Polish Society of Composite Materials
Polskie Towarzystwo Materiałów Kompozytowych

23: 2 (2023) 84-88

COMPOSITES THEORY AND PRACTICE
ISSN: 2084-6096
ISSN (online): 2299-128X

Jakub Smoleń*, Kaja Orzechowska, Klaudia Tomaszewska, Krzysztof Stępień Aleksander Peryt, Tomasz Pawlik

Silesian University of Technology, Faculty of Materials Engineering, ul. Z. Krasińskiego 8, 40-019 Katowice, Poland
** Corresponding author: E-mail: jakub.smolen@polsl.pl*

Received (Otrzymano) 22.03.2023

POLYMER CONCRETE FILLED WITH MILLED CAR WINDSHIELD AND GFRP WASTE

The paper describes the process of preparing polymer concrete consisting of waste materials. The matrix was a polyester terephthalic resin produced from PET bottles, while the fillers were laminated car glass with PVB foil, as well as GFRP waste. The preparation of the fillers consisted in producing appropriate fraction sizes. Using a cross-beater mill, a fine fraction with an average size of 2 mm was obtained. The coarse fraction was achieved after the initial grinding process with a size greater than 2 mm. Two series of samples were created from the prepared materials, with different contents of resin, car glass and GFRP. The compression test and the three-point bending test showed that the obtained polymer concrete containing 1 vol.% GFRP has an average compressive strength of 51.75 MPa and an average flexural strength of 20.49 MPa. The polymer concrete with 2 vol.% GFRP showed an average compressive strength of 75.63 MPa and an average flexural strength of 17.89 MPa. The Archimedes method results showed that the samples with the amount of 1 vol.% GFRP reached 1.11% open porosity and the samples with 2 vol.% GFRP achieved 1.23%. The use of waste materials such as windshields with PVB foil and GFRP composites can be used as fillers in polymer concrete technology.

Keywords: **polymer concrete, mechanical recycling, windshield glass with PVB, GFRP waste**

INTRODUCTION

Among the most commonly employed engineering materials in construction, concrete is used. It is less expensive than other construction materials, it is durable and has good formability. The durability of concrete is represented by a set of properties that ensure a specific service life, reliability and stability over time [1].

Traditional concrete has some limitations, among the most important there are: low impact strength, insufficient flexural strength, relatively high water permeability, low modulus of elasticity, insufficient thermal insulation, chemical corrosion and difficulty in forming complex shapes [2]. With the appropriate modifications, it is possible to minimize some limitations depending on the area of application. A limitation may also be the long setting time of concrete, for example, the time when CEM III (EN 197-1: a specially formulated blend of traditional cement and a minimum of 50% ground granulated blast-furnace slag), acquires the maximum mechanical properties is 28 days [3]. It is beneficial to shorten the concrete setting time due to the economy of the process. However, during cement production, large amounts of carbon dioxide are emitted into the atmosphere [4].

According to the Portland Cement Association, the production of 1000 kg of concrete emits 102.5 kg of carbon dioxide into the atmosphere [5]. All of that comes from reducing limestone ($CaCO_3$) to lime (CaO)

$$CaCO_3 \xrightarrow{T} CaO + CO_2 \tag{1}$$

Because of the insufficient mechanical properties of traditional cement-based concrete, scientists between 1950 and 1960 started experimental research to find a different binder than cement. During their attempts, polymer concrete (PC) was developed [6, 7]. It is a material from the group of polymer matrix composites (PMCs). In this material, cement is replaced or partly replaced with a polymer – typically resin. The polymer in this material works as a binder or elastic phase that increases the impact strength. It was also concluded that the modification of concrete with polymers can eliminate the insufficient properties of this material [8-10]. Polymer concrete became well known in 1970 when it began to be used in repairs, thin overlays and floors, and precast components [11].

PCs are characterized as more durable, corrosion and chemical-resistant materials with low open porosity and low water permeability and they are excellent construction materials because of their low weight – mechanical properties ratio. Moreover, because of the elastoplastic character of the polymer matrix, they have sufficient vibration-damping properties [12, 13]. Owing to those properties, PCs are frost-resistant and can work outdoors [14, 15]. Another advantage is the time when it is possible to test polymer concrete, which takes one day.

