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COMPOSITES THEORY AND PRACTICE

Patrycja Pawłowska[1*], Agnieszka Deja[2], Marek Pijanowski[3], Krzysztof Nozdrzykowski[3]

[1] Maritime University of Szczecin, Faculty of Engineering and Economics of Transport, ul. Henryka Pobożnego 11, 70-507 Szczecin, Poland
[2] Maritime University of Szczecin, ul. Wały Chrobrego 1-2, 70-500 Szczecin, Poland
[3] Maritime University of Szczecin, Faculty of Mechanics, Basic Technical Sciences Institute, ul. Willowa 2-4, 71-650 Szczecin, Poland
**Corresponding author. E-mail: p.pawlowska@am.szczecin.pl*

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ASSESSMENT OF COMBUSTIBILITY OF POLYESTER MATRIX REINFORCED WITH DIFFERENT FIBRES

The article presents the issues of recycling materials made of plastics and composite materials based on a plastic product. The way of preparing samples made of polyester resin being the matrix with cotton, jute and glass fibre reinforcement was described. Moreover, the results of combustibility property tests of the prepared composite materials were shown. The studies were carried out according to the UL 94 standard, used by American Underwriters Laboratories. The results of the tests were presented in the form of final conclusions.

Keywords: combustibility, composites, recycling, thermal treatment (recycling)

OCENA PALNOŚCI KOMPOZYTÓW POLIESTROWYCH O ZRÓŻNICOWANYM MATERIALE WZMOCNIENIA

Przedstawiono zagadnienia dotyczące recyklingu materiałów wykonanych z tworzyw sztucznych oraz materiałów kompozytowych na bazie wykonanej z tworzywa sztucznego. Opisano sposób wytwarzania próbek wykonanych z żywicy poliestrowej będącej osnową oraz zbrojenia bawełnianego, juty i maty z włókna szklanego. Zaprezentowano również wyniki badań właściwości palnych przygotowanych materiałów kompozytowych, które to badania przeprowadzono zgodnie ze standardem UL 94, stosowanym przez American Underwriters Laboratories. Wyniki badań ujęte zostały w postaci wniosków końcowych.

Słowa kluczowe: palność, kompozyty, recykling, przetwarzanie termiczne

INTRODUCTION

The manufacturers and recipients of products made of plastic are expected to conduct a rational policy of their use, which is connected to the negative impact of the excessive amount of substances used for plastic materials production and those from postproduction waste. The measures limiting the usage of plastics for the production of packaging and other products should include [1]: limitations on the volume and mass of materials for packaging as much as necessary:

1. designing and production of a product or packaging in a way that enables their multiple use in the first place, and then their recycling or, if this is not possible, then at least their reprocessing and if the latter is not possible - another form of their recycling;
2. minimising the number of substances which pose a threat to human life or health or to the environment in the products and/ or packaging.

In order to make packaging or other plastics available for multiple use, recycling or another form of their recovery, they should comply with the standards referred to in the act from 30th August 2002 on the system of compliance assessment (consolidated text, Journal of Laws, No 138 of 2010, item 935). The utilisation of post-consumer waste and those wastes generated during production processes as secondary raw materials is an important aspect of good and rational management of these resources for the environment. The reuse of materials reduces production costs, limits the threat to the natural environment and saves primary raw materials. Reusing waste in production processes is commonly known as recycling [1].

One of the main problems of the contemporary economy is the threat caused by plastics, therefore their processing is crucial from the perspective of waste management.

These materials can undergo [2]:

- mechanical recycling, also known as material recycling;
- chemical recycling, also called foodstock recycling;
- energy recycling, characterized by combustion.

It is homogenous waste, whose degradation is minimal, that undergoes mechanical recycling. This mechanism implies the transformation of used plastic into fragmented regranulate which will be reused [3-9].

As a result of chemical recycling we achieve a product that can be used as an admixture to other materials or be an independent plastic. This type of recycling implies the decomposition of compounds called polymers into monomers under chemical reactions.

