Arch. Metall. Mater. **69** (2024), 4, 1637-1642

DOI: https://doi.org/10.24425/amm.2024.151435

M.A. PLATON[1], O. NEMES[1*]

FIBREGLASS REINFORCEMENT INFLUENCE ON THE MECHANICAL BEHAVIOUR OF AN ABS – PMMA – FIBREGLASS COMPOSITE MATERIAL

This study's aim is to provide detailed information on how to control the mechanical behaviour of a short fibre unoriented composite material and adapt it for various applications. This study focusses on the challenging problem of recycling fibreglass waste mixed with thermoplastic polymers. The used method was thermoforming; preliminary studies have indicated this method as the most suitable for closing the loop in a manufacturing process – under the principles of a circular economy. Although this method is sustainable for this type of mixed waste, the research process is at an early stage and further studies and characterisations are required. From the data collected so far, this recycling method is the most efficient, both energetically and considering the added value of the final product. The results are encouraging and indicate a predictable behaviour of the studied reinforced composite material.

Keyword: Polymers; composite material; recycling; sustainability; waste

1. Introduction

Polymethyl-methacrylate (PMMA) and acrylonitrile-butadiene-styrene (ABS) are versatile polymers widely utilized in industries such as aerospace and automotive [1-4]. This study addresses the technical challenges associated with reinforcing a composite material consisting of non – oriented short fibres. The raw material employed in the production of the bathtubs comprises sheets of thermoplastic polymers PMMA and ABS, with proportions of 10% and 90%, measuring 120×180×2.5 mm. To reinforce the bathtubs, roving – shaped short fibreglass, mixed with polyester resin is robotically applied, using a process known as simultaneous projection. After the deburring process of the bathtubs, the waste, containing the polymers and short fibreglass fibres, is thermoformed for research purposes. Due to the variable composition and difficult control of constituents, the mechanical behaviour of the newly thermoformed material becomes unpredictable. The matrix of the material comprises polymers and fibreglass as reinforcement. Analysis of the internal morphology revealed random fibreglass distribution with tendencies for clustering and material porosity. These characteristics make it challenging to define and control the mechanical behaviour. To regulate the mechanical properties, fibreglass meshes were employed, and the plates were thermoformed with 1 to 3 meshes. The meshes are made of fibreglass roving with a diameter of 0,5 to 1 mm and the size of a grid is 0,5×0,5 mm.

This study primarily focuses on recycling thermoforming waste generated in the manufacturing process of bathtubs. Thermoforming is considered a superior and circular method from an economic perspective compared to traditional recycling options. Correia, Almeida, and Figueira argue against landfilling this type of waste, which is considered the least preferable option. Countries such as Germany have already banned the landfilling of composite waste. Among all the recycling methods for the studied waste type (as depicted in TABLE 1), thermoforming proves to be the most advantageous in terms of environmental impact reduction, decreased pollution levels, and increased economic value. Recent research directions focus on solving energy and environmental issues as long global policies are become increasingly sustainable [5-6]. The products obtained through thermoforming have significantly higher market value compared to the waste itself [7-12].

2. Experiment

The working hypothesis assumes that both, the type of reinforcement material, and its shape, including the dimension

