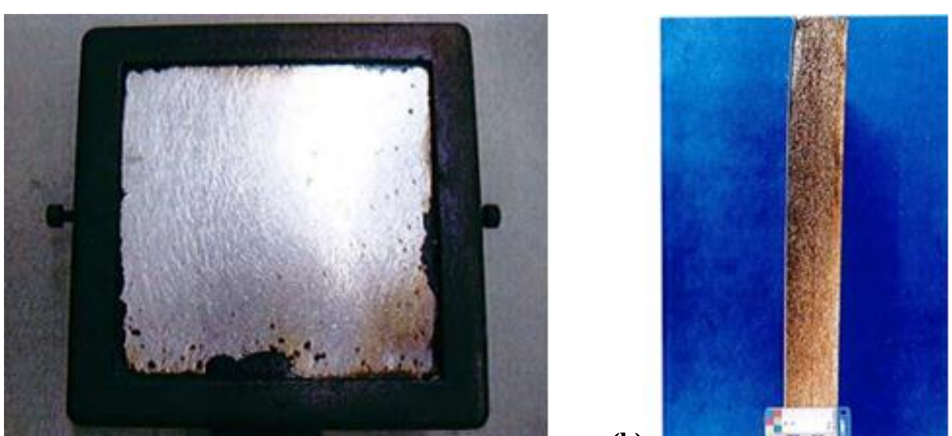
Fire resistance test

The averaged results of the fire test performed on the 42-mm-thick Plycork Al composite are shown in Table 6. The calculated and maximum admissible values for subsequent hazard levels of the CIT are summarized in Table 7.

Table 7. CIT Values for Plycork Al Composite

Parameter	Calculated Values	Admissible Values		
		HL1	HL2	HL3
CIT_4	0.00	1.2	0.9	0.75
CIT_8	0.00			
CIT_G	0.00			

The measured concentration of the individual gas components allows the values of the CIT_4 and CIT_8 parameters to be calculated. The CIT_G values for the tested composite were equal to zero (Table 7). The highest HL3 requirement for the toxicity of gas was met. The product did not pose a toxic hazard due to released gases. The Plycork Al sample after fire testing is shown in Fig. 13. In comparison of Plycork Al composites and birch plywood their fire resistance and gas toxicity are quite differ because the latter is combustible and inflammable material (Bergman *et al.* 2010). The Plycork Al composites as non- combustible and non-inflammable materials improve fire safety and reduce or eliminate the risk of the ignition. Making ignition harder and retarding the spread of fire the Plycork Al composites can be important contribution in minimizing fire danger in transportation industry at first.

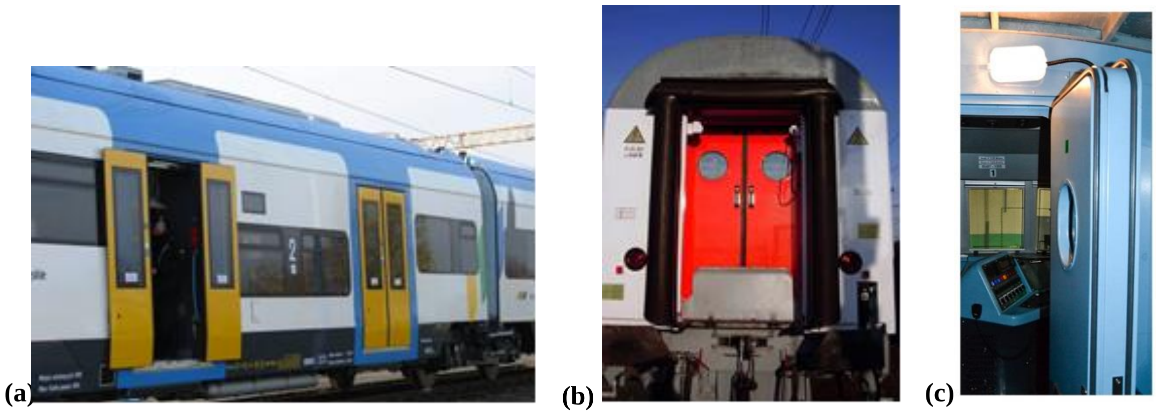


(a) **(b)**

Fig. 13. Plycork Al samples after the fire resistance test: (a) front face, (b) sideways

APPLICATIONS OF PLYCORK ALU COMPOSITES IN TRANSPORTATION

The use of modern Plycork Al composites in the transportation industry ensures the achievement of many benefits, such as weight reduction and a noticeable reduction in cost with the possibility of long-term use.



(a) (b) (c)

Fig. 14. Application of a Plycork Al composite in (a) the entrance door of the train, (b) the partition door of the train, and (c) the door of the train engine

Fig. 15. Application of Plycork Al composite in the entrance door of the tram

(a) (b)

Fig. 16. Application of Plycork Al composite in the train toilet: (a) door and (b) floor and walls

Fig. 17. Application of Plycork Al composite in luggage racks on the train

Plycork Al composite has been used in rail transportation wherever a weight reduction, thermal and/or acoustic insulation, insensitivity to temperature changes, and easy formability are desired. Below, in Figs. 14 through 17, some interesting applications of these multilayer composites are shown (images were made available by the archives of the Rawicz's Factory Waggon Equipment RAWAG Sp. z o.o. Co., Rawicz, Poland).

CONCLUSIONS

1. Lightweight Plycork Al sandwich composites composed of a natural cork agglomerate and aluminum sheets can successfully replace conventional materials, such as birch plywood, in many applications in the transportation industry due to their operational safety advantages. The Plycork Al composites did not burst into flame in fire and did not form sharp edges during material destruction.
2. Fire resistance tests of the Plycork Al composite showed that the conventional index of toxicity (CIT) values were equal to zero for the tested composite and thereby its highest requirement for the toxicity of released gas was met.
3. The destruction of the Plycork Al composite was characterized by the absence of sharp edges being other than birch plywood destruction with sharp splinters, which can be due to the difference in destruction mechanism and elasticity both of materials (for 9-mm-thickness - 1.7% and 1.0% strain under max load, respectively).
4. Together with the increase of the core material thickness (9, 15, and 30 mm) a noticeable effect was observed on the mechanical properties of the Plycork Al composite when the flexural strength and strain decreased from 25.1 MPa to 14.5 MPa and from 1.7% to 0.4%, respectively, while the flexural modulus of elasticity rose from 3373 MPa to 5128 MPa at the same time. Therefore, an optimization of the properties to meet requirements can be achieved by controlling the thickness of the core.
5. The Plycork Al composites are recyclable as only approximately 3% of the composite is not reusable, *i.e.*, its polyurethane adhesive layer.

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