Combustion, at a simultaneous gain of energy, is the most widely used way of recycling. This method is so common since it can be used for each type of waste while changing its volume - by about 90% [5]. Sometimes waste undergoes treatment before it is subjected to combustion in order to obtain high-calorie fractions (known as RDF). In such a case it is important to distinguish the material components of the waste. It is extremely troublesome from the perspective of complex materials like composites. In Poland, the generated post-production waste amounts to 2000 tonnes and post-consumption waste reaches 20000 tonnes annually [6-10]. The high level of composite production in Europe is an effect of the demand for these materials both in construction and transport [7]. The production of composites based on glass fibres in form of glass tissues, long fibres, using thermosetting resins, in European Union countries in 2004-2014 is shown in Figure 1.

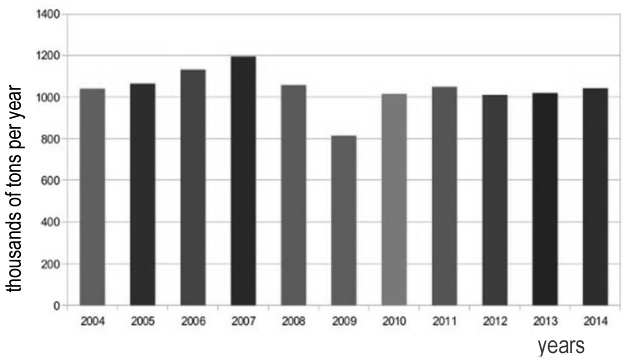

Fig. 1. Production of composites based on glass fibres in form of glass tissues, long fibres, using thermosetting resins, in European Union countries, in 2004-2014 [11]

Rys. 1. Produkcja kompozytów opartych na włóknach szklanych w postaci mat szklanych, włókien długich, z zastosowaniem żywic termoutwardzalnych w krajach Unii Europejskiej w latach 2004-2014 [11]

The dynamic development of the production of the given materials contributes to their continuous modification due to designing different types of reinforcement and matrix materials. It imposes continuous studies connected to their structure and the "behaviour" of composites in certain conditions in order to plan waste management and/ or their recycling [12-17]. Their combustion resistance is not unimportant here as it has an impact on the way and method of combustion. It is also crucial to define the chemical transformation properties of these materials as they constitute a group of flammable materials (owing to the polymer matrix) with the possibility of emitting smoke and toxic gases during combustion. Therefore, it is key to stipulate the thermal transformation properties of composites in order to choose correct filters for protection during the combustion process.

AIM OF STUDY AND STUDY MATERIAL

The aim of the study was to define the combustion properties of composites with various reinforcement phase material which determine the way of feedstock recycling of the studied plastics, as well as operational safety of the studies products.

Study material: Polyester resin PLUS 720 by NOVOL and hardener Betox - 50PC in the proportion 100:3 were used as the matrix material, and three types of fibres: glass tissue, jute fibre and cotton (Fig. 2) were used as the reinforcement.

The materials were produced by the transfer moulding method. It requires introducing the plastic material to a mould. Then the material was hardened and solidified [18].

Next, three identical moulds were put one on the other. Such samples placed centrally in the pressing station were infiltrated for 15 minutes. After 45 minutes the moulds were taken apart and the composites were removed.

Figure 3a presents a mould consisting of two plates, the first of which closes the mould and the second - having two moulding nests and one overflow nest. Figure 3b shows the sectional view of the plate filled with reinforcement and resin along with the marked force application point, whereas Figure 3c presents the mould placed inside the press. The symbols of the composites that were subjected to thermal transformation and their composition are shown in Table 1.