---

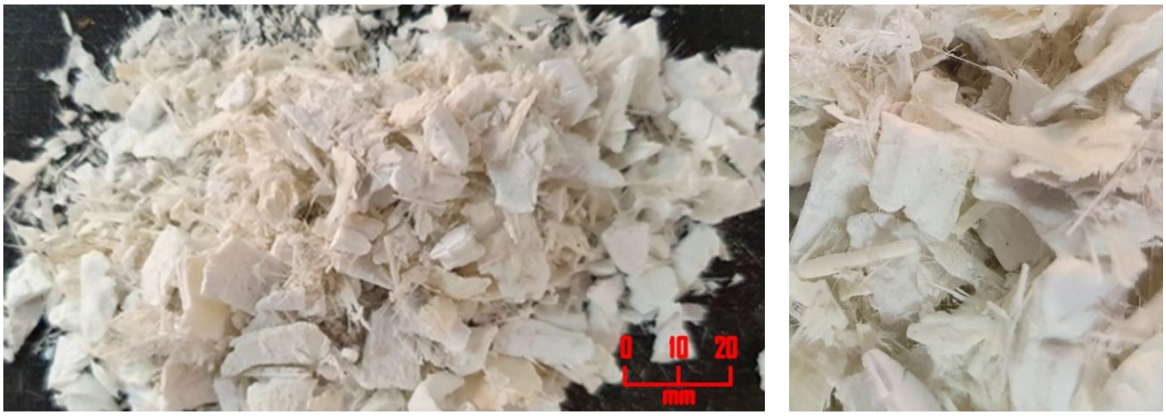
[1] TECHNICAL UNIVERSITY OF CLUJ-NAPOCA, FACULTY OF MATERIALS AND ENVIRONMENTAL ENGINEERING, BD. MUNCII 103-105 400641, CLUJ-NAPOCA, ROMANIA

* Corresponding author: ovidiu.nemes@sim.utcluj.ro

TABLE 1

Advantages and disadvantages of the main recycling methods [11]

Recycling Method	Pyrolysis	Solvolysis	Cement filler	Incineration in the cement manufacturing process	Mechanical recycling	Thermoforming
Advantages	Technology is easily available on the market	Technology is easily available on the market	Quantity savings can be up to 15%.	Waste generates added value by being added to cement	Products resulting from recycling can be reused	Finished product with high added value. Reduced energy costs compared to pyrolysis, solvolysis and incineration
Disadvantages	High energy costs. Fibres lose mechanical strength	High energy costs. Low value of waste	Under-use of waste	The process generates pollution. Low added value	Fibreglass has low mechanical properties	Unpredictable mechanical behaviour of the products obtained



a) b)

Fig. 1. Raw materials: a) Mixed waste; b) Waste details

of the flakes, are suitable for matrix – reinforcement interactions and capable of providing resistance to mechanical tests. It is also expected that the mechanical strength will gradually increase with the number of reinforcements meshes used.

To maximize the reinforcement effect, it is essential for the matrix – reinforcement interactions to be as closely linked as possible. This aspect is influenced by the working temperature and viscosity of the polymers.

For the production process of the new composite material, 150 grams of mixed waste were used for each plate. The resulting plates have a diameter of 142 mm and a thickness of 10 mm. The thermoforming system, depicted in Fig. 2, consists of a cylindrical mold with two movable heated plates situated at the top and bottom. The working pressure ranged from 3.17 to 9.55 MPa, while the working temperature varied between 130 to 150°C. The chosen working temperature range considering the glass transition temperature of the constituents, 105°C for ABS and PMMA. This range allows operation in the highly elastic zone and prevents the constituents from melting in the thermoforming system, considering their respective melting points of 204 to 238°C for ABS and 130°C for PMMA [13].

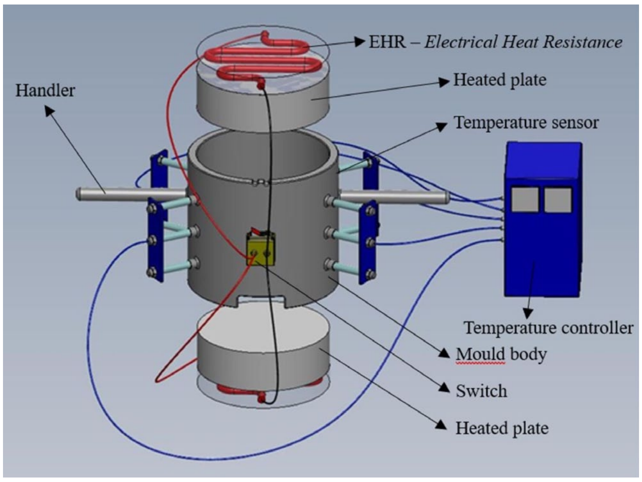


Fig. 2. Moulding system

Considering that the primary objective of thermoforming the waste is to achieve a solid material with controlled mechanical properties, it is necessary to subject it to testing under the most common forces that a material with a mechanical stiffening role must endure tensile, compression, and flexural forces. In the experimental section, the mechanical testing machine Instron model 4466 with a maximum capacity of 10 kN was used for the mechanical tests.

