IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Use of Optical Fiber and Black Marble Waste as Reinforced Concrete Material

***Sanjay Kumar Bhagat**

Research Scholar, Department of Civil Engineering, Ramchandra Chandravanshi University, Palamu.

**** Dr. Anita Sinha**

Principal RCIT, RCU, Palamu.

***Prof (Dr.) Ranjeet Kumar Singh, Professor Department of Chemistry, BIT Sindri

Abstract

It is necessary to prioritize recycling applications to contribute to the marble industry, ecology, and economy. In the current study, it is seen that the optical fiber and waste marble is used extensively in concrete instead of aggregate and cement. Several studies have sought to improve the quality of concrete, as well as its durability and strength, by adding fibers (metallic, polypropylene, carbon, vegetables) or by replacing the aggregate. The use of optical fiber waste in concrete is still incipient and few studies address the use of marble aggregate to be used in concrete. In this connection the experimental work was planned to utilize the black marble waste as coarse aggregate. In order to know the compressive and pull out bond strengths behaviour of marble aggregate concrete, cube specimens were cast with steel crimpled fibres and black marble aggregate at various replacements. Fifteen mixtures were taken with different percentages of black marble stone aggregates (0, 25, 50, 75 and 100%) and different percentages of crimped steel fibres (0, 1 and 2%). The cubes were tested for compressive and bond strengths. The results provided significant information about the strengths and it is observed that as the percentage of steel fibres increases in the mix the strengths are increased and also noticed that, with increase in the black stone waste aggregate in the concrete mixes the strengths were decreased. This research assesses the behaviour of the mixture composed of: Portland cement + fine aggregate (sand from crushed marble waste) + coarse aggregate (gneiss) + optical fiber waste and water. The compressive strength, the tensile strength and the modulus of elasticity of concrete and the durability of optical fiber waste in alkaline composite were tested through microstructural evaluation. The results present an increase of about 20% in the mechanical properties and a reduction in the rigidity of the mixture, making the material more ductile. The superficial protection of the fibers made them more resistant to the alkaline attack of the cement. The knowledge acquired would allow the creation of sustainable concrete reinforced with optical fiber in a much more efficient way.

Keywords: optical fiber, black marble, reinforced concrete, polymer optical fiber (POF)

INTRODUCTION:

Currently, most industrial processes are sources of waste, causing major environmental degradation and compromising sustainable development (Cox et al., 2014; Almada et al., 2020). The current challenge concerns the rational use of waste arising from that system (Aliabdo, Elmoaty & Auda, 2014; Ashish, 2018, Almada et. al., 2020). In such context, building industry, due to its large volume of resources consumed-either renewable or not-is one of the main technological sectors recommended for carrying out this absorption of solid waste (Munir, Kazmi & Wu, 2017; Vardhan et al., 2015).

The technical and scientific areas have experienced a boom with regard to studies that seek to find alternatives regarding the total replacement of the natural fine aggregate in order to face the growing shortage of supply and the resulting increase in its price, as well as the reuse of other waste from different sectors (Kou & Agrela, 2011; Medina, Rojas & Frias, 2013; Arel, 2016; Preira-Mercado et al., 2016). In such context, studies developed in the early 2000's have evidenced the reuse of crushed marble waste as a fine aggregate for the manufacture of concrete and mortar (Barbosa, Santos & Coura, 2018; Ashih, 2018). The consumption of ornamental marble stones (metamorphic rocks composed of calcite and dolomite) by the building industry raises a concern about the environmental impacts caused by the waste generated in the extraction and processing steps. It is estimated that 20−30% of the raw material is turned into waste (Buyuksagis, Uygunoglu & Tatar, 2017). The largest amount of waste was obtained in the phases of extraction and primary processing (cutting the plates) and secondary processing (cutting the final pieces for ornamentation), and such waste can be used as aggregates (Ashish, 2019).

Most studies in the literature address the waste resulting from marbles when evaluating the use of marble jms.ccsenet.org Journal of Management and Sustainability Vol. 11, No. 1; 2021 50 aggregates as a substitute for fine aggregate, having been observed that there was a lower water demand in mortars containing up to 50% of those wastes. This can be explained by the marble powder thixotropic, which caused the mortar to flow with less energy when compared to the reference mixture. The increase in the incorporation content tends to increase the demand for water, reducing workability (Ashish, 2018). It was observed that the use of marble powder in the proportion of 10 to 15% in concrete increases the tensile and compressive strength by about 15 to 20%, due to the reduction of the water/cement ratio (Singh, Srivastava, & Bhunia, 2018). Moreover, lower w/c ratios promote lower porosity, which can be achieved with the use of plasticizer or super plasticizer admixtures (Sardinha, Brito & Rodrigues, 2016). This is corroborated by the observation of the microstructure, which shows that the concretes with marble waste in the mixtures were denser, with a lower formation of crystals (calcium hydroxide and ettringite), reduced ITZ thickness and lower presence of large pores (Alyamaç & Ince, 2009). Other studies have sought to improve the quality of concrete, as well its durability and strength, by adding fibers such as metallic fibers (Yap et al., 2015; Yap et al., 2015), polypropylene (Lanzoni, Nobili & Tarantino, 2012), carbon (Viana et al., 2020) and vegetables (coconut, sisal, among others).