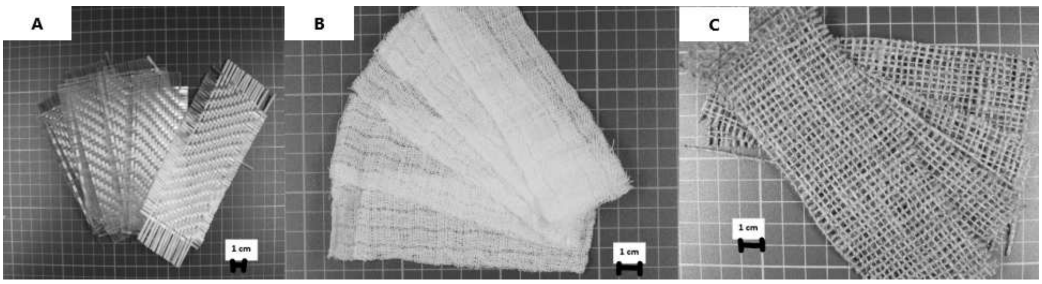

Fig. 2. Materials used for reinforcement: A) glass tissue (PS), B) cotton (PB), C) jute (PJ)

Rys. 2. Materiały wykorzystane na umocnienie: A) tkanina z włókna szklanego (PS), B) bawełna (PB), C) juta (PJ)

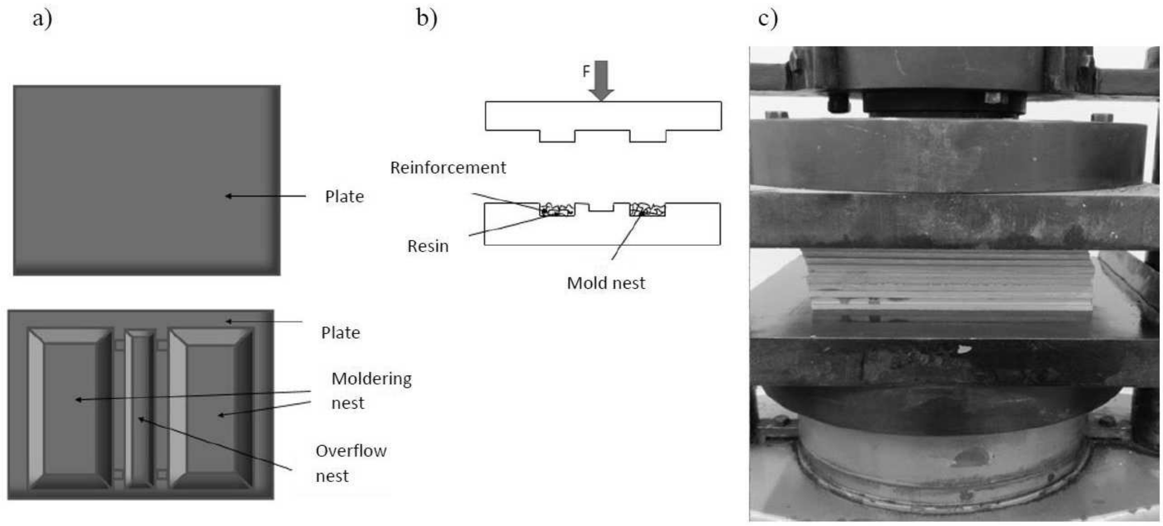

Fig. 3. Project of mould (a), sectional view (b), view of mould mounted on pressing station (c)

Rys. 3. Projekt formy (a), widok w przekroju (b) oraz widok form zamontowanej na prasie (c)

TABLE 1. **Symbols and composition of studied composites**
TABELA 1. **Oznaczenia i skład badanych kompozytów**

OZN	Matrix material	Type of reinforcement material	Reinforcement material	Form of reinforcement material	Reinforcement content [vol.%]	Number of reinforcement layers
PS3	polyester resin	synthetic fibre	glass fabric	fabric	9.1	3
PJ3	polyester resin	natural fibre	jute fibre	fabric	9	3
PB3	polyester resin	natural fibre	cotton fibre	fabric	7.4	3
PS6	polyester resin	synthetic fibre	glass fabric	fabric	17.2	6
PJ6	polyester resin	natural fibre	jute fibre	fabric	16.9	6
PB6	polyester resin	natural fibre	cotton fibre	fabric	14.3	6
PS9	polyester resin	synthetic fibre	glass fabric	fabric	22.6	9
PJ9	polyester resin	natural fibre	jute fibre	fabric	22	9
PB9	polyester resin	natural fibre	cotton fibre	fabric	18.4	9
P0	polyester resin	-	-	-	-	-