The tensile test is a destructive procedure that measures the force required to break a specimen and the extent to which the specimen stretches or elongates until it reaches the breaking point. This test provides data on various parameters including tensile strength (yield and fracture), tensile modulus, tensile stress, elongation, percentage elongation at yield, and elongation at break in percent. The tensile strength (σ_t) is calculated using the following relation:

$$\sigma_t = \frac{F_{\max}}{a \times b} \tag{1}$$

Where: $F_{\max}$ – force at break [N]; a, b – length and width of the specimen [mm].

The compressive strength refers to the material's capacity to withstand direct pressure from an applied compressive force. The compressive strength (σ_m) is calculated as the ratio of the maximum compressive force ($F_{\max}$) reached at the point of inflection or rupture to the initial cross-sectional area of the specimen when the relative deformation ε is less than 10%.

The compressive strength is calculated using the relations:

$$\sigma_m = \frac{F_{\max}}{a \times b} \tag{2}$$

Where: $F_{\max}$ – force at break [N]; $a \times b$ – initial cross – sectional area of the specimen [mm^2].

The relative deflection is determined using the relation:

$$\varepsilon_m = \frac{X_m}{d_0} \cdot 100 [\%] \tag{3}$$

Where: X_m – displacement corresponding to the maximum force achieved [mm]; d_0 – initial thickness of the specimen [mm].

The flexural test involves subjecting a specimen to a bending force, typically applied at three or four points along its length. By measuring the deflection and load at different points, it is possible to determine the material's flexural strength, flexural modulus, and other related parameters. The flexural test provides valuable insights into the material's behaviour under bending conditions and is particularly relevant for evaluating the mechanical performance of composite materials.

The relation used for the flexural strength is:

$$F_S = \frac{3 \times P \times L}{2 \times b \times d^2} \tag{4}$$

Where: P – test load [N]; b – specimen width [mm]; L – the opening between the test points [mm]; d – specimen thickness [mm] [14].

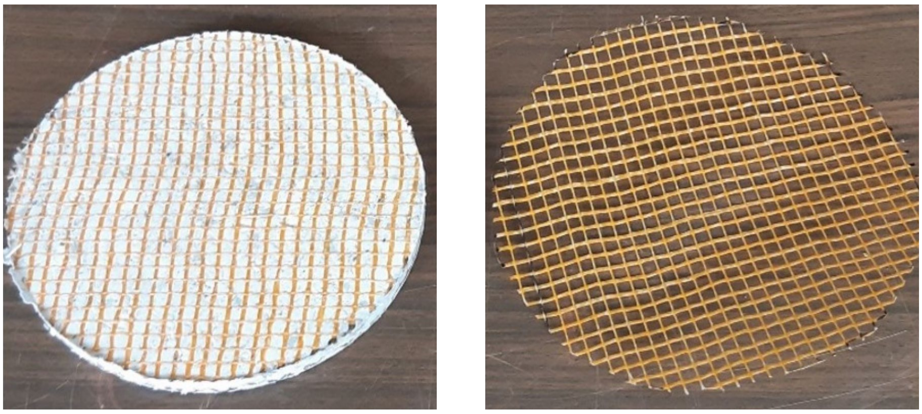
TABLE 2

Used standards for mechanical tests [11]

Mechanical test	Used standard
Flexural	ASTM D7264 / D7264M-15 [19]
Tensile	ASTM D3039 / D3039M-17 [20]
Compression	ASTM D3410 / D3410M-16 [21]

