New composite materials using polyester woven fabric scraps as reinforcement and thermoplastic matrix

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ABSTRACT – REZUMAT

New composite materials using polyester woven fabric scraps as reinforcement and thermoplastic matrix

In this study, polypropylene-based thermoformed composites have been obtained using polyester woven fabric scraps as reinforcement. Four types of matrix have been used for the experiments: biaxially oriented polypropylene bag waste (BOPP), polypropylene nonwoven waste (TNT), 50/50 BOPP/TNT waste and virgin polypropylene fibres (PP). The percentage of matrix has been varied at four levels: 20%, 30%, 40%, and 50%. The effect of matrix/reinforcement mass ratio and matrix type on the mechanical properties of composite materials has been studied. Since the composite materials are intended to replace the oriented strand boards (OSB) in construction and furniture applications, comparison with the characteristics of 8 mm OSB has been made.

Keywords: *composite materials, polypropylene waste matrix, polyester fabric scraps reinforcement, recycling*

Noi materiale compozite care utilizează resturi de țesături din poliester ca armare și matrice termoplastică

În acest studiu, compozitele termoformate pe bază de polipropilenă au fost obținute folosind resturi de țesături din poliester. Patru tipuri de matrici au fost folosite pentru experimente: deșeuri din pungi de polipropilenă orientate biaxial (BOPP), deșeuri din nețesute din polipropilenă (TNT), deșeuri 50/50 BOPP/TNT și fibre virgine de polipropilenă (PP). Procentul de matrice a fost variat la patru niveluri: 20%, 30%, 40% și 50%. A fost studiat efectul raportului de masă matrice/armare și al tipului de matrice asupra proprietăților mecanice ale materialelor compozite. Întrucât materialele compozite sunt destinate să înlocuiască plăcile OSB în aplicații de construcții și mobilier, s-a efectuat o comparație cu caracteristicile OSB de 8 mm.

Cuvinte-cheie*: materiale compozite, matrice de deșeuri din polipropilenă, armare cu resturi de țesături din poliester, reciclare*

INTRODUCTION

The growth trend of world population, the improvement in the living standard, and the shortening of product life cycle all lead to an increase in the amount and diversity of waste. Even if waste management has improved significantly in the last decades, there are still great amounts of waste that are landfilled. Waste disposal into landfills has negative impacts on:

- environment – chemicals contained in waste can contaminate air, soil and ground water with harmful consequences for animals, plants and ecosystems;
- climate – emissions of methane and carbon dioxide from landfills cause the greenhouse effect on planet;
- human health – people's health is affected by air, soil and water pollution;
- economy – valuable materials are thrown away and this causes pressure on virgin resources.

In 2015, the European Commission has launched the first Circular Economy Action Plan that aimed to stimulate the transition to a circular economy in order to accelerate the sustainable economic growth and to create new jobs. The traditional linear economy is characterized by a "make-use-dispose" pattern. Instead, in a circular economy the waste is reduced at minimum by keeping the materials and resources within the economy as long as possible. Although 95% of all textiles worldwide can be reused or recycled, only less than 1% are recycled into new products [1]. The necessity of textile recycling has become a top priority due to fast fashion culture that shortens the product life cycle and generates larger amounts of both post-consumer and pre-consumer waste.

Textile recycling has an old history, textiles being recycled since the eighteenth century. Traditionally, in the mechanical recycling the fabric scraps are shredded into fibres and then spun into yarns or converted into nonwoven fabrics [2–8]. In recent years, research has been done concerning the use of shredded fibres as reinforcement in composite materials [9–14].

In the first research works regarding the obtaining of a composite material based on textile waste, the authors used virgin polypropylene fibres ax matrix and shredded fibres from knitted fabric scraps as reinforcement. The resulted composite material has found applications as chair seat, successfully replacing the textile straps. As the advanced shredding of the knitting fabric scraps is costly and the virgin polypropylene fibres are quite expensive, research has been focused towards the use of textile waste both as matrix and reinforcement. Therefore, pre-consumer and post-consumer waste in the form of polyester woven fabric scraps have been used as reinforcement and 100% polypropylene waste has been used as matrix (BOPP packaging bags and/or nonwoven material) in order to obtain composite materials at the Research Center for Advanced Processes, Products and Materials from the Faculty of Industrial Design and Business Management of Iasi.