STUDY METHODS

Combustion was carried out in compliance with the UL 94 standard which is used by American Underwriters Laboratories. The horizontal burning test for combustibility grade UL 94 HB was performed for three samples with every reinforcement and with mere polyester resin. The dimensions of the samples were as follows: length 5” (127 mm), width 0.5” (12.7 mm) and a thickness not exceeding 0.5” (12.7 mm). The studies samples were labelled with symbols - at the distance of 1” and 4”. Then the sample was mounted from one side in the horizontal position, and the burner was tilted towards it at the angle of 45° and adjusted so that its flame was blue and its length equalled 1”. Combustion was carried out for a time shorter than 30 s, with the flame pointing at the front edge of the plastic material at the correct angle so that it covered more or less ¼ of its front edge, then the flame was removed. If the sample burned to the line of 1” before the time of 30 s passed, the flame was instantly removed. Figure 4 presents the burning test process carried out in the Laboratory of the Department of Materials Engineering of the Maritime University of Szczecin.

Fig. 4. Burning test in compliance with UL 94 HB

Rys. 4. Przebieg próby palenia wg UL 94 HB

According to standard UL 94 HB the studied material achieves combustibility class if, after the flame is removed:

1. Burning speed does not exceed 1.5” (38.1 mm) a minute, in the case if the thickness of the sample falls between 0.120÷0.500” (3.05÷12.7 mm) or
2. Burning speed does not exceed 3.0” (76.5 mm) a minute, in the case if the thickness of the sample is less than 0.120” (3.05 mm) or
3. The material stops burning before the flame reaches the line of 4”.

TEST RESULTS

The results of the test are shown in Table 2. The thickness of all the samples was between 4.5±0.3 mm. In the case of the material with glass fibre, the difference between the 3- and 6-layered and 9 -layered materials was 0.1 mm. In the cotton samples the difference in thickness between the 3-layered material and 6-layered one also reached 0.1, and 0.2 mm between the 6- and 9-layered ones. The difference in thickness between the 3-, 6- and 9-layered materials with jute equalled 0.2 mm.

During the studies the behaviour of the studied materials in the flame was described. It was observed that all the studied materials burn, and the glass composites additionally make crackling sounds while burning. This is related to the inflammable character of the glass fibre and to the burning of the resin in the void between the fibres or thermal cracks of the glass fibre.

The behaviour of all the samples after removing the flame was similar, namely every sample kept burning and smoking, which was probably related to the same matrix material used. The next characteristic property of the studied materials was their smoking time after extinguishing the flame and time of their incandescence. Using natural fibre as a reinforcement phase fosters extending the incandescence time due to its thickness. The longest average incandescence time was displayed by the jute fibre. The smoking time for the material with glass fabric of 3, 6, and 9 layers equaled 3, 7 and 11 seconds respectively. In the case of resin reinforced with cotton, the smoking time and incandescence time for 3 layers amounted to 6 and 8 seconds, for 6 layers - 11 and 14 seconds, and for 9 layers - 16 and 20 seconds respectively. The resin with the jute reinforcement was characterized by the following time values: 8 and 11 seconds for 3 layers, 18 and 24 seconds for 6 layers and 27 and 33 seconds for 9.