The fibers contribute to a greater toughness to tensile strength and to a reduction of the porosity and of the shrinkage cracks of concrete. Glass recycling is an environmental issue due to its high volume, the excessive cost of recycling it and its insolubility in the environment (Sales et al., 2017). There are many studies on the use of glass waste, such as: in cement mortars applied as pozzolan (Chen et al., 2002) and aggregate applied in concrete (Shayan & Xu, 2006). In most research related to the addition of glass to concrete, the glass contains fine particles with a diameter of about 150 ȝm (different percentages of glass that increase in use as a replacement powder of cement and aggregates) (Ling, Poon & Kou, 2012). The results of the application of glass powders in different percentages (lower than 20%) indicated a slight increase in the compressive strength (Lee et al., 2011) and the tensile strength of the concrete. Research (Sales et al., 2017; Alvarenga et al., 2019) on the incorporation of glass waste as a fine aggregate in mortar or as a substitute for cement concluded that the presence of glass tends to reduce the heat conduction in these composites, improving thermal insulation properties.

The use of optical fiber waste in concrete is still incipient (Ge et al., 2015). The addition of that waste (Barbosa et al., 2013) results in a product with some qualities, specifically technical (quality proven by mechanical tests), environmental (high consumption of fiber residues from optical fiber waste) and economic (due to the possibility of reducing the size of the concrete pieces as opposed to the increase in tensile strength, consequently reducing the cost of the material). Also, from their implementation up to the end of their lifespan, optical fibers generate waste, as they are extremely thin and fragile.

The handling of such fibers is delicate and, once broken; their waste cannot be fully reused for the same purpose, which promotes studies to reuse them in other industrial sectors. Besides that, the fiberglass is damaged by the degradation that can occur due to the alkalinity of Portland cement (Reis et al., 2009). Therefore, this study aimed to analyse the durability of optical fiber waste (composed of dielectric, crystalline and homogeneous materials forming concentric capillaries) in an alkaline environment. Analyses of the mechanical properties of concrete were carried out, in which the incorporation of recycled aggregates and optical fiber waste and the behavior of the microstructure of glass fibers were evaluated after 5 years of exposure to alkaline compounds in concrete.

Optical fibers (OF) are made of two basic coaxial layers, i.e., the core, which is a transmission medium in which light moves, and the surrounding jacket. Most often, the core is made of quartz glass or a plastic with similar parameters, while the coat is made of a polymer with a refractive index less than the core factor. The entire fiber is surrounded by an outer protective jacket. Several polymers such as polymethylmethacrylate (PMMA), polycarbonates (PC), polystyrene (PS), cyclic olefin copolymer, and amorphous fluoropolymer are used for the preparation of mechanically improved of. These types of fibers are called polymer optical fibers (POFs). Generally, the OFs are used in active and passive forms in diverse branches of science and engineering. The use of the OFs in biomedical technology can be categorized into three types: monitoring of physical parameters, imaging, and surgical operation. They are especially used in medical research, particularly endoscopic research. Such devices are also used as guide wires and in ultrasound, X-ray, and magnetic resonance imaging machines.

Waste marble:

The leading factor influencing the quality of cement-based composites and their appropriate adherence is ordinary Portland cement. The manufacturing of ordinary Portland cement requires a meaningful consumption of energy and the production of enormous greenhouse gas emissions, including carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxides (NOx), black carbon (BC), and sulfur dioxide (SO2), therefore contributing to environmental pollution. Global cement production (4.18 billion tones in 2014) is the third biggest source of carbon dioxide emissions. The average value of CO2 intensity emissions from all worldwide cement production is 222 kg of CO2/t of cement. From an economic point of view, it can be seen to be reasonable to replace a part of ordinary Portland cement with waste mineral dust. In addition, this treatment is an environmentally friendly solution. Due to an excessive amount of very fine particles in dust, the voids in cement-based materials could be thoroughly filled. The particle size and chemical composition of this by-product allow this material to be treated as an attractive additive in cement-based material technology. Marble has been widely used as a building material in the civil engineering industry. During the mining process and in the polishing of marble stone, marble dust is perceived as a waste material.

These by-products are present in the environment and contribute to pollution. The utilization of marble dust reduces the cost of cement-based material production and also decreases the costs of removing it from the environment. The possibility of using waste materials such as marble dust as a partial substitution in the production of mortar and concrete has often been investigated by researchers. Its mechanical properties are the main aspect of the analysis. Consequently, it has been proved that the utilization of waste marble dust (WMD) in cement mortar improves its mechanical and physical properties when subjected to the water-curing condition. The author's previous study showed that the water-curing condition, when compared to the air-curing condition, was profitable for the acceleration of the hydration rate of cement-based materials blended with WMD dust. However, on real construction sites, cement-based materials are mainly prepared and stored in air conditions (in nature). Based on the performed literature review, there is no study related to the properties of air-cured mortar containing WMD. To fill this knowledge gap, this research studies the effect of the partial replacement of ordinary Portland cement with WMD on the macro and micro properties of mortars stored at an air temperature equal to 22 ± 2 ◦C and a relative humidity of 20 ± 1% by determining the compressive strength and apparent density. In addition, scanning electron microscopy (SEM) analysis was also performed to determine the porosity and Si/Ca ratios of ACM after 28 days of being cured.