This research work aims to study the influence of matrix/reinforcement mass ratio and matrix type on the mechanical properties of thermoformed composites. Matrix/reinforcement ratios of 20/80, 30/70, 40/60, 50/50 have been selected. Four variants of matrix have been used: BOPP bag waste, nonwoven (TNT) waste, 50/50 BOPP bag waste/TNT waste, and, for comparison purposes, virgin polyprolylene fibres. Polyester woven fabric scraps have been used as reinforcement. The composite materials have been engineered as sustainable replacement for fibreboards or oriented strand boards (OSB).

MATERIALS AND METHODS

The raw materials used to obtain composite materials with matrix/reinforcement ratios of 20/80, 30/70, 40/60, 50/50 are presented in table 1.

The composite materials have been manufactured by thermoforming. The technological flow used to obtain composite materials that have waste of BOPP and/or TNT as matrix is the presented in figure 1.

The matrix and reinforcement components were manually blended using “sandwich” (horizontal) layers. The blend was fed to the cutting machines placed perpendicular to each other. The technological parameters of the cutting machines were as follows: blade speed 900 rpm, feeding speed 1.2 m/min, and the gauge between feed roller and the rotating blade 40 mm.

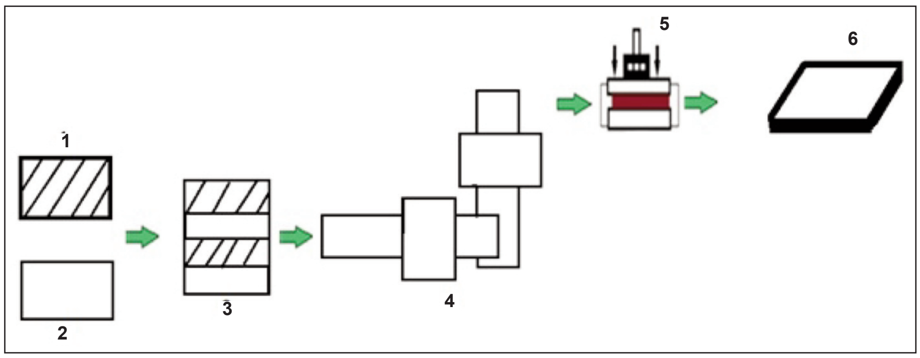


Fig. 1. Technological flow of thermoformed composite manufacturing process: *1* – matrix; *2* – reinforcement; *3* – matrix/reinforcement blend; *4* – cutting machines; *5* – thermoforming machine; *6* – composite material

Table 1

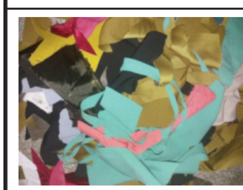
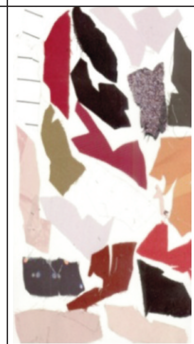
RAW MATERIALS USED TO OBTAIN COMPOSITE MATERIALS			
Raw material		**Description**	**Function**
	Polyester (PES) woven fabric scraps	Clippings generated in garment manufacturing	Reinforcement
	BOPP bag waste	Nonconformities of BOPP bags used in food packaging	Matrix
	Polypropylene nonwoven waste (TNT)	Clippings generated in upholstery industry	Matrix
	Virgin polypropylene fibres	Linear density 6.69 dtex, fibre length 76 mm, tenacity 3.33 cN/dtex, elongation at break 222.62%, melting point 165°C	Matrix

Table 2

THE SIZE OF THE PIECES OF PES WOVEN FABRIC SCRAPS AFTER CUTTING					
Size class (cm²)	12–15	8–12	5–8	3–5	0.5–3
					
Mass (g)	180	120	96	72	132
Percentage (%)	30	20	16	12	22

The blend between virgin polypropylene fibres and PES woven fabric scraps has been done after scraps' cutting. Samples of 600 g of cut pieces have been used to analyse their size. The pieces have been scanned and the area of each piece has been measured using AutoCad software. Cut pieces have been distributed in five classes according to their size. The percentage of each class has been determined. As can be seen in table 2, the weight of the classes corresponding to an area higher than 5 cm^2 is significant (66%).