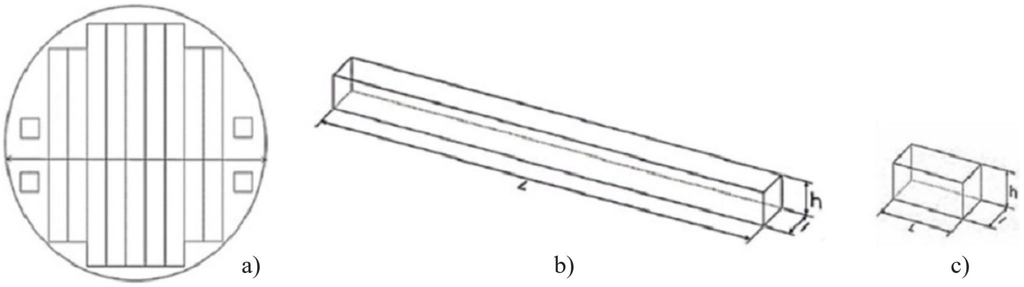
3. Results and discussion

The results are listed in TABLE 3. To enhance and regulate the mechanical behaviour of the plates, various configurations were employed during thermoforming, involving the insertion of fibreglass meshes. These meshes were positioned in the middle section of some plates, while others had two meshes located on



a) b)

Fig. 3. Composite plate: a) Plate with incorporated mesh; b) Mesh used for reinforcement



a) b) c)

Fig. 4. Used specimen design: a) Cutting plan; b) Specimen shape for tensile and flexural tests; c) Specimen shape for compression test

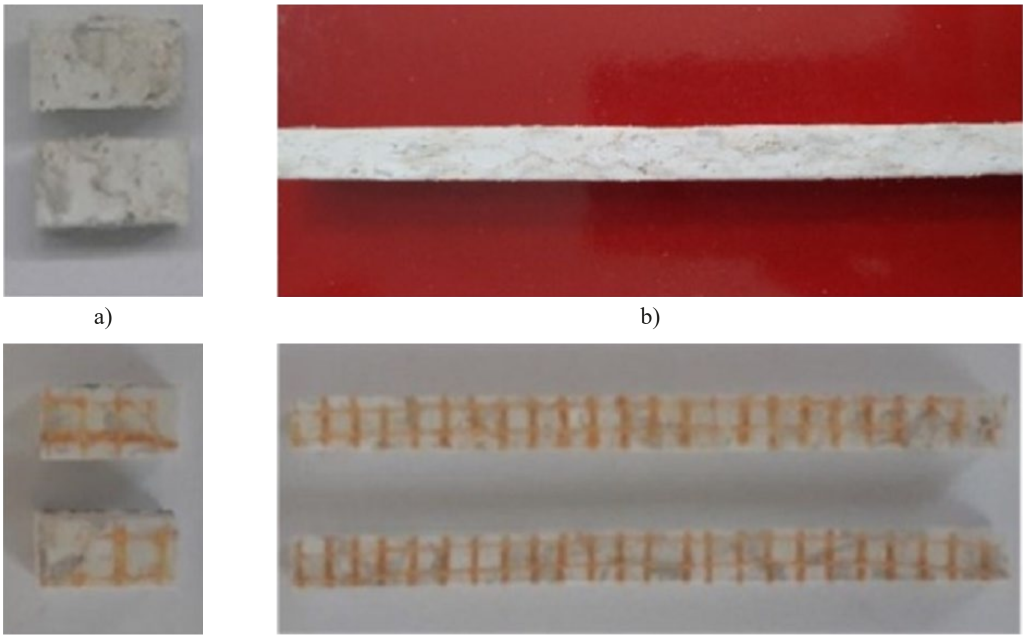

a) b) c) d)

Fig. 5. Testing samples: a) Waste samples for compression test; b) Meshed samples for compression test; c) Waste samples for tensile and flexural test; d) Meshed samples for tensile and flexural test