Hardened Concrete:

After curing at 7 and 28 days in fresh water, the specimens were made dried and then tested to evaluate strength characteristics.

Compressive strength:

Compressive strength of concrete is evaluated by the concrete at 7 and 28 days cube strength. Compressive strength of concrete for various proportions of waste marble powder is shown in table-1 and represented in Graph-1 & 2.

Split tensile strength:

The split tensile strength of concrete for cylinders, all mixes at 28 days of curing is presented in table-2 and shown in Graph-2. Three cylinders were casted for various percentage replacements of cement by WMP and they are tested by placing them horizontal in CTM. The split tensile strength test set up is shown in fig-2. The following equation is used to evaluate the split tensile strength of cylinder.

Flexural strength of concrete:

The flexural strength of concrete for prisms, all mixes at 28 days of curing is presented in table-2 and shown in graph-4. Three prisms were cast for various percentage replacements of cement by Waste Marble Powder and tested in UTM of 40T capacity by applying two point loads. These point loads acted at equidistance from centre of prism. Prism was placed in the Universal Testing Machine and load is applied at rate of 140kg/cm/min.

Table 1: Compressive Strength of M20, M30, and M40 Grads of concrete specimens at 7, 28 days of curing

S.no	% of Waste Marble powder	Compressive strength for M_{20} grade(MPa)		Compressive strength For M_{30} grade(MPa)		Compressive strength for M_{40} grade (MPa)	
		7 days	28 days	7 days	28 days	7 days	28 days
1	0	16.36	24.93	25.18	38.36	29.88	45.51
2	5	22.66	34.52	25.81	39.32	37.43	57.01
3	10	25.18	38.36	26.44	40.28	31.44	47.89
4	15	24.55	37.4	28.33	43.16	31.06	47.31
5	20	14.31	21.8	23.29	35.48	26.2	39.91

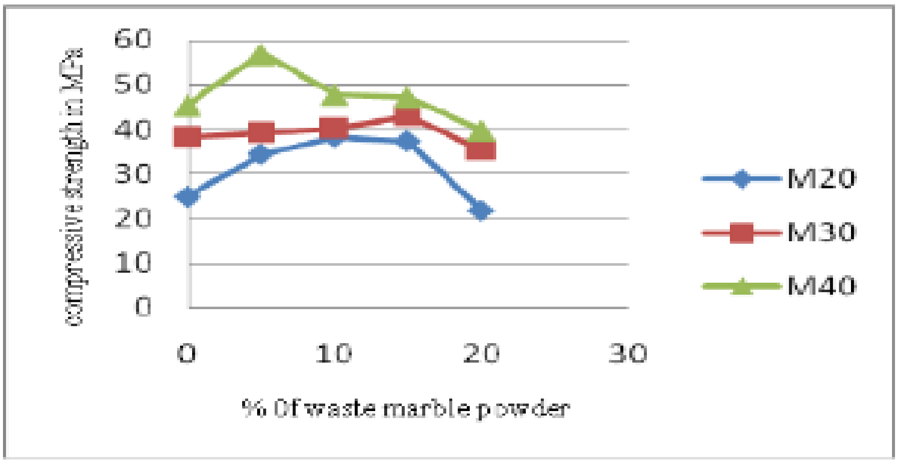


Table 2: Split Tensile Strength of concrete specimens at 28 days of curing

S.no	% of Waste Marble powder	Split tensile strength of M_{20} grade of concrete (MPa)	Split tensile strength of M_{30} grade of concrete(MPa)	Split tensile strength of M_{40} grade of concrete (Mpa)
1	0	2.16	3.33	3.24
2	5	2.99	3.41	4.16
3	10	3.33	3.75	3.49
4	15	3.24	3.45	3.45
5	20	2.08	3.08	2.91

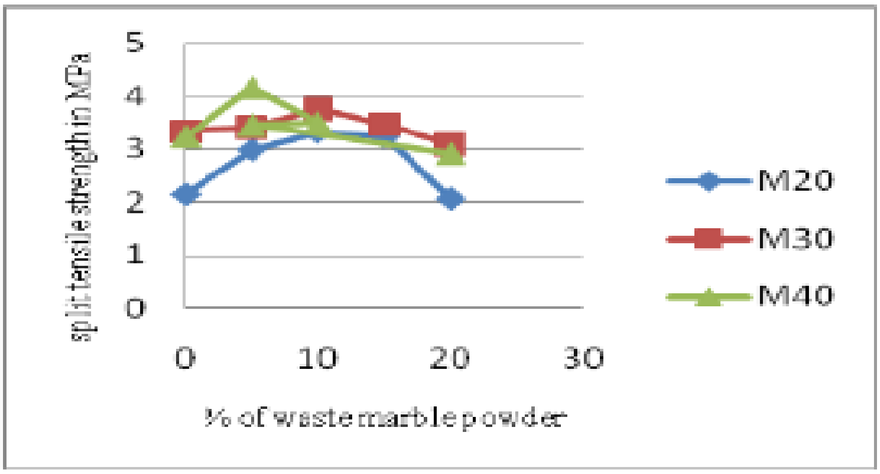
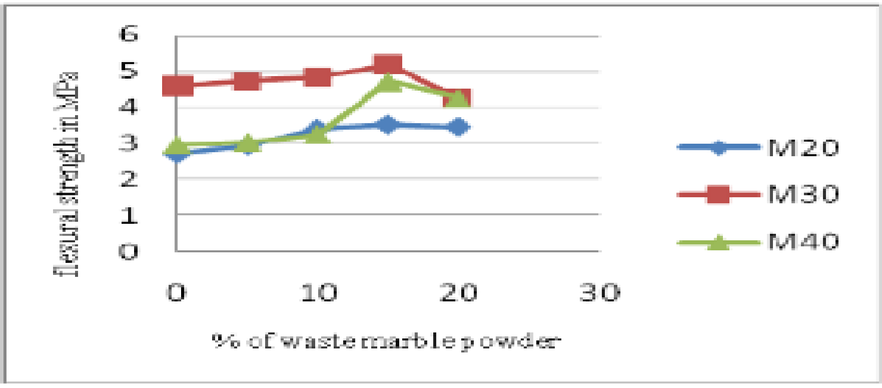
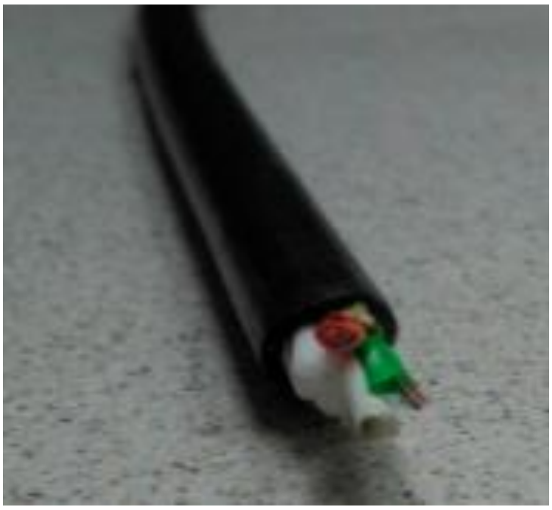


Table 3: Flexural Strength of concrete specimens at 28 days of curing

S.no	% of Waste Marble powder	Flexural strength for M_{20} grade of concrete (MPa)	Flexural strength for M_{30} grade of concrete (MPa)	Flexural strength for M_{40} grade of concrete (MPa)
1	0	2	4.6	2.96
2	5	2.94	4.71	3.03
3	10	3.4	4.83	3.25
4	15	3.52	5.17	4.71
5	20	3.46	4.25	4.25



Optic Fiber Waste:



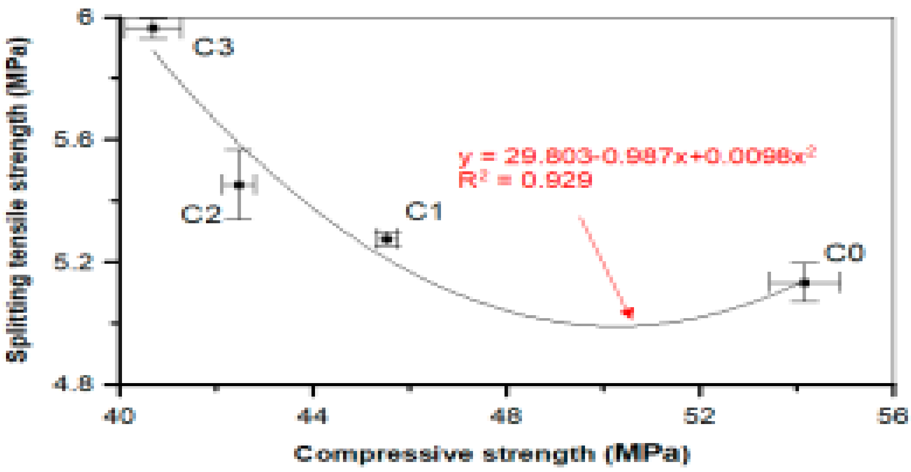


Figure 1: Relationship between the compressive and splitting tensile strength of a concrete.

On the basis of the test results, the dependencies and associations between the different concretes with and without POF properties were proposed. The graph in Figure 1 shows the dependence between the compressive and splitting tensile strengths for the tested concretes. The fibers delay the appearance of the micro cracks and bridge the macro cracks. The compressive strength corresponds to the splitting tensile strength of concrete with or without POF. The polynomial trend was characterized by a good determination coefficient (R 2 = 0.929) and relatively low errors in the intercept. It is essential to point out that the amount of fibers had an influence on the data.