The thermoforming has been done on a machine specially designed and manufactured for the experiments. The thermoforming machine has two plates that can be electrically heated up to 250 °C in order to melt the polypropylene matrix. The plates are connected to a water-cooling system (figure 2).

A quantity of 1200 g of each intimate blend of matrix and reinforcement was placed in a mould (40 cm length × 30 cm width × 15 cm height) jointed with the inferior plate. In order to obtain the composite material, the blend of matrix and reinforcement was heated and pressed.

Based on previous experiments, the following technological parameters have been kept constant:

- Temperature – 190 °C;
- Pressure force – 9 tf;
- Thermoforming time – 15 min.

Sixteen variants of composite materials using virgin PP, BOPP waste, TNT waste and 50/50 BOPP/TNT waste as matrix and PES woven fabric scraps as reinforcement have been obtained in the following mass ratio: 20/80, 30/70, 40/60, 50/50.

Composite materials have been subjected to flexural and tensile testing on LBG testing equipment using TCSoft2004 Plus software (figure 3). Six samples of each composite material variant have been prepared for flexural tests according to BS EN 310 standard. This standard for wood-based materials has been used because the investigated composite materials are aimed to replace the fibreboards/oriented strand boards in construction applications. The sample

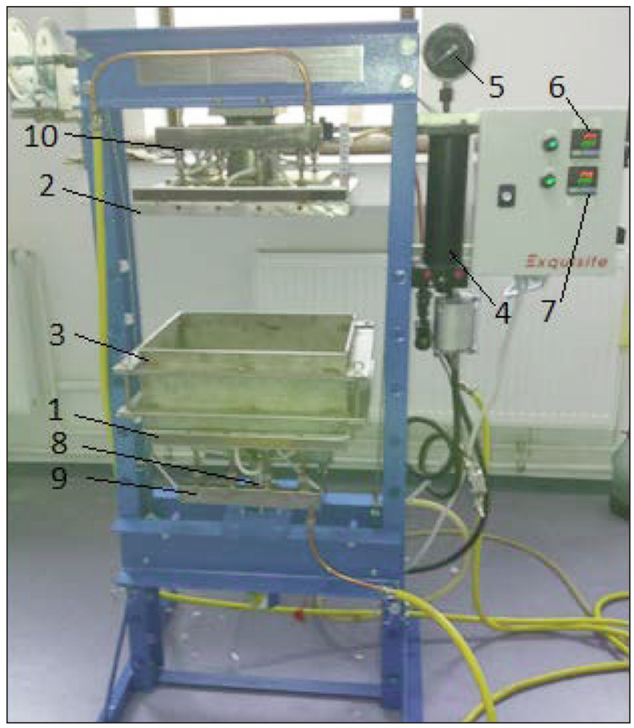
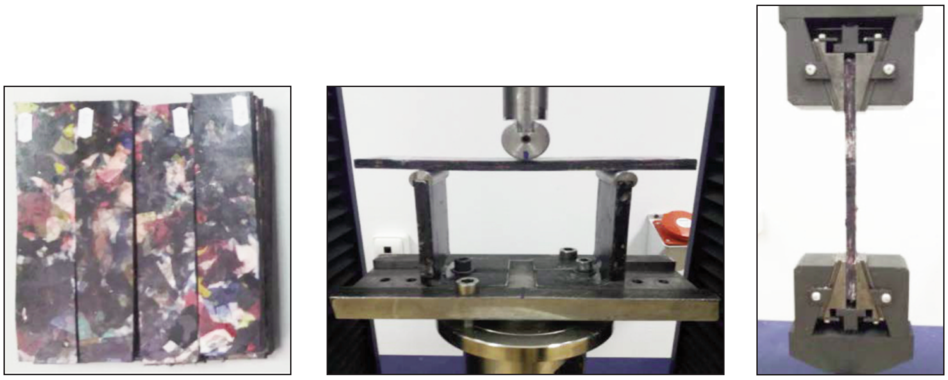


Fig. 2. Thermoforming machine: *1* – inferior plate; *2* – superior plate; *3* – stainless steel mould; *4* – hydraulic pump; *5* – manometer; *6* – superior plate temperature display; *7* – inferior plate temperature display; *8* – hydraulic cylinder; *9, 10* – water-cooling system

width was 50 mm. The sample length was established in accordance with the thickness of the samples at 20%·(20·t + 50 mm), where t is the sample thickness (mm) and 20·t is the distance between supports. The reduction by 20% of the distance between supports has been decided because the samples subjected to flexure did not break. In order to record the maximum bending force in 60±30 s, the speed test was set at 20 mm/min.

