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PLSR Models for Mechanical Strengths of Concrete Composite Materials Reinforced with Pultrusion Wastes

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Abstract

In this paper, we present two Partial Least Squares Regression (PLSR) models for compressive and flexural strength responses of a concrete composite material reinforced with pultrusion wastes. The main objective is to characterize this cost-effective waste management solution for glass fiber reinforced polymer (GFRP) pultrusion wastes and end-of-life products that will lead, thereby, to a more sustainable composite materials industry. The experiments took into account formulations with the incorporation of three different weight contents of GFRP waste materials into polyester based mortars, as sand aggregate and filler replacements, two waste particle size grades and the incorporation of silane adhesion promoter into the polyester resin matrix in order to improve binder aggregates interfaces. The regression models were achieved for these data and two latent variables were identified as suitable, with a 95% confidence level. This technological option, for improving the quality of GFRP filled polymer mortars, is viable thus opening a door to selective recycling of GFRP waste and its use in the production of concrete-polymer based products. However, further and complementary studies will be necessary to confirm the technical and economic viability of the process.

1 Introduction

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Pultrusion is a well-established and cost-effective technique for manufacturing fibre reinforced polymer (FRP) structural components with a constant cross-section in a continuous manner [1,2]. Profiles made with glass fibre reinforced polymers (GFRP) are, nowadays, widely used in infrastructures of wastewater treatment plants, as internal or external reinforcement of concrete structures, for retrofitting and rehabilitation purposes of structural elements [3] and, even more recently, in composite construction systems [4,5].

Currently, having eco-efficient procedures is a mandatory requisite for all manufacturing industries that are determined to becoming a driver for innovation and technological competitiveness. Improving eco-efficient procedures in the GFRP profiles industry can be done by reducing the consumption of natural resources and by using GFRP production wastes and end-of life GFRP products that are usually landfilled due to their limited recycling ability. Turning wastes into resources, apart from preventing pollution, drives innovation that leads to the manufacturing of cleaner products with new functionalities [6].

The present study aims modelling by Partial Linear Squares (PLS) a novel application for mechanically recycled GFRP pultrusion wastes and end-of-life products, based on the incorporation of the recycled material as aggregate and reinforcement in a new concrete like composite material. The model of the mechanical responses, for both compressive and flexural strengths, considers as main parameters the percentage of recyclate content, the size grade of the recyclate material and the addition of an adhesion promoter.

2 Materials and methods

Raw materials and specimens

The concrete specimens were prepared by mixing an unsaturated polyester resin (20% w/w) with different sand aggregates/GFRP waste ratios. Two differently processed GFRP wastes, with distinct size grades, were used as partial substitute for sand aggregates within a range from 0% to 12% in weight of total aggregates. Plain concrete specimens were also casted and tested for comparison purposes.

In addition, and due to the fact that one of the main common problems reported in several research studies focused on the feasibility of FRP waste incorporation into new composite materials arises from the weak adhesion at recyclate-binder interface [8,9,10], an adhesion promoter, between resin matrix and aggregates/recyclates mix, was also considered as a parameter. Thus, a second series of experiments was carried out in which 1% of active silane coupling agent by weight of resin matrix was added to all formulations in analysis.

Two different size grades of ground GFRP waste were obtained using bottom sieves inside the grinding chamber with differently-sized meshes, hereinafter designated by coarse (CW) and fine (FW) pultrusion waste, according the length of glass fibres.

The GFRP recyclates were characterized with respect to organic and inorganic fraction contents and particle size distribution. The results of burning tests carried out on five random samples showed a composition with an average inorganic material content of 71% (w/w) corresponding to glass (55% w/w) and calcium carbonate (16% w/w), and an average resin content of 29% (w/w).

The particle size distribution of both types of recyclates, obtained by sieving and laser diffraction techniques revealed an average diameter of 390 μm or 950 μm, and a fineness modulus of 1.64 or 2.69 for FW or CW admixtures, respectively. Both grades of recyclates have the same proportion of glass fibre, calcium carbonate and organic resin and only differ on fibers and particles size distribution.

Siliceous foundry sand (SP55, Sibelco Lda), with particle size between 50 µm and 850 µm, an average diameter of 245 µm and a fineness modulus of 3.04 was used as sand aggregate.