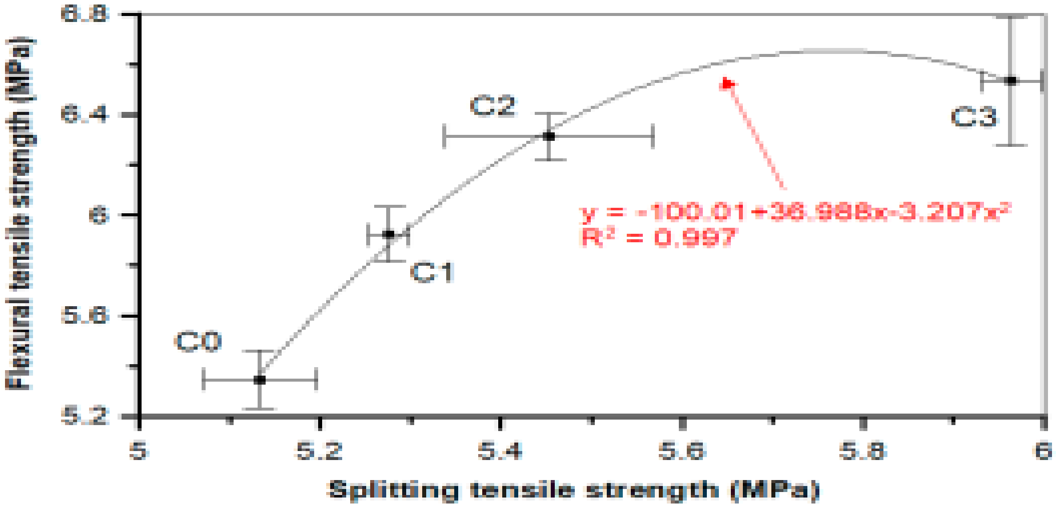


Figure 2: Relationship between the splitting and flexural tensile strengths of a concrete.

The relationship between the flexural tensile and splitting tensile strengths for a concrete is presented in figure 2. The relationship between the flexural tensile and splitting tensile strengths for a concrete with and without POF is presented in the form of the polynomial formula y = -100.01+ 36.988x2. The high determination coefficient equal to 0.997 indicates that the data have been matched by the best R2 value.

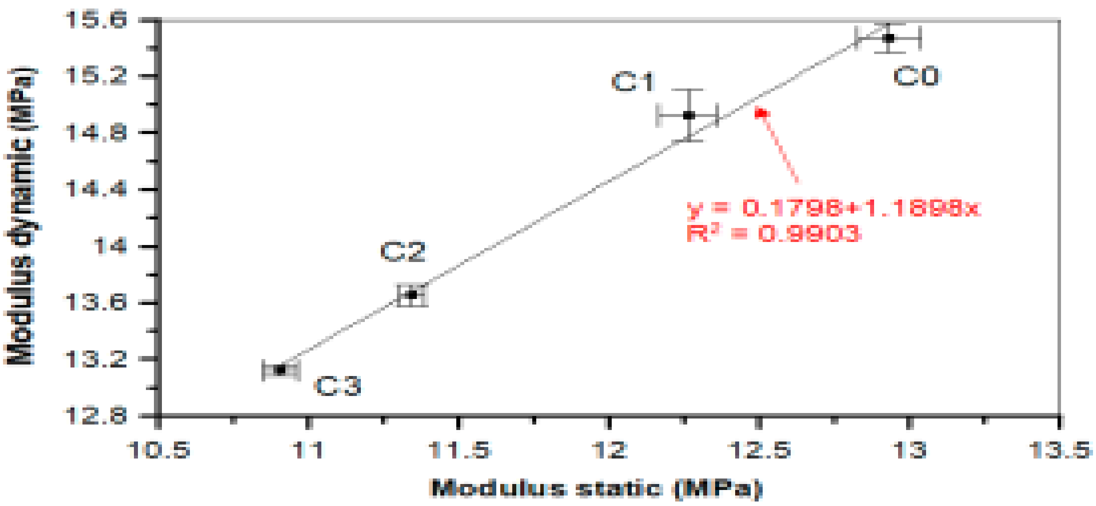


Figure 3: Correlation between the static and dynamic moduli of a concrete

Illustrates the dependence of the static the dynamic moduli of elasticity for all analysed concretes. It was observed that the static modulus is completely congruous with the dynamic modulus. The liner trends was characterized by a good determination coefficient (R2= 0.990) and low errors in the intercept.