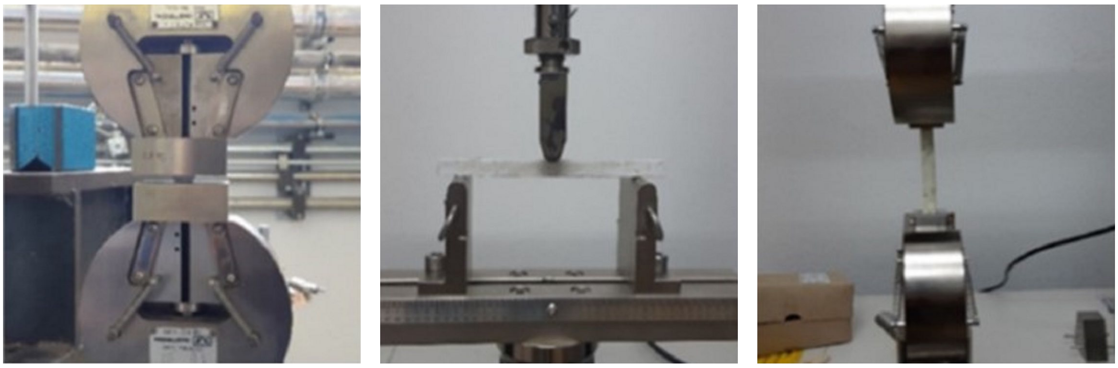

a) b) c)

Fig. 6. Testing equipment: a) compression; b) flexural; c) tensile

the top and bottom, and further some plates had three meshes situated on the top, bottom, and middle sections. Additionally, the average values for the mechanical tests of plates without mesh reinforcements were included in the table for comparison purposes.

A clear and consistent enhancement in the mechanical behaviour is evident across all categories of mechanical tests, with percentage improvements ranging from 40% to 100%. The substantial improvement of the mechanical behaviour is reflected in the samples with 1 mesh compared to those without meshes (43% in flexural, 54% in tensile and 53% in compressive behaviour). Further, the increase still ranges, in those with 2 meshes compared to those with 1 mesh and those with 3 compared to those with 2 depending on the degree of porosity. Studies focused on the internal morphology of the material (Computer Tomography) have shown that the studied material is porous [14]. The porosity is determined by the thermal behaviour of the main constituent – ABS under the working temperatures (130 to 150°C) [15-16]. Thus, the variable porosity of the material influences its mechanical behaviour. Even with this porous-induced behaviour, the reinforcement behaves predictably, and the mechanical strength increases proportionally to the number of meshes used.

TABLE 3

Results obtained for mechanical testing

Mechanical test	**Average value σ_r for samples without meshes [MPa]**	**Number of meshes used**	**Average value σ_r for samples with meshes [MPa]**
Flexural	16.31	1	28.92
		2	35.71
		3	36.44
Tensile	5.53	1	12.11
		2	12.96
		3	15.36
Compression	24	1	51.50
		2	56.37
		3	58.63

4. Conclusions

The obtained results validate the hypothesis that, despite the lack of homogeneity [17] and also the porosity of the studied waste the plate with fibreglass meshes exhibit a predictable behaviour and the mechanical strength increases with the number of meshes used. The percentage comparison from TABLE 4 demonstrates that the behaviour can be controlled.

TABLE 4

The percentage analyses of the results

Number of meshes used	Average value σ_r [MPa]	Mechanical behaviour improvement [%]
0	**16.31**	—
1	28.92	43.60
2	35.71	19.01
3	36.44	2
0	**5.53**	—
1	12.11	54.33
2	12.96	6.55
3	15.36	15.62
0	**24**	—
1	51.50	53.39
2	56.37	8.63
3	58.63	3.85

The specific mechanical behaviour of the composite material plates is correlated with the properties of the constitutive elements. ABS properties are determined by factors like the dispersion, size, and shape of the elastomers [22-25] and the behaviour of the composite material depends on the processing parameters [26-27].