TABLE 2. **Results of burning test of studied materials**
TABELA 2. **Wyniki parametrów palenia badanych materiałów**

	Number of layers	Average sample thickness [mm] before burning	Behaviour in flame	Behaviour after removing flame	Average smoking time after extinguishing (visible smoke) [s]	Average afterglow time [s]	Appearance of sample after test
P0	0	4.2	burns	Flame sustains and smokes	2	-	Sample very much blackened, burned at edges, shortened by about 7 mm
PS	3	4.3	burns, characteristic crackling sound	Flame sustains and smokes	3	-	Sample very much blackened, edges complete, shortened by about 3 mm
	6	4.3	burns, characteristic crackling sound	Flame sustains and smokes	7	-	Sample very much blackened, edges complete, shortened by about 2 mm
	9	4.4	burns, characteristic crackling sound	Flame sustains and smokes	11	-	Sample very much blackened, edges complete, got shorter by about 2 mm
PB	3	4.2	burns	Flame sustains and smokes	6	8	Sample very much blackened, burned at the edges, got shorter by about 4 mm
	6	4.3	burns	Flame sustains and smokes	11	14	Sample very much blackened, burned at edges, shortened by about 3 mm
	9	4.5	burns	Flame sustains and smokes	16	20	Sample very much blackened, burned at the edges, got shorter by about 2 mm
PJ	3	4.3	burns	Flame sustains and smokes	8	11	Sample very much blackened, burned at edges, shortened by about 5 mm
	6	4.5	burns	Flame sustains and smokes	18	24	Sample very much blackened, burned at edges, shortened by about 3 mm
	9	4.7	burns	Flame sustains and smokes	27	33	Sample very much blackened, burned at edges, shortened by about 2 mm

Figure 5 presents the appearance of the studied materials after the combustion test. The samples were placed in order: 3, 6, and 9 layers of glass fibre, cotton and jute. Every one was very much blackened, and the deficit in their length declined along with the increase in the number of reinforcement layers.

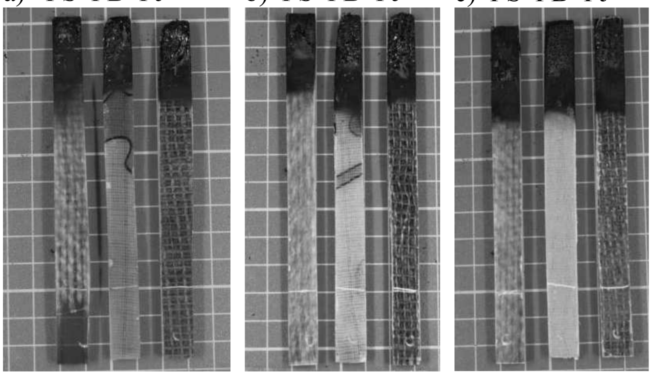

Fig. 5. View of samples after burning: a) 3 layers of reinforcement, b) 6 layers of reinforcement, c) 9 layers of reinforcement

Rys. 5. Widok próbek po paleniu: a) 3 warstwy umocnienia, b) 6 warstw umocnienia, c) 9 warstw umocnienia

CONCLUSIONS

The results of the performed studied allow the following conclusions to be formulated:

1. All the studied materials met the requirements of the horizontal burning test for combustibility class UL 94 HB. As a point of reference a sample made of mere resin was used. All the samples had a similar thickness and they burned even after removing the flame. The material reinforced by the glass fabric was the one that faded the quickest and that had the minimal smoking time after extinguishing and the sample with 9 layers of jute smoked and incandesced the longest (27 and 33 seconds respectively).
2. The smallest change in length was obtained by the material with glass fabric. Similar material defects can be observed in the materials reinforced by cotton and jute fibre. All the studied materials were sooted emitted by the smoke, which also emitted an unpleasant smell.
3. The sample reinforced by the glass fabric turned out to be most durable: the resin of this fabric burned but the reinforcement remained untouched.
4. Regardless of the fact that the glass fabric samples displayed the smallest changes, the natural fibre composites - jute or cotton - achieved the same combustibility class, which could suggest the possibility of interchanging such types of reinforcement.

Such tests connected to selecting the processing techniques of the studied materials are significant from the point of view of combustion process characteristics and choosing the right techniques the materials can be subjected to. Combustion studies can contribute to defining the net caloric values of the described composites. This issue will be the subject of further publications.

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