Complementary information concerning the particle size distributions of GFRP waste recyclates and sand aggregates can be found in [11].

The commercial unsaturated polyester resin AROPOL® FS3992, Ashland, with a styrene content of 42% (w/w), was used as polymer binder. The polymerisation process of the resin system was activated by cobalt octoate (0.5 phr), as promoter, and 50% methyl ethyl ketone peroxide solution (2 phr), as initiator.

An organofunctional silane chemical solution (Dow Corning® Z-6032), with 40% (w/w) of active silane in methanol, was used as an adhesion promoter of resin binder to both inorganic aggregates and GFRP recyclates. The Z-6032 silane solution contains a vinylbenzyl and amine organic groups and a trimethoxysilyl inorganic group. This chemical agent was used as an additive to the polyester resin binder in the proportion of 1% of active silane by weight of resin content. Hereinafter, the letter 'S' (or its absence) indicates if the resin used in the study possesses (or not) silane coupling agent in its composition.

The set of formulations made for analysis correspond to a three-factor full factorial design (2^2 4^1), in which 'Silane Content', 'Waste Type' and 'Waste Content' were considered as material factors and each one was run, respectively, at 2 (0% and 1% silane content), 2 (CW and FW grades) and 4 (0%, 4%, 8% and 12% in weight of aggregates mass) variation levels. The resin to total aggregate (sand and recyclates) weight ratio was kept constant at 1:4 in all formulations; therefore, the GFRP recyclates played the role of sand aggregate replacement.

Standard prismatic specimens (40 x 40 x 160 mm^3) were prepared according to RILEM recommendation CPT PC-2:1995. For each formulation, six specimens were considered. The specimens were stripped off of the moulds after hardening process (24 hours at 30ºC/50% RH) and then further cured for 3 hours at 80ºC. After a minimum conditioning period of 24 hours at room temperature, the prismatic specimens were tested in three-point bending up to failure at the loading rate of $1mm.min^{-1}$ over a span length of 100 mm, as specified by RILEM CPT PCM-8 test method. One of the two leftover parts of each broken specimen in bending was tested afterwards in compression at the loading rate of 1.25 $mm.min^{-1}$, in compliance with UNE 83821:1992 standardized test.

Data treatment and modelling

For data treatment and modelling the MatLab software, R2013a version, was used to implement Partial Least Squares Regression (PLSR) model for both compressive and flexural strength responses of polymer concrete formulations modified with GFRP wastes according to the variations of material factors.

3 Results and discussion

The basic statistic descriptors for compressive and flexural test results, which were obtained according to the experimental methodologies previously described, are summarized in Tables 1 and 2.

Table 1. Average compressive strengths and correspondent standard deviations of trial formulations

Comp. Str. (MPa)	CW trial formulations				FW trial formulations			
	0%	4%	8%	12%	0%	4%	8%	12%
Average	76.89	83.27	86.22	82.81	76.89	77.80	85.18	80.48
St. Dev.	0.98	2.02	2.12	2.90	0.98	0.77	1.75	0.64
	S0%	S4%	S8%	S12%	S0%	S4%	S8%	S12%
Average	81.29	97.52	104.69	82.42	81.29	84.80	84.51	77.20
St. Dev.	0.74	1.00	0.66	2.42	0.74	1.27	2.10	4.31

Table 2. Average flexural strengths and correspondent standard deviations of trial formulations

Flex. Str. (MPa)	CW trial formulations				FW trial formulations			
	0%	4%	8%	12%	0%	4%	8%	12%
Average	25.17	27.74	26.29	26.18	25.17	26.06	26.82	26.26
St. Dev.	0.74	0.31	0.99	0.51	0.74	0.91	0.87	1.11
	S0%	S4%	S8%	S12%	S0%	S4%	S8%	S12%
Average	36.00	40.35	41.70	37.35	36.00	40.40	35.53	31.52
St. Dev.	0.53	0.93	1.81	4.30	0.53	1.18	1.84	1.48

The PLSR model achieved for both compression and flexural strengths are given by equations 1 and 2, respectively.

$$\text{Compressive strength (MPa)} = 99.7956 - 9.5966\ WT - 3.5274\ WC + 1.7985\ WT\text{x}WC \quad (1)$$

$$\text{Flexural strength (MPa)} = 40.3884 - 8.6914\ WT + 0.3075\ WC + 4.0805\ WT\text{x}WC \quad (2)$$

ANOVA tests for both PLSR models, compression and flexural strengths, were done and accepted with a 95% of confidence.