Traditional concrete, besides cement, has fillers, typically sand and gravel with coarse and fine fractions to eliminate free spaces between the grains, which allows better connection of the fillers with the binder and the achievement of structural compaction [16]. In recent years, there has been an increase in interest in recycling focused on replacing traditional aggregates with waste materials, as evidenced by numerous scientific publications in this field [17, 18]. One of the difficult wastes is car windshields, commonly made out of safety glass. This glass is made out of two glass panels with polyvinyl butyral (PVB) foil in between [19]. The most important feature of PVB foil is to prevent instant fragmentation at the moment of impact. Moreover, its transparency provides visibility [20]. According to data from The International Organization of Motor Vehicle Manufacturers (OICA), global car production in 2021 was about 80 million cars per year [21]. The total worldwide amount of PVB film produced for the automotive and construction industries is estimated at around 170 million kg per year [22]. The problem with recycling this material is complex. Car glass waste is undesirable in glassworks using glass cullet as a raw material because the PVB film during thermal decomposition leads to the formation of pores, which contribute to significant deterioration of the glass properties. As a consequence, car window waste contaminated with PVB film is not directly used in glassworks and ends up in landfills. In the last few years, attempts have been made to lower the cost of PCs by replacing raw fillers with waste materials [23-27].

The next step in the development of PCs is to find a way to reinforce them. Attempts were made using short-glass fibers [17]. The article describes the effect of adding milled glass fiber reinforced polymer (GFRP) waste containing short glass fibers. This material finds its application in every branch of the industry from aerospace engineering to power engineering.

In this work, terephthalic polyester resin based on waste PET bottles was used to obtain polymer concrete. Waste laminated glass from the automotive industry and GFRP waste were used to confirm the application potential of replacing traditional aggregates with waste materials that are difficult to recycle. Moreover, an attempt was made to show that it is possible to make material using waste, which has better properties than cement-based concrete. Due to the better mechanical properties of polymer concrete than traditional concrete, thin-walled products are made, thereby decreasing the carbon footprint made in the transportation of goods.

MATERIALS AND METHODS

Estromal 14.PB-06 (LERG S.A., Poland) terephthalic polyester resin, catalyzed with Metox 50 (Oxytop Sp. z o. o., Poland) and a 10% cobalt accelerator (ILT Elżbieta Szymczak, Poland), was selected as the matrix material. The mass ratio of resin to hardener and cobalt accelerator was 1000:10:1. The volume ratio of the coarse aggregates and the fine aggregates was constant for all the samples and was 1:1. Two series of samples with a variable content of GFRP waste were made, according to Table 1.

TABLE 1. **Percentage by volume of individual components**

	Coarse aggregates (glass waste with PVB foil) [vol.%]	Fine aggregates (glass waste with PVB foil) [vol.%]	GFRP waste [vol.%]	Polyester resin [vol.%]
Series A	37	37	1	25
Series B	35	35	2	28

The fillers were waste windshields with PVB foil and GFRP waste. These materials were milled into appropriate fractions. The coarse fraction (Fig. 1) was achieved after the initial milling process with a particle size greater than 2 mm. Using a cross-beater mill, a fine fraction (Fig. 2) with an average particle size below 2 mm was obtained.

Fig. 1. Coarse fraction of fillers (average grain size above 2 mm)

Fig. 2. Fine fraction of fillers (average grain size below 2 mm)

The samples were produced in a multi-step process. Firstly, the fillers were prepared in the selected ratio (Table 1): GFRP waste was added to the waste glass windshields and mixed mechanically. After this, the materials for the matrix were mixed in the following order: resin, cobalt accelerator and hardener. Then the resin was added to the fillers. The next step was to mix the composition with an electrical concrete mixer (Atika RL1400). At the end, the mass was cast to molds and cured in room temperature (about 21°C).

The compression test of the samples was carried out in accordance with the PN-EN ISO 604: 2006 standard on an MTS-810 testing machine with the strain rate of 10 mm/min until complete destruction of the sample (Fig. 5). A three-point bending test was carried out according to the PN-EN ISO 14125 standard on rectangular specimens my means of an INSTRON 4469 with strain rate 10 mm/min and spacing of supports 190 mm. In order to determine the open porosity, density and water absorption, the Archimedes test was performed. The shape and geometry of the samples are shown in Figure 3.