The bending strength of composite samples is calculated as a ratio between the bending moment (at the maximum load F_{max}) to the moment of inertia of its full cross section:



a *b* *c*

Fig. 3. Testing of composite materials on LBG testing equipment: *a* – front view of composite samples for flexural tests; *b* – flexural testing; *c* – tensile testing

$$f_m = \frac{3F_{max} l_1}{2bt^2} \qquad (1)$$

where f_m is the bending strength [N/mm^2], F_{max} – the maximum load [N], l_1 – the distance between the supports [mm], b – the width of the test sample [mm], t – the thickness of the test sample [mm].

The samples for tensile testing have been cut according to EN 326-1 standard at the dimensions of type 2 sample: 250 mm length and 25 mm width. The tensile tests were run in accordance with SR EN ISO 527-42006 standard using a crosshead speed of 20 mm/min and a distance between grips of 150 mm.

Taking into account that the matrix and the reinforcement components were randomly blended, the samples for tensile and flexural testing were cut only in longitudinal direction.

RESULTS AND DISCUSSIONS

The mechanical properties of the manufactured composite materials are presented in table 3. Since the composite materials have been engineered as sustainable replacement for oriented strand boards, the mechanical characteristics of 8 mm OSB were also determined, for comparison purposes. Table 3 also presents the requirements set out in standard for bending strength and bending modulus of elasticity of oriented strand boards of 6 to 10 mm thickness.

In figure 4, the tensile stress of composite materials is presented. Regardless of the matrix type, as matrix percent increases up to 30–40% the tensile strength of composite materials increases. After this matrix content the increase is attenuated. The bonds between PES scraps and PP matrix are physical

Table 3

MECHANICAL PROPERTIES OF COMPOSITE MATERIALS AND ORIENTED STRAND BOARD

Variant	Composition	Tensile stress (Mpa)	Breaking elongation (%)	Bending strength (Mpa)	Bending modulus of elasticity (N/mm²)
V1	20/80 PP/PES woven scraps	7.56±1.3	10.55±1.16	15.1±2.1	948.08±135.56
V2	30/70 PP/PES woven scraps	11.65±1.25	9.73±0.82	22.0±1.89	1073.04±119.02
V3	40/60 PP/PES woven scraps	12.72±0.6	11.64±1.38	24.2±1.48	1177.70±181.03
V4	50/50 PP/PES woven scraps	13.31±0.53	11.97±1.09	26.5±1.47	1196.60±170.95
V5	20/80 TNT/PES woven scraps	8.54±0.5	14.20±1.71	18.1±2.4	1033.80±198.07
V6	30/70 TNT/PES woven scraps	14.22±1.4	18.19±2.6	30.4±1.4	1173.40±69.28
V7	40/60 TNT/PES woven scraps	19.24±1.14	24.08±1.55	32.3±0.74	1265.90±87.43
V8	50/50 TNT/PES woven scraps	20.47±0.19	24.44±1.23	32.4±1.57	1246.20±81.54
V9	20/80 BOPP/PES woven scraps	8.64±0.77	16.40±1.72	14.3±1.5	966.10±213.61
V10	30/70 BOPP/PES woven scraps	13.03±0.4	19.06±2.67	25.9±2.12	1056.13±152.13
V11	40/60 BOPP/PES woven scraps	20.07±0.81	23.63±2.69	30.8±1.83	1138.70±66.96
V12	50/50 BOPP/PES woven scraps	20.19±1.66	23.82±2.12	31.8±2.46	1235.11±88.66
V13	20/80 (BOPP+TNT)/PES woven scraps	9.07±1.01	16.00±1.09	17.1±1.51	1084.90±191.49
V14	30/70 (BOPP+TNT)/PES woven scraps	13.84 ±1.2	18.70±1.92	28.7±2.41	1275.32±107.21
V15	40/60 (BOPP+TNT)/PES woven scraps	20.73±2.4	24.24±2.12	33.8±1.22	1305.70±101.01
V16	50/50 (BOPP+TNT)/PES woven scraps	21.19±1.64	25.20±4.29	34.5±1.65	1379.55±98.56
-	OSB – transversal 8 mm	2.26	1.40	9.9	1499.00
-	OSB – longitudinal 8 mm	5.68	1.20	23.2	3427.70
-	OSB SN-EN300:2006 transversal 6–10 mm	-	-	11	1400
-	OSB SN-EN300:2006 longitudinal 6–10 mm	-	-	22	3500