4 Conclusions

Based on the obtained results, it is possible to conclude that the partial replacement of sand aggregates by GFRP waste materials has an incremental effect on both the flexural and compressive strengths of specimens tested, regardless of the GFRP waste content and silane coupling agent adding, over reference trials formulations.

In particular for the waste type (coarse and fine) adding, it interferes on the mechanical behavior of the specimens – the fine fraction of GFRP recyclates enhances the compressive strength by providing an inferior void volume for dry-packed aggregate and the coarse fraction acts mainly as a reinforcing material, which improves flexural strength.

In relation to silane coupling agent inclusion, an improvement is also verified compression and flexural strengths.

Two Partial Least Squares regression models were achieved for this data and suggest, with a 95% confidence level, that this technological option for improving the quality of GFRP filled polymer mortars is viable, thus opening a door to selective recycling of GFRP waste and its use in the production of concrete-polymer based products. However, further and complementary studies will be necessary to confirm the technical and economic viability of the process.

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References

[1] Hollaway, L.C., Head, P.R. (2001), Advanced polymer composites and polymers in the civil infrastructure, first ed. Elsevier Science Ltd, Oxford.

[2] Stewart, S.D., Sumerack, J.E. (2000), The pultrusion process, in T. Starr (Ed.), Pultrusion for Engineers. Cambridge: Woodhead Publishing Ltd., Cambridge, pp. 19-65.

[3] Hollaway, L.C. (2010), A review of the present and future utilization of FRP composites in the civil infrastructure with reference to their important in-service properties, *Construction and Building Materials*, **24**, 2419-2445.

[4] Correia, J.R., Almeida, N.M., Figueira, J.R. (2011), Recycling of FRP composites: Reusing fine GFRP in concrete mixtures. *Journal of Cleaner Production*, **19**, 1745-1753.

[5] Ribeiro, M.C.S., Tavares, C.M.L., Ferreira, A.J.M., Marques, A.T. (2002), Static flexural performance of GFRP-polymer concrete hybrid beams, *Key Engineering Materials*, **230-232**, 148-151.

[6] Lehni, M. (2000), Eco-Efficiency: Creating more value with less impact. WBCSD Report, World Business Council for Sustainable Development.

[7] Ribeiro, M.C.S., Meira Castro, A.C, Silva, F.J.G., Meixedo, J.P., Oliveira, L., Alvim, M.R., Fiúza, A., Dinis, M.L. (2013), A Case Study on the Eco-Efficiency Performance of a Composite Processing Industry: Evaluation and Quantification of Potential Improvements, *Journal of Research Updates in Polymer Science*, **2**, 79-84

[8] DeRosa, R., Telefeyan, E., Gaustad, G., Mayes, S. (2005), Strength and microscopic investigation of unsaturated polyester BMC reinforced with SMC recyclate, Journal of Thermoplastic Composite materials, **18**, 333-349.

[9] Palmer, J., Ghita, O.R., Savage, L., Evans, K.E. (2009), Successful closed-loop recycling of thermoset composites, *Composites Part A* Appl. S. **40**, 490-498.

[10] Wong, K.H., Mohammed, D.S., Pickering, S.J., Brooks, R. (2012), Effect of coupling agents on reinforcing potential of recycled carbon fibre for polypropylene composite, Composite Science and Technology, **72**, 835-844.

[11] Ribeiro, M.C.S., Castro, A.C.M, Silva, F.J.G., Meixedo, J.P., Oliveira, L., Alvim, M.R. Fiúza, A., Dinis, M.L., (2013) A Case Study on the Eco-Efficiency Performance of a Composite Processing Industry: Evaluation and Quantification of Potential Improvements, *Journal of Research Updates in Polymer Science*, **2**, 79-84