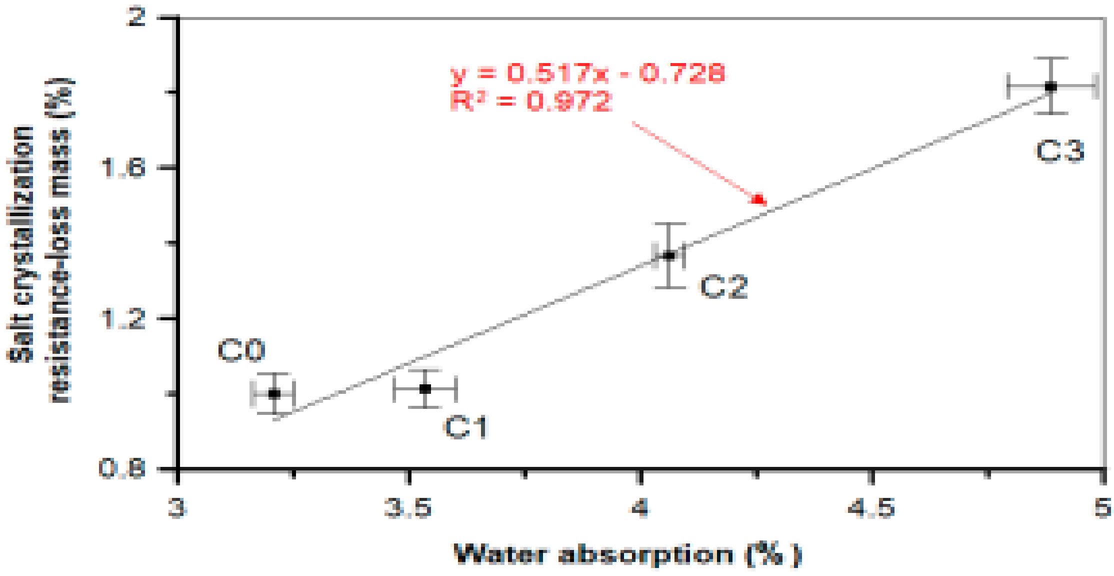


Figure 4: Relationship between the water absorption and salt crystallization resistance of a concrete.

An interesting relationship can be observed for the changes in water absorption of a material and mass loss after the salt crystallization test. The diagram presented in Figure 4 shows the linear dependence between those two factors, with a slope value equal to 0.517 and y-intercept value close to 0, which confirms a good linear dependence between those two values, additionally confirmed by a high determination coefficient (R 2 = 0.973).

Conclusion:

The recycling process of waste should follow an appropriate methodology so that the products developed may present performances compatible with the technical standards and do not cause environmental risks. With regard to waste, the object of this research, it is clear that the results are compatible with, and even higher to, the technical standards, reinforcing the great benefits. The main conclusions drawn regarding the use of marble waste as an aggregate and optical fiber waste for the production of mixed concrete was that the concrete with marble waste has good mechanical properties and the addition of optical fiber waste improved the performance of the concrete. As an indicator of long-term sustainability, it can be used in concrete to achieve one or several of the following: replacement of non-renewable materials with recycled materials or waste; reduction in energy requirements in the manufacture of concrete; improvement in the durability of concrete in a particular environment; reduction in the cost of materials; utilization of local unconventional raw materials (for example: marble waste and/or optical fiber waste) in low-cost concrete.

To the best of our knowledge, in the literature there are no examples of the use of POFs for dispersed reinforcement in concrete and reinforced concrete structures. Therefore, this study focused on the evaluation of the modification of concrete by POFs. The aim of this work was POF recycling through their usage as a supplementary material for concrete. This reduces the amount of waste stored and increases the tensile strength of concrete. The quality of the obtained concretes supplemented with plastic optical fibers was evaluated within the investigation of their physical and mechanical properties, such as their bulk density, open porosity, flexural tensile strength, compressive strength, splitting tensile strength, static and dynamic modulus of elasticity, frost and salt resistance, and other properties. Thus, by considering the economic and ecological aspects of the decrease in waste, its application in the technology of concrete production is a reasonable choice for reinforcing concrete.

REFERENCES:

1. Aliabdo, A., Elmoaty, A., & Auda, E. M. (2014). Re-Use of Waste Marble Dust in the Production of Cement and Concrete. Construction and Building Materials, 50, 28−41. https://doi.org/10.1016/j.conbuildmat.2013.09.005
2. Almada, L. S., Melo, D. J. B., Bubani, L. C., Silva, G. J., Santos, W. J., & Aguilar, M. T. (2020). Influence of the heterogeneity of waste from wet processing of ornamental stones on the performance of Portland cement composites. Construction and Building Materials, 262, 120036. https://doi.org/10.1016/j.conbuildmat.2020.120036
3. Alvarenga, C. B. C. S., Heiderick, O. M., Couto, T. A., Cetlin, P. R., Sales, R. B. C., & Aguilar, M. T. P. (2019). Influence of soda-lime waste glass microparticles on workability and thermal properties of portland cement compounds. Materiales de Construcción, 69(335). https://doi.org/10.3989/mc.2019.05818
4. Alyamaç, K., & Ince, R. (2009). A preliminary concrete mix design for SCC with marble powders. Construction and Building Materials, 23(3), 1201−1210. https://doi.org/10.1016/j.conbuildmat.2008.08.012
5. Arel, H. (2016). Recyclability of waste marble in concrete production. Journal of Cleaner Production, 131, 179−188. https://doi.org/10.1016/j.jclepro.2016.05.052
6. Ashish, D. (2018). Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth. Journal of Building Engineering, 15, 236−242. https://doi.org/10.1016/j.jobe.2017.11.024
7. Ashish, D. (2019). Concrete made with waste marble powder and supplementary cementitious material for sustainable development. Journal of Cleaner Production, 211, 716−729. https://doi.org/10.1016/j.jclepro.2018.11.245
8. Barbosa, M. T., Maia, M., Castanõn, J., & Ludwig, Z. (2013). ECODOR: sustainable proportion for concrete sleeper. Procedings of Portugal SB13 - Contribuition of sustainable building to meet EU 20-20-20 Targets. Proceedings 1 (pp. 365−370).
9. Barbosa, M. T., & Santos, W. (2013). ARGAD: High Performance Mortar (vol. 1, pp. 387−394). In Portugal SB13 - Contribuition of sustainable building to meet EU 20-20-20 Targets.
10. Barbosa, M. T., Santos, W. J., & Coura, C. V. (2018). High quality of mortar with marble waste aggregate. Ambiente Construído, 18(2). https://doi.org/10.1590/s1678-86212018000200260
11. Buyuksagis, I. S., Uygunoglu, T., & Tatar, E. (2017). Investigation on the usage of waste marble powder in cement-based adhesive mortar. Construction and Building Materials, 154, 734−742. https://doi.org/10.1016/j.conbuildmat.2017.08.014
12. Chen, G., Lee, H., Young, K., Yue, P., Wong, A., Tao, T., & Choi, K. (2002). Glass recycling in cement production-an innovative approach. Waste Manage., 22, 747−753. https://doi.org/10.1016/S0956-053X(02)00047-8
13. Kou, S., Poon, C., & Agrela, F. (2011). Comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures. Cement and Concrete Composites, 33(8), 788−795. https://doi.org/10.1016/j.cemconcomp.2011.05.009
14. Lanzoni, L., Nobili, A., & Tarantino, A. (2012). Performance evaluation of a polypropylene-based draw-wired fibre for concrete structures. Construction and Building Materials, 28(1), 798−806. https://doi.org/10.1016/j.conbuildmat.2011.10.017
15. Ling, T., Poon, C., & Kou, S. (2012). Influence of recycled glass content and curing conditions on the properties of self-compacting concrete after exposure to elevated temperatures. Cement and Concrete Composites, 34(2), 265−272. https://doi.org/10.1016/j.cemconcomp.2011.08.010

16. Munir, M., Kazmi, M., & Wu, S. (2017). Efficiency of waste marble powder in controlling alkali-silica reaction of concrete: A sustainable approach. Construction and Building Materials, 154, 590−599. https://doi.org/10.1016/j.conbuildmat.2017.08.002
17. Reis, J., Nunes, L., Triques, A., Valente, L., & Braga, A. (2009). Mechanical characterization using optical fiber sensors of polyester polymer concrete made with recycled aggregates. Materials Research, 12(3). https://doi.org/10.1590/S1516-14392009000300004
18. Sales, R., Sales, F., Figueiredo, E., Santos, W. J., Mohallem, N., & Aguilar, M. T. (2017). Durability of Mortar Made with Fine Glass Powdered Particles. Advances in Materials Science and Engineering. https://doi.org/10.1155/2017/3143642
19. Sardinha, M., Brito, J., & Rodrigues, R. (2016). Durability properties of structural concrete containing very fine aggregates of marble sludge. Construction and Building Materials, 119, 45−52. https://doi.org/10.1016/j.conbuildmat.2016.05.071
20. Singh, M., Srivastava, A., & Bhunia, D. (2018). Long term strength and durability parameters of hardened concrete on partially replacing cement by dried waste marble powder slurry. Congress on Technical Advancement 2017. https://doi.org/10.1061/9780784481035.007
21. Viana, T., Bacelar, B., Coelho, I., Ludvig, P., & Santos, W. J. (2020). Behaviour of ultra-high-performance concretes incorporating carbon nanotubes under thermal load. Construction and Building Materials, 263, 120556. https://doi.org/10.1016/j.conbuildmat.2020.120556
22. Jenny, R.; Kittelberger, S.; Volpi, A.G.; Auburn, N.Y. Fundamentals of optics—An introduction for beginners. Int. J. Comput. Vis. 2000, 40, 142–167.
23. Khanarian, G.; Celanese, H. Optical properties of cyclic olefin copolymers. Opt. Eng. 2001, 40, 1024–1029. [CrossRef]
24. Nielsen, K.; Rasmussen, A.J.L.; Planken, P.C.M.; Bang, O.; Jepsen, P.U. Bendable, low-loss Topas fibers for the terahertz frequency range. Opt. Express 2009, 17, 8592–8601. [CrossRef]
25. Iftekhar, S.; Grins, J.; Eden, M. Composition-property relationships of the La2O3 - Al2O3 -SiO2 glass system. J. Non-Cryst. Solids 2010, 356, 1043–1048. [CrossRef]
26. Rajesh, M.; Nampoori, V.P.N. Fabrication and Characterisation of Polymer Optical Fibers for Smart Sensing and Optical Amplification. Ph.D. Thesis, Cochin University of Science & Technology, Kerala, India, 2006.
27. Luo, Y.; Yan, B.; Zhang, Q.; Peng, G.-D.; Wen, J.; Zhang, J. Fabrication of Polymer Optical Fibre (POF) Gratings. Sensors 2017, 17, 511. [CrossRef] [PubMed]
28. Starecki, F.; Charpentier, F.; Doualan, J.L.; Quetel, L.; Michel, K.; Chahal, R.; Troles, J.; Bureau, B.; Braud, A.; Camy, P. Mid-IR optical sensor for CO2 detection based on fluorescence absorbance of Dy3+: Ga5Ge20Sb10S65 fibers. Sens. Actuators B Chem. 2015, 207, 518–525. [CrossRef]
29. Baldini, F.; Giannetti, A.; Mencaglia, A.A.; Trono, C. Fiber Optic sensors for biomedical applications. Curr. Anal. Chem. 2008, 4, 378390. [CrossRef]
30. Mignani, A.G.; Baldini, F. Biomedical sensors using optical fibres. Rep. Progress Phys. 1996, 59, 1–28. [CrossRef]
31. Yang, C.; Zhao, C.; Wold, L.; Kaufman, K.R. Biocompatibility of a physiological pressure sensor. Biosens. Bioelectron. 2003, 19, 51–58. [CrossRef]
32. Zou, X.; Wu, N.; Tian, Y.; Wang, X. Broadband miniature fiber optic ultrasound generator. Opt. Express 2014, 22, 18119–181127. [CrossRef] [PubMed]
33. Zubia, J.; Arrue, J. Plastic optical fibers: An introduction to their technological processes and applications. Opt. Fiber Technol. 2001, 7, 101–140. [CrossRef] 1. Arel, H. ¸S. Recyclability of waste marble in concrete production. J. Clean. Prod. 2016, 131, 179–188. [CrossRef]
34. Siddique, R. Performance characteristics of high-volume Class F fly ash concrete. Cem. Concr. Res. 2004, 34, 487–493. [CrossRef]
35. Stajanˇca, M.; Eštoková, A. Environmental Impacts of Cement Production; University of Košice: Košice, Slovakia, 2012.