The novelty of this work lies in the recycling method, or rather, upcycling, where the output material is superior to the input material (the studied waste). In addition, the successful method of reinforcing the plates adds to the novelty of the research. Future studies will focus on determining, analysing, and controlling the internal interactions between the matrix and the reinforcement to achieve a composite material that is superior and predictable in its mechanical behaviour. The findings from this research pave the way for further advancements in the field of composite material recycling and upcycling, with applications in various industries that demand high-performance materials with controlled mechanical properties.

Acknowledgments

Research Contract No. 19249/05.08.2020 “Ecological method for recyclable wastes valorization” – ECOWASTE. This paper was financially supported by the Project “Network of excellence in applied research and innovation for doctoral and postdoctoral programs/InoHubDoc”, project co-funded by the European Social Fund financing agreement no. POCU/993/6/13/153437.

REFERENCES

[1] A. Baker, S. Dutton, D. Kelly, Astronautics Composite materials for Aircraft Structures, Blacksburg (2004).

[2] H. Iancău, O. Nemeș, Materiale Compozite: concepție și fabricație, Cluj-Napoca (2003).

[3] F. Ştefănescu, G. Neagu, G. A. Mihai, Materialele viitorului se fabrică azi. Materialele compozite, București (1996).

[4] P. Bere, G. Marin, Fabricația materialelor compozite, Chișinău (2018).

[5] Noor Fifinatasha Shahedan, Mohd Mustafa Al Bakri Abdullah, Norsuria Mahmed, Andri Kusbiantoro, Sam Tammas-Williams, Long-Yuan Li, Ikmal Hakem Aziz, Petrică Vizureanu, Jerzy J. Wysłocki, Katarzyna Błoch, Marcin Nabiałek, Properties of a New Insulation Material Glass Bubble in Geopolymer Concrete. Mater. **14**, 809 (2021).
DOI: https://www.mdpi.com/1996-1944/14/4/809

[6] Liew Yun Ming, Andrei Victor Sandu, Heah Cheng Yong, Yuyun Tajunnisa, Siti Fatimah, Azzahran Ridho Bayuji, Mohd Mustafa Al Bakri Abdullah, Petrica Vizureanu, Kamarudin Hussini, Tan Soo Jin, Foo Kai Loong, Compressive Strength and Thermal Conductivity of Fly Ash Geopolymer Concrete Incorporated with Lightweight Aggregate, Expanded Clay Aggregate and Foaming Agent. Rev. Chim. **70**, 4021-4028 (2019).
DOI https://doi.org/10.37358/RC.70.19.11.7695

[7] J.R. Correia, N.M. Almeida, J.R. Figueira, Recycling of FRP composites: reusing fine GFRP waste in concrete mixtures. Jou. of Clean. Prod. **19**, 1745-1753 (2011).
DOI: https://doi.org/10.1016/j.jclepro.2011.05.018

[8] P. Asokan, M. Osmani, A.D.F. Price, Assessing the recycling potential of glass fibre reinforced plastic waste in concrete and cement composites. Jou. of Clean. Prod. **17**, 821-829 (2009).
DOI: https://doi.org/10.1016/j.jclepro.2008.12.004

[9] A. Yazdanbakhsh, L.C. Bank, Y. Tian, Mechanical processing of GFRP waste into large-sized pieces for use in concrete. Recyc. **3** (1), 8 (2018).
DOI: https://doi.org/10.3390/recycling3010008

[10] T. Francesca, S. Surendra, Effect of low dosages of waste GRP dust on fresh and hardened properties of mortars. Constr. and Build. Mat. **47**, 1532-1538 (2013).
DOI: https://doi.org/10.1016/j.conbuildmat.2013.06.086

[11] T. Francesca, Effect of low dosages of waste GRP dust on fresh and hardened properties of mortars: Part 2. Constr. and Buil. Mat. **24**, 1539-1543 (2013).
DOI: https://doi.org/10.1016/j.conbuildmat.2013.06.086

[12] M. Santos Ribeiro, A. Fiuza, A. Ferreira, M. Lurdes Dinis, A.C.M. Castro, J.P. Meixedo, M.R. Alvim, Recycling Approach towards Sustainability Advance of Composite Materials. Ind. Recyc. **1**, 178-193 (2016).
DOI: https://doi.org/10.3390/recycling1010178

[13] V. Goodship, Management, recycling and reuse of waste composites, Cambridge (2010).