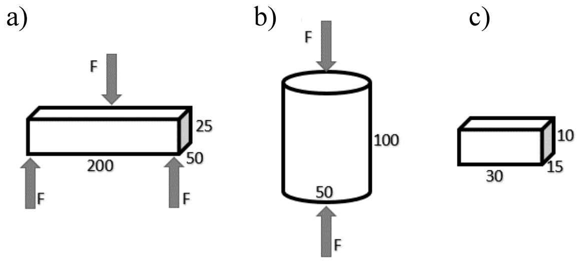

Fig. 3. Sample dimensions: a) three-point bending test, b) compressive test, c) Archimedes test

RESULTS AND DISCUSSION

Compression test results

The results of the compression test are shown in Figure 4. According to the EN1992-1-1 standard, concrete marked C16/20 has a minimum compressive strength of 16 MPa for cylindrical samples and 20 MPa for cubic samples. A comparison of the obtained test results of polymer concretes with the properties of typical cement concretes indicate a more favorable compressive strength for the polymer concrete. The samples with the addition of 1 vol.% GFRP waste had an average compressive strength of 51.75 MPa, while the samples with 2 vol.% GFRP waste had an average compressive strength of 75.63 MPa.

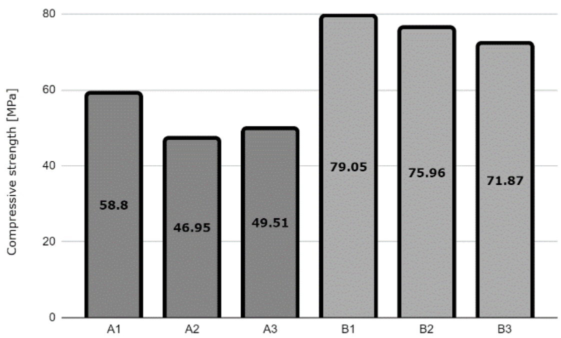

Fig. 4. Compressive strength of tested polymer concrete – designations according to Table 1

The increase in the content of short glass fibers (derived from milled GFRP waste) in polymer concrete leads to improvement in the compressive strength, which is attributed to the more compacted structure of the polymer concrete containing a higher amount of GFRP waste. The large surface of the glass particles creates internal notches, contributing to the reduction in mechanical strength and a large dispersion of the obtained results. During the test, the first breakage happened at the edges of glass pieces with a sizable surface because glass does not have good wettability by resin. A further increase in the compression force caused complete failure of the sample (Fig. 5).

Fig. 5. Series B sample after compression test

Three-point bending test results

All the samples had similar flexural strength (Fig. 6). It can be concluded that the differences between the 1 and 2 vol.% addition of milled GFRP waste do not have a significant impact on the flexural strength of polymer concrete. The PC samples with the 1 vol.% addition of GFRP waste (Fig. 7A) showed slightly higher flexural strength, on average 20.49 MPa, than the samples with the 2 vol.% addition of GFRP waste (Fig. 7B) – 17.89 MPa. All the samples demonstrated higher flexural strength than cement-based concrete (class C 35/45), which has a flexural strength of over 5.5 MPa.

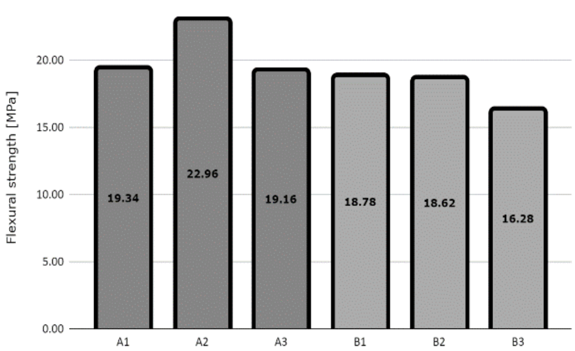

Fig. 6. Flexural strength of tested polymer concrete – designations according to Table 1

Although the results for both series are similar, differences in the crack character were observed. The samples with the higher content of the GFRP filler maintained their overall integrity, with only small cracks on the surface (a scratch) appearing upon sample failure (Fig. 7B). This suggests that the increased content of short glass fibers (derived from milled GFRP) exceeds the critical length, positively influencing the observed structural strengthening effect. Such behavior of the material during destruction is beneficial because it protects the users against loss of health and collapse of the structure.

Fig. 7. Samples after three-point bending test. A – A sample, B – series B sample

Archimedes test results

The results obtained by the Archimedes method showed that the increase in the content of GFRP waste in polymer concrete increases the open porosity.

TABLE 2. **Archimedes test results**

	Open porosity [%]	Apparent density [g/cm^3]	Water absorbability [%]
Series A	1.11 ± 0.23	2.03 ± 0.22	0.60 ± 0.13
Series B	1.23 ± 0.28	1.99 ± 0.01	0.71 ± 0.12

The open porosity in the series with the 1 vol.% addition of milled GFRP is 1.11% and with the 2 vol.% addition of milled GFRP it is 1.23%. The water absorption of the material also increases in parallel with the increase in porosity. The differences in water absorption between the series are not significant; for the series with the 1 vol.% GFRP addition it is 0.60%, and for the series with 2 vol.% GFRP addition it is 0.71. The density of both the polymer concretes is similar and is about 2000 kg/m^3.

CONCLUSIONS

- An increase in the volume fraction of milled GFRP waste leads to an increase in compressive strength, where the samples with 1 vol.% GFRP have an average compressive strength of 51.75 MPa, and the samples with 2 vol.% GFRP – 75.63 MPa.
- The increase in the content of GFRP in the structure of polymer concrete is unfavorable for the bending strength, which may result from the inhomogeneity of the material or insufficient wettability of the fibers. The 1 vol.% GFRP samples reached the bending strength of 20.49 MPa, and the samples with 2 vol.% GFRP – 17.89 MPa.
- The obtained polymer concrete has a compressive strength similar to that of some traditional concretes (16-70 MPa) and several times higher bending strength than traditional concrete, for which the bending strength is about 5 MPa. The mechanical strength of polymer concrete based on waste materials is therefore higher than that of traditional cement-based concrete.
- The obtained results prove low porosity (the samples with 1 vol.% GFRP – 1.11%, and the samples with 2 vol.% GFRP – 1.23%), which is an advantage of the obtained material and makes the frost resistance of the tested polymer concrete better than in the case of traditional concretes.
- It has been proven that a fully functional construction material can be made from waste materials such as car windshields with PVB foil and GFRP. Also, fillers made out of those wastes can be used as an alternative for raw materials (sand, gravel).
- The samples with the higher content of short glass fibers from GFRP waste in the bending test did not show a violent crack leading to disintegration of the material. A scratch appeared on the surface, indicating damage to the polymer concrete. The addition of GFRP ensures the integrity of the structure in the event of damage to the structure, which increases the safety of use. Even though polymer concrete is more expensive than traditional concrete, its mechanical properties allow the formation of complex products with thin walls.

REFERENCES

[1] Mather B., Concrete durability, Cement and Concrete Composites 2004, 26(1), 3-4, DOI: 10.1016/S0958-9465(02)00122-1.

[2] Marchand J., Samson E., Predicting the service-life of concrete structures – Limitations of simplified models, Cement and Concrete Composites 2009, 31.8, 515-521, DOI: 10.1016/j.cemconcomp.2009.01.007

[3] Jamroży Z., Beton i jego technologie, Wydawnictwo Naukowe PWN, Warszawa – Kraków 2000.

[4] Abdul M.I., Arumairaj P.D., Geopolymer concrete – a review, International Journal of Engineering Sciences & Emerging Technologies 2012, 1(2), 118-122.

[5] Portland Cement Association https://www.cement.org/docs/default-source/th-paving-pdfs/sustainability/carbon-foot-print.pdf (accessed 01.09.2022).

[6] Nodehi M., Epoxy, polyester and vinyl ester based polymer concrete: a review, Innovative Infrastructure Solutions (2022), 7(1), 64, DOI: 10.1007/s41062-021-00661-3.

[7] Barbuta M., Rujanu M., Nicuta A., Characterization of polymer concrete with different wastes additions, Procedia

Technology 2016, 22, 407-412, DOI: 10.1016/j.protcy.2016.01.069.

[8] Ohama Y., Handbook of Polymer-Modified Concrete and Mortars: Properties and Process Technology, William Andrew 1995.

[9] Kardon J.B., Polymer-modified concrete, Journal of Materials in Civil Engineering 1997, 9(2), 85-92, DOI: 10.1061/(ASCE)0899-1561(1997)9:2(85).

[10] Ollitrault-Fichet R., Gauthier C., Clamen G., Boch P., Microstructural aspects in a polymer-modified cement, Cement and Concrete Research 1998, 28(12), 1687-1693, DOI: 10.1016/S0008-8846(98)00153-7.

[11] Fowler D.W., Polymers in concrete: a vision for the 21st century, Cement and Concrete Composites 1999, 21(5-6), 449-452, DOI: 10.1016/S0958-9465(99)00032-3.

[12] Hop T., Betony polimerowe, Wydawnictwo Politechniki Śląskiej, Gliwice 1992.

[13] Figlus T., Kozioł M., Kuczyński Ł., Impact of application of selected composite materials on the weight and vibroactivity of the upper gearbox housing, Materials 2019, 12, 2517, DOI: 10.3390/ma12162517.

[14] Laustsen S., Hasholt M.T., Jensen O.M., Void structure of concrete with superabsorbent polymers and its relation to frost resistance of concrete, Materials and Structures 2015, 48, 357-368, DOI: 10.1617/s11527-013-0188-0.

[15] Bondarev B.A., Borkov P.V., Bondarev A.B., An outlook on the application of glass-reinforced plastic and polymer concrete components in bridge construction, Procedia Engineering 2016, 150, 1617-1622, DOI: 10.1016/j.proeng.2016.07.139.

[16] https://www.gorazdze.pl/pl/node/9722 (accessed 09.16.2022).

[17] Reis J.M.L., Ferreira A.J.M., Assessment of fracture properties of epoxy polymer concrete reinforced with short carbon and glass fibers, Construction and Building Materials 2004, 18(7), 523-528, DOI: 10.1016/j.conbuildmat.2004.04.010.

[18] Bulut H.A., Şahin R., A study on mechanical properties of polymer concrete containing electronic plastic waste, Composite Structures 2017, 178, 50-62, DOI: 10.1016/j.compstruct.2017.06.058.

[19] Mederski T., Gawdzik A., Recykling odpadów z szyb samochodowych i szkła budowlanego z folią PVB, Proceedings of ECOpole 2016, 10(2), 721-731, DOI: 10.2429/proc.2016.10(1)079.

[20] Tuchinda C., Srivannaboon S., Lim H.W., Photoprotection by window glass, automobile glass, and sunglasses, Journal of the American Academy of Dermatology 2006, 54(5), 845-854, DOI: 10.1016/j.jaad.2005.11.1082.

[21] OICA, The International Organization of Motor Vehicle Manufacturers, 2014, Available online: https://www.oica.net/category/production-statistics/2021-statistics/ (accessed on 01.09.2022).

[22] Šooš Ľ., Matúš M., Pokusová M., Čačko V., Bábics J., The recycling of waste laminated glass through decomposition technologies, Recycling 2021, 6(2), 26, DOI: 10.3390/recycling6020026.

[23] Gorokhovski A.V., Escalante-Garcia J.I., Gashnikova G.Y., Nikulina L.P., Artemenko S.E., Composite materials based on wastes of flat glass processing, Waste Management 2005, 25, 733-736, DOI: 10.1016/j.wasman.2004.11.007.

[24] Andiç-Çakır Ö., Üzüm O., Yüksel C., Sarikanat M., Waste glass aggregate for cementitious and polymer concrete, Proceedings of the Institution of Civil Engineers-Construction Materials 2016, 169(2), 106-116, DOI: 10.1680/coma.15.00011.

[25] Saribiyik M., Piskin A., Saribiyik A., The effects of waste glass powder usage on polymer concrete properties, Construction and Building Materials 2013, 47, 840-844, DOI: 10.1016/j.conbuildmat.2013.05.023.

[26] Hejna A., Przybysz-Romatowska M., Kosmela P. et al., Recent advances in compatibilization strategies of wood-polymer composites by isocyanates, Wood Science and Technology 2020, 54, 5, 1091, DOI: 10.1007/s00226-020-01203-3.

[27] Alhazmi H., Shah S.A.R., Anwar M.K. et al., Utilization of polymer concrete composites for a circular economy: A comparative review for assessment of recycling and waste utilization, Polymers 2021, 13, 2135. DOI: 10.3390/polym13132135.