36. Kurad, R.; Silvestre, J.D.; de Brito, J.; Ahmed, H. Effect of incorporation of high volume of recycled concrete aggregates and fly ash on the strength and global warming potential of concrete. J. Clean. Prod. 2017, 166, 485–502. [CrossRef]
37. Arunta¸s, H.Y.; Gürü, M.; Dayı, M.; Tekin, I. Utilization of waste marble dust as an additive in cement production. Mater. Des. 2010, 31, 4039–4042. [CrossRef]
38. Andrew, R.M. Global CO2 emissions from cement production. Earth Syst. Sci. Data 2018, 10, 195. [CrossRef]
39. Worrell, E.; Price, L.; Martin, N.; Hendriks, C.; Meida, L.O. Carbon dioxide emissions from the global cement industry. Annu. Rev. Energy Environ. 2001, 26, 303–329. [CrossRef]
40. Alyousef, R.; Khadimallah, M.A.; Soussi, C.; Benjeddou, O.; Jedidi, M. Experimental and Theoretical Study of a New Technique for Mixing Self-Compacting Concrete with Marble Sludge Grout. Adv. Civ. Eng. 2018, 1–11. [CrossRef]
41. Nežerka, V.; Hrbek, V.; Prošek, Z.; Somr, M.; Tesárek, P.; Fládr, J. Micromechanical characterization and modeling of cement pastes containing waste marble powder. J. Clean. Prod. 2018, 195, 1081–1090. [CrossRef]
42. Toubal Seghir, N.; Mellas, M.; Sadowski, Ł.; Zak, A. E ˙ ffects of marble powder on the properties of the air-cured blended cement paste. J. Clean. Prod. 2018, 183, 858–868. [CrossRef]
43. Nagrockiene, D.; Girskas, G.; Skripki ˙ unas, G. Properties of concrete modified with mineral additives. ¯ Constr. Build. Mater. 2015, 135, 37–42. [CrossRef]
44. Su, H.; Jing, H.; Yin, Q.; Yu, L. Effect of Thermal Environment on the Mechanical Behaviors of Building Marble. Adv. Civ. Eng. 2018, 1–8. [CrossRef]
45. Hebhoub, H.; Aoun, H.; Belachia, M.; Houari, H.; Ghorbel, E. Use of waste marble aggregates in concrete. Constr. Build. Mater. 2011, 25, 1167–1171. [CrossRef]
46. Uysal, M. The Use of Waste Maroon Marble Powder and Iron Oxide Pigment in the Production of Coloured Self-Compacting Concrete. Adv. Civ. Eng. 2018, 1–10. [CrossRef]
47. Celik, M.Y.; Sabah, E. Geological and technical characterisation of Iscehisar (Afyon-Turkey) marble deposits and the impact of marble waste on environmental pollution. J. Environ. Manag. 2008, 87, 106–116. [CrossRef]