[14] M.A. Platon, Studii și cercetări privind reciclarea deșeurilor în amestec fibră de sticlă și rășini organice. Universitatea Tehnică Cluj-Napoca, Cluj-Napoca, RO, 400114, September.

[15] F. Hermouet, T. Rogaume, E. Guillaume, F. Richard, D. Marquis, X. Ponticq, Experimental characterization of the reaction-to-fire of an Acrylonitrile-Butadiene-Styrene (ABS) material using controlled atmosphere cone calorimeter. Fire Saf. Jour. **121**, 103291 (2021). DOI: https://doi.org/10.1016/j.firesaf.2021.103291

[16] P. Vizureanu, N. Cimpoesu, V. Radu, M. Agop, Investigations on Thermal Conductivity of Carbon Nanotubes Reinforced Composites. Jou. of Ther. En. Gen., Tran., Stor., and Conv. **28** (1), 37-57, (2015). DOI: https://doi.org/10.1080/08916152.2013.803176

[17] M.A. Platon, O. Nemeș, A.-E. Tiuc, C. Vilău, C.M. Dudescu, S. Pădurețu, The Influence of Process Parameters on the Mechanical Behaviour of a Composite Material Made from Mixed Plastic Wastes. Arch. Metall. Mater. **67** (4), 1235-1241 (2022). DOI: https://doi.org/10.24425/amm.2022.141047

[18] O. Nemeș, Analiza, modelarea si proiectarea ecologică a materialelor și structurilor complexe. Cluj-Napoca (2016).

[19] ASTM D7264 / D7264M-15, Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials, ASTM International, West Conshohocken, PA (2015). www.astm.org

[20] ASTM D3039 / D3039M-17, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International, West Conshohocken, PA (2017). www.astm.org

[21] ASTM D3410 / D3410M-16, Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading, ASTM International, West Conshohocken, PA (2016). www.astm.org

[22] A. Casale, O. Salvatore, G. Pizzigoni, Measurement of Aging Effects of ABS Polymers. Pol. Eng. and Sci. **15**, 286-293 (1975). DOI: https://doi.org/10.1002/pen.760150410

[23] E. Scalco, T.W. Huseby, L.L. Blyler Jr., Some Viscoelastic Properties of ABS Polymer. Jour. of App. Pol. Sci. **12**, 1343-1353 (1968). DOI: https://doi.org/10.1002/app.1968.070120606

[24] B.E. Tiganis, L.S. Burn, P. Davis, A.J. Hill, Thermal degradation of acrylonitrile–butadiene–styrene (ABS) blends. Pol. Degrad. and Stab. **76**, 425-434 (2002).
DOI: https://doi.org/10.1016/S0141-3910(02)00045-9

[25] S. Zangana, J. Epaarachchi, W. Ferdous, J. Leng, A novel hybridised composite sandwich core with Glass, Kevlar and Zylon fibres – Investigation under low-velocity impact. Inter. Jour. of Imp. Engin. **137**, 103430 (2020).
DOI: https://doi.org/10.1016/j.ijimpeng.2019.103430

[26] W. Ferdous, T. Ngo, K.Q. Nguyen, A. Ghazlan, P. Mendis, A. Manalo, Effect of fire-retardant ceram powder on the properties of phenolic-based GFRP composites. Comp. Part B. **155**, 414-424 (2018).
DOI: https://doi.org/10.1016/j.compositesb.2018.09.032

[27] M. Nasraoui, P. Forquin, L. Siad, A. Rusinek, A. E. Dossou, DYMAT-International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading **2**, EDP Sciences, Bruselles (2009).