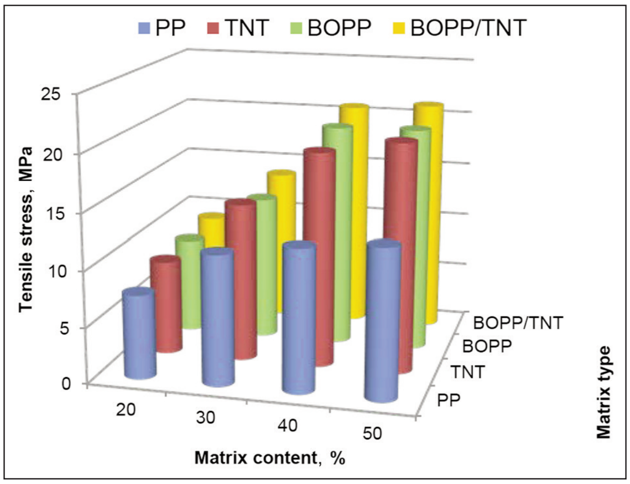


Fig. 4. Tensile stress of composite materials

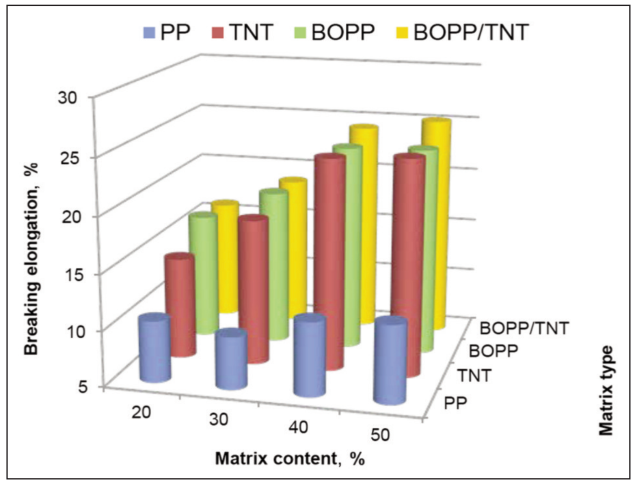


Fig. 5. Breaking elongation of composite materials

bonds. The augmentation of matrix content improves the blend homogeneity and the impregnation with melted PP of PES woven scraps. Therefore, the number of bonds between reinforcement and matrix increases. The lowest value of tensile stress was shown by the virgin polypropylene based-composite materials, probably due to the differences in the form of presentation of matrix component and reinforcement component that led to a non-uniform blend. The matrix component was in the form of densely packed fibers, while the reinforcement component was in the form of scrap pieces with an area ranging from 0.5 to 15 cm^2. The 50/50 TNT/BOPP waste-based composite materials showed the highest tensile strength, no matter the matrix percent. Given the number of determinations (6) and the experimental error, the differences between V8, V12 and V16 are small. A possible explanation for the better tensile strength of V16 variant could be the use of both types of polypropylene waste in the matrix. BOPP and TNT waste have different thicknesses and textures which improves the homogeneity of the mixture with the polyester reinforcement. Irrespective of the matrix type and content, when compared with OSB tensile strength (5.68 MPa in longitudinal direction), the composite materials show an increased tensile strength by 33 % to 373 %.

Figure 5 shows the breaking elongation of investigated composite materials. Generally, an increase in the matrix content leads to an increase in the elongation at break of composite materials. For a given matrix content, the virgin polypropylene based-composite materials presented the lowest values of breaking elongation. The blend of PP fibres and PES scraps is more uneven than the other matrix/reinforcement blends because of the differences between the dimensions and volume of the two components. A comparison between composite materials and OSB highlights values of breaking elongation of composite materials higher by at least 595 % than the values of OSB breaking elongation. Wood has low elongation at break in comparison with both PP matrix and PES reinforcement.

The bending strength of composite materials using virgin PP, BOPP waste, TNT waste and 50/50 BOPP/TNT waste as matrix and PES woven fabric scraps as reinforcement is presented in figure 6. The aim of this research is to validate the possibility to

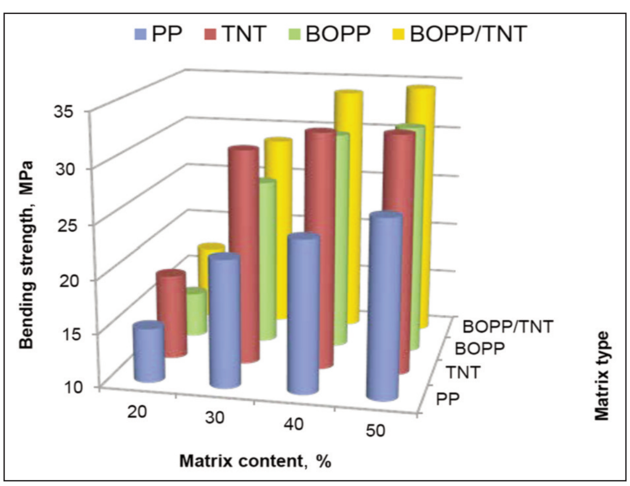


Fig. 6. Bending strength of composite materials

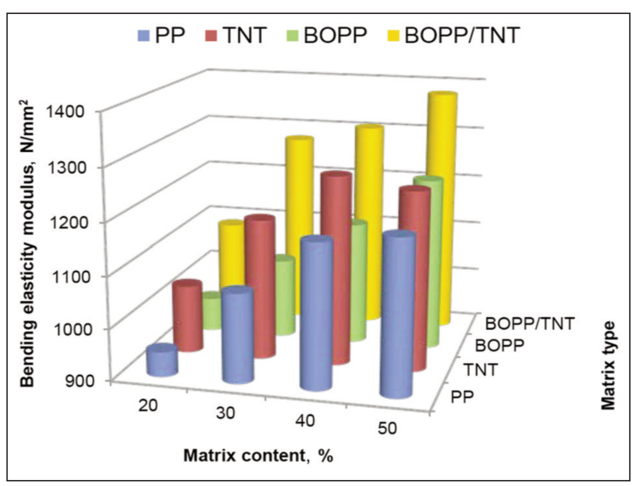


Fig. 7. Bending modulus of elasticity of composite materials

use PES woven scrap waste and PP waste in order to obtain composite materials that have similar characteristics with OSB. Except for the composite materials obtained with a matrix content of 20% that show bending strength lower than the requirements set out in standard for OSB (22 MPa in longitudinal direction), all the other variants of composite materials have a bending strength up to 56.8 % higher than the OSB standard requirements (table 3).

As seen in figure 7, an increase in the matrix content leads to an increase in the bending modulus of elasticity. The bending modulus of elasticity is the only characteristic of composite materials that has lower values than those of OSB, but this could be an advantage in such applications as furniture elements.

CONCLUSIONS

The results of the study show that the recycling of woven fabric scraps into reinforcements of polypropylene waste-based composites is a viable solution for recycling of both post-consumer and pre-consumer textile waste. The use of virgin polypropylene fibres as matrix brings no advantage to the mechanical characteristics of composite materials, all the more so as their price is higher than the price of polypropylene based waste. Composite materials with 50/50 matrix/reinforcement ratio show the best mechanical properties. Taking into account that PES woven fabric scraps are difficult to shred, the aim is to embed in the composite material an amount as large as possible of this category of waste. The TNT and BOPP waste can be reused in the same application as their original one. Therefore, the recommended percent of matrix is 30–40 % due to the fact that the composite materials with this matrix content fulfil the requirements set out in standard for OSB mechanical characteristics.

Taking into consideration the short technological flow, the low costs of raw materials and the solutions provided to environmental issues, the polypropylene waste-based thermoformed composite materials constitute a new solution for the sustainable replacement of fibreboards or oriented strand boards (OSB) used both in construction applications and furniture